The Container Tree Nursery Manual

Volume Four
Seedling Nutrition and Irrigation

Chapter 2
Irrigation and Water Management

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Contents

4.2.1 The Importance of Water in Seedling Culture

The importance of water to the growth of container tree seedlings cannot be overemphasized. Water is considered to be the principal growth-limiting factor in natural terrestrial ecosystems and is one of the most important growth-promoting factors in artificial ecosystems such as greenhouses. The ecological importance of water reflects its physiological importance, and almost every plant process is directly of indirectly affected by water. As an example, photosynthesis decreases drastically as moisture stress increases (figure 4.2.1).

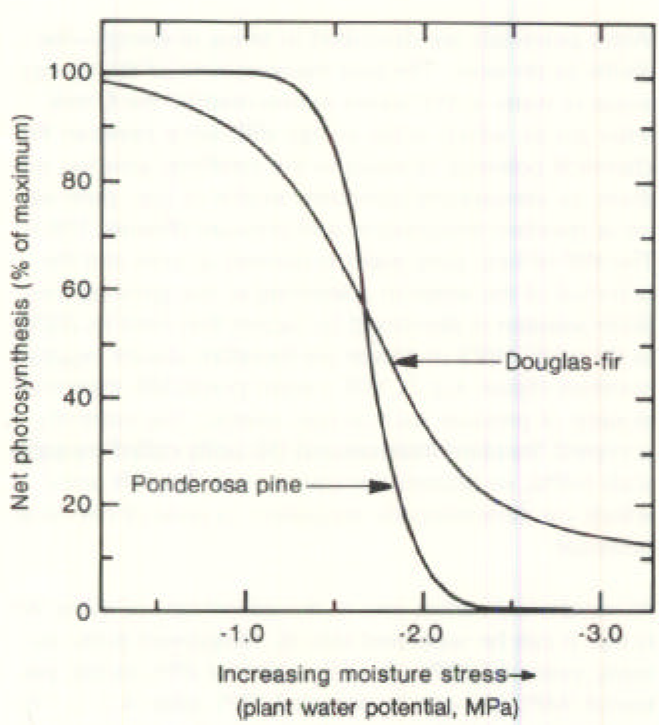


Figure 4.2.1—*Increasing moisture stress, as measured by more negative plant water potential, reduces photosynthesis of tree seedlings at different rates, depending on species characteristics (modified from Cleary 1971).*

Water influences plant growth in four major ways (Kramer 1983):

1. Water is a major constituent of a plant, composing 80 to 90% of the fresh weight.

2. Water is the "universal solvent;" providing nutrient transport within the plant.

3. Water is a biochemical reactant in many plant processes, including photosynthesis.

4. Water is essential for maintaining turgidity in plant cells, promoting cell expansion and plant growth.

4.2.2 The Water Status of Container Tree Seedlings

An understanding of the physicochemical aspects of seedling water relations is not absolutely necessary for successful management of a container tree seedling nursery irrigation program. However, nursery managers should be familiar with the terms that are universally used to describe plant water relations. Seedling water status can be described in several different ways: water content, water potential, and water movement. Probably the most useful measures of seedling water status are water content and water potential (Spomer 1985).

4.2.2.1 Water content

The water content of a seedling can be viewed as an equation. At any time, seedling water content reflects an integrated balance between water absorption through the roots and transpirational losses from the foliage to the atmosphere (McDonald and Running 1979) (fig. 4.2.2). Ritchie (1984) describes the water cycle as a simple input-output system:

$$W = A - T + S$$

where: W = seedling water content
A = absorption
T = transpiration
S = storage

Seedling water content is in a constant state of change during the day, when transpirational losses through the foliage usually exceed the rate of water absorption through the roots. This lag between water uptake and water loss creates a condition of internal water stress within the seedling. Seedling water stress is a normal physiological condition during daylight hours; however, if this stress is allowed to reach extreme levels for extended periods, the seedling growth rate declines and eventually the seedling dies. In container tree seedling nurseries, seedling water stress is maintained at low levels during the growing season through the use of irrigation to stimulate seedling growth. Although plant water stress has been described with many different terms, the most useful way to describe seedling water status involves water energy or potential.

4.2.2.2 Water potential

A full discussion of water potential (WP) is well beyond the scope of this manual, but an understanding of the basic concepts is useful for container tree seedling nursery managers. The following discussion of WP will help familiarize the reader with the terms and units of WP that will be used in this chapter (table 4.2.1).

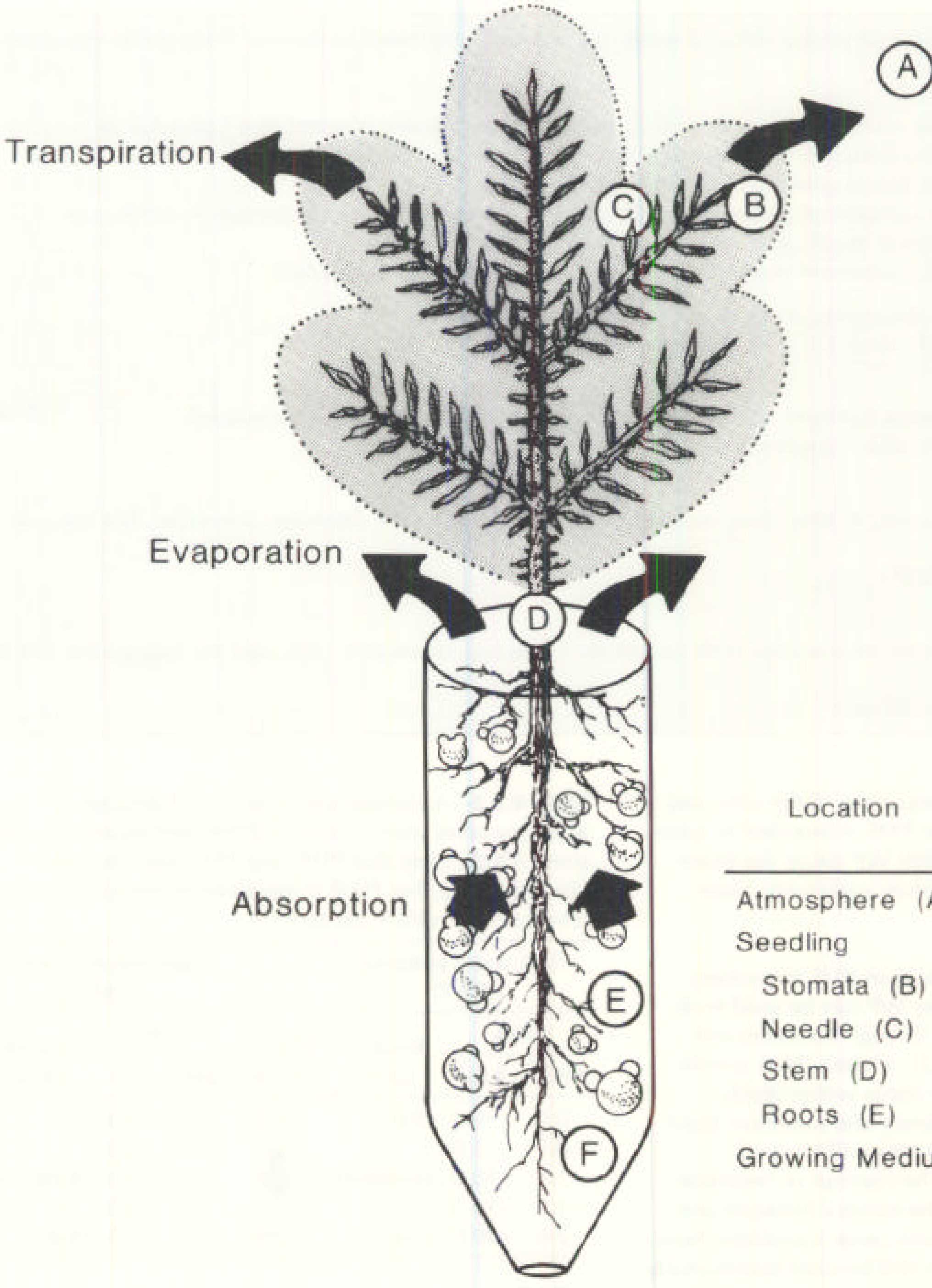
Although the terminology surrounding WP may appear complicated at first, it is the best way to describe seedling water status because the basic principles and units remain the same from the growing medium, through the seedling, and into the atmosphere (Spomer 1985) (figure 4.2.2). Components of WP, from the matric potential in the soil to the water vapor in the atmosphere, can be described in the same units. A practical advantage of the water potential system is that the various influences that affect water use and availability, such as salinity, can all be described in WP terms (osmotic potential in table 4.2.1).

Water potentials are described in terms of energy-the ability to do work. The best measurement of the energy status of water is WP (often represented by the Greek letter psi ?), which is the energy difference between the chemical potential of water in the seedling, growing medium, or atmosphere compared to that of free, pure water at standard temperature and pressure (Kramer 1983). The WP of free, pure water is defined as zero and the potential of the water in a seedling or the growing medium solution is decreased by factors that limit its ability to do work; WP's in nature are therefore always negative numbers (figure 4.2.2). WP is most practically expressed in units of pressure such as bars (metric), the currently accepted Standard International (SI units called megapascals (MPa), or pounds per square inch (English units), which are dimensionally equivalent to units of chemical potential.

As mentioned earlier, one of the advantages of using WP is that it can be separated into its component parts: osmotic potential (OP), pressure potential (PP), matric potential (MP), and gravity potential (GP) (table 4.2.1). The components of WP in a seedling or in the growing medium differ, however, because of the unique properties of each system. Some components, such as the effect of gravity (GP), are negligible in small seedlings or in short containers, whereas other components, such as PP, are not significant in the growing medium (table 4.2.1).

4.2.2.3 Plant water potential

There are two terms commonly used to describe the water status of tree seedlings; most nursery scientists prefer *plant water potential* (PWP), whereas many nursery managers and reforestation foresters are more familiar with plant moisture stress (PMS). The two terms are identical in absolute value: PWP is always expressed in negative terms, whereas PMS is always a positive number (for example, a PWP value of - 1.5 MPa equals a



Location	Water potential (MPa)
Atmosphere (A)	-125
Seedling	
Stomata (B)	-25
Needle (C)	-0.9
Stem (D)	-0.6
Roots (E)	-0.3
Growing Medium (F)	-0.1

Figure 4.2.2—*Water is drawn along a gradient of water potential that is driven by evapotranspirational losses, from higher (less negative) levels in the growing medium, through the seedling to the lower (more negative) levels in the atmosphere (modified from McDonald and Running 1979).*

Table 4.2.1—*Terms, definitions, and units used in seedling water relations*

Water potential (WP)—a measure of energy status of water that is usually expressed in pressure units and is composed of the following factors:

WP = OP + PP + MP + GP

OP = osmotic potential—the component produced by dissolved solutes (always negative, see figure 4.2.3)

PP = pressure potential—the component produced by the inward pressure of cell walls in plants, or due to water weight or air pressure in soil (always positive, see figure 4.2.3)

MP = matric potential—the component produced by the adhesive attraction of water molecules to surfaces or adhesion and cohesion in small capillaries (always negative)

GP = gravity potential—the component produced by the force of gravity (always negative).

Plant water potential (PWP)—the energy status of water within a seedling:

(MP is small in well-watered plants; GP is negligible in small seedlings)

PWP = OP + PP

Growing medium water potential (GMWP)—the energy status of water within the growing medium:

(PP and GP are negligible in short containers)

GMWP = MP + OP

Plant moisture stress (PMS)—a way of describing seedling water status that has the same absolute value, but opposite sign, as plant water potential:

PMS = positive values of PWP

Units:

Water potential and plant moisture stress are both commonly expressed in pressure units, and the megapascal (MPa) is the preferred SI unit:

1 MPa = 10 bars -10 atm -150 psi

PMS value of 1.5 MPa). A comparison of the units and descriptive terms for PWP and PMS is provided in table 4.2.2. Note that a relatively high WP rating (for example, - 1.0) is "less negative" than a relatively lower value (for example, - 3.0).

PWP is actually more practical than PMS for nursery management purposes because WP can be used to describe the water relationships through the entire soil-plant-air continuum (fig. 4.2.2), whereas PMS is only useful in describing the water status within plants. Therefore, to maintain consistency and minimize possible confusion, WP units and terms will be used throughout this publication. The concept of "moisture stress" is well established in the nursery literature and everyday jargon. This should not cause a problem, however, and the term "stress" can still be used operationally because PWP and PMS are dimensionally equivalent and only differ in sign (table 4.2.2).

PWP is composed of two major components: osmotic potential (OP) and pressure potential (PP) (table 4.2.1). The interrelationship of these factors is illustrated in figure 4.2.3, which shows how PWP changes with seedling water content (Hofler 1920, as discussed in Ritchie 1984). When a seedling is fully turgid, its PWP is zero

Table 4.2.2—*A comparison of units and descriptive terms for plant water potential (PWP) and plant moisture stress (PMS). Note that PWP and PMS have the same absolute value, but PWP is measured in negative units, whereas PMS values are positive.*

Plant water potential (PWP)				Plant moisture stress (PMS)		
Units		Relative rating	Relative moisture	Units		Relative rating
MPa	Bars			MPa	Bars	
0.0	0.0	High	Wet	0.0	0.0	Low
−0.5	−5.0		↓	0.5	5.0	
−1.0	−10.0	Moderate		1.0	10.0	Moderate
−1.5	−15.0			1.5	15.0	
−2.0	−20.0	Low	Dry	2.0	20.0	High

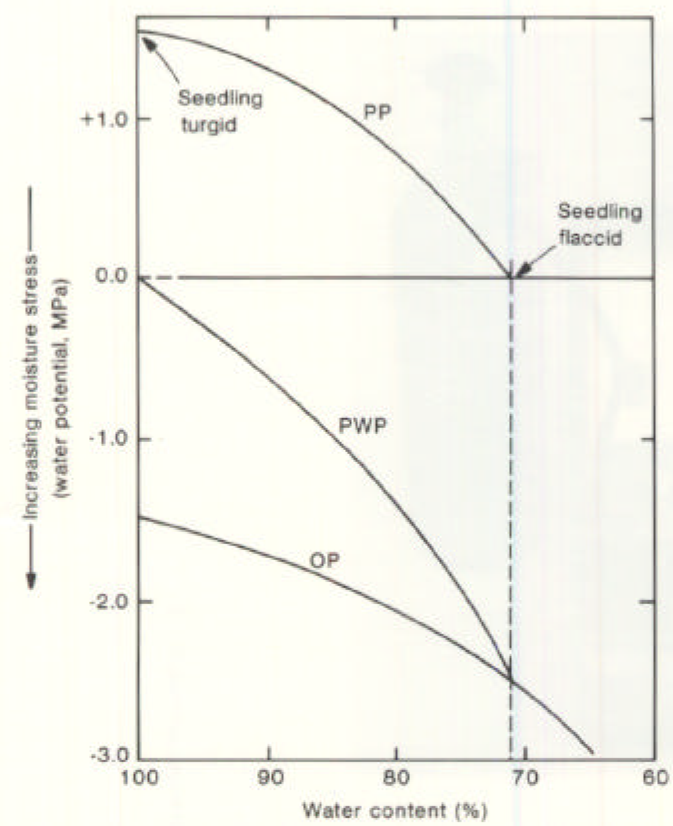


Figure 4.2.3—*The interrelationships between plant water potential (PWP) and its components, osmotic potential (OP) and pressure potential (PP), change over the range of seedling water contents from turgidity to the wilting point (Ritchie 1984).*

because the PP is positive and equal to the OP, which is negative. As the seedling loses water content through transpiration, it also loses turgidity (wilts) and the PP declines in value until it reaches zero, at which point the seedling is completely flaccid and the PWP equals the OP (figure 4.2.3). This point of zero turgidity, some times called the "wilting point;' is physiologically dangerous for the seedling: growth stops and cellular damage and even death may result if this condition exists for too long.

PWP is dynamic and changes with time as soil moisture and atmospheric demand change. Typical diurnal patterns for PWP are given in figure 4.2.4 for two different combinations of growing medium moisture and atmospheric demand. On a typical day in a well-irrigated growing medium (A in fig. 4.2.4), a seedling begins to transpire as soon as the sun comes up, and its PWP decreases (stress increases) until the stomata close, at

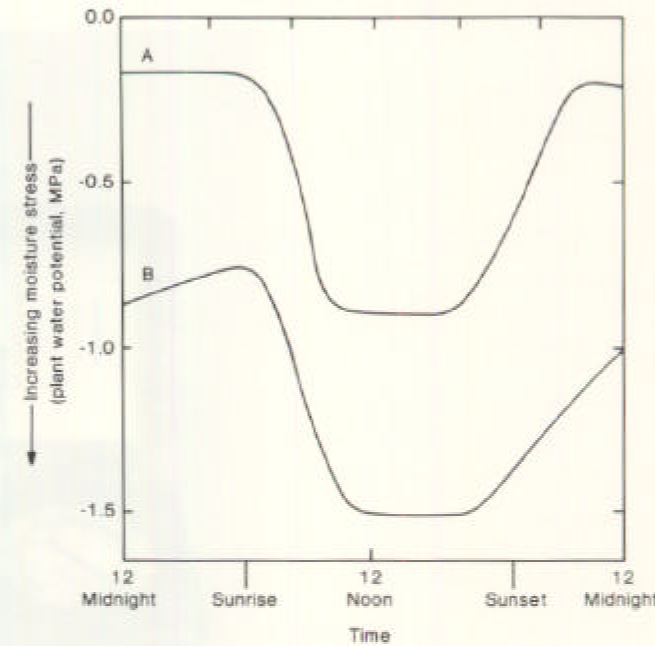


Figure 4.2.4—*Diurnal patterns of plant water potential for a seedling under two different environments: high growing medium water potential and low evaporative demand (**A**) and low growing medium water potential and high evaporative demand (**B**). (Adapted from McDonald and Running 1979.)*

which point the PWP levels off. Towards sunset, the PWP begins to increase as atmospheric demand declines and the seedling replenishes its moisture content from the water in the growing medium. The second curve (B in fig. 4.2.4) shows the PWP pattern for a seedling under a high evaporative demand and in a moderately dry growing medium. The PWP begins at a lower initial level, because the seedling has not been able to completely recharge its moisture supply overnight and, therefore, its PWP declines to lower levels (higher stress) during the afternoon. If this pattern continues over time, damaging moisture stress levels can develop within the seedling.

PWP can be measured by several techniques, but the most practical for nursery operations is the pressure chamber (fig. 4.2.5). The technique for operating this instrument is well-described by McDonald and Running (1979):

> Cut a small twig or needle from a seedling and place it in the chamber with the cut end protruding from the lid. A useful analogy is to imagine the water column in the seedling as a rubber band. As the water

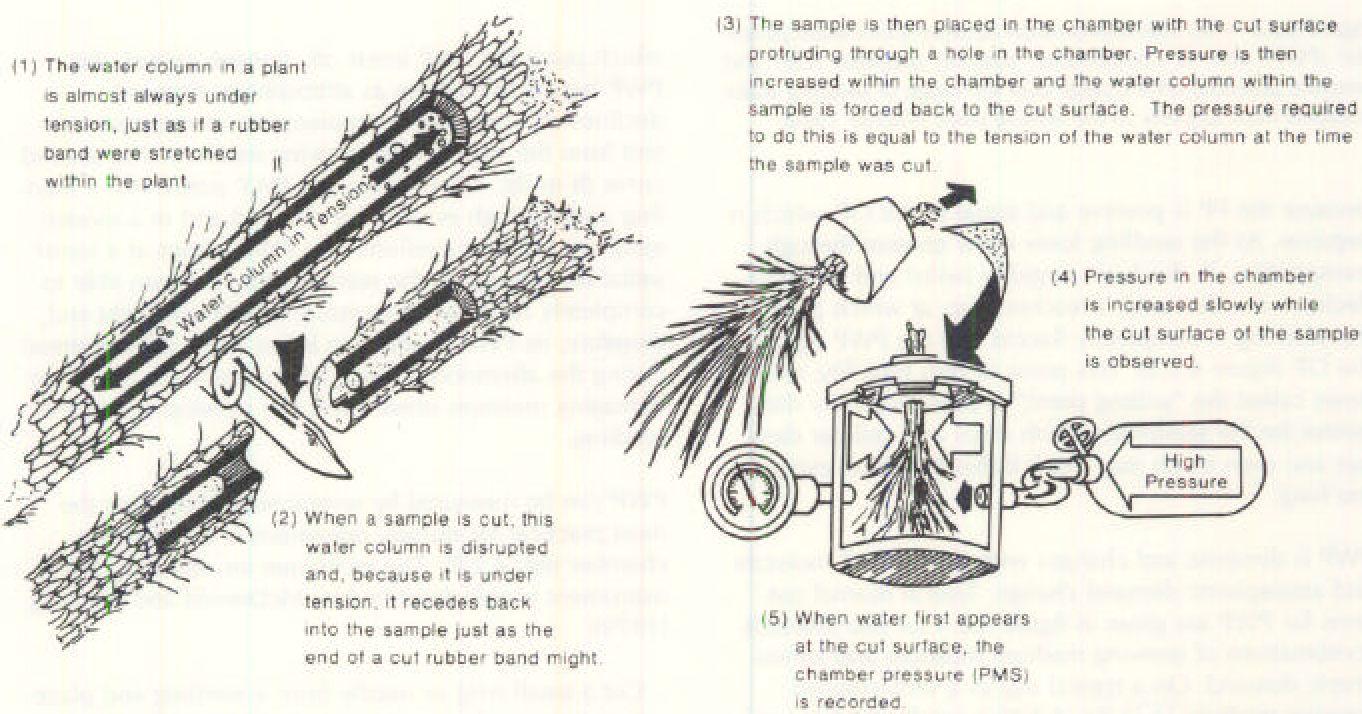


Figure 4.2.5—*The pressure chamber offers a direct measure of plant water potential or plant water stress (courtesy of PMS Instrument Company, Corvallis, OR).*

stress increases in the seedling, this rubber band is stretched. When the twig or needle is cut from the seedling, the tension on the rubber band (water column) causes the water to withdraw back from the cut surface. By slowly applying gas pressure to the cut twig in the chamber, the water is forced back to the cut surface of the twig. When the gas pressure is exactly equal to the tension (PWP) that is on the water column, water will appear at the cut surface; by reading the gauge on the pressure chamber as soon as the water appears, the PWP can be measured.

New techniques for measuring PWP are being developed. Dixon and Tyree (1984) describe a hygrometer that can be attached to the stem of woody plants that will directly measure PWP The hygrometer is a small metal chamber housing tiny thermocouple sensors that can remain attached to a woody stem for several weeks. One limitation of this technique is that the optimum stem diameter is about 8 to 10 mm (0.31-0.39 in), which is larger than most reforestation stock. Although primarily a research procedure at present, future modification of this technology may yield a technique for continuously monitoring PWP in an operational nursery.

4.2.2.4 Growing medium water potential

Because of large variations in bulk density, pore space, and pore size distribution, water in the growing medium is best described by potentials rather than on the traditional weight basis. A fine-textured medium usually contains more water by weight than a coarse-textured medium, but less water will actually be available for plant uptake and growth (Bunt 1976). Water potential, on the other hand, gives an indication of the water available for plant growth regardless of growing medium texture.

The potential of water in the growing medium solution is called the growing medium water potential (GMWP) and is composed of two parts: OP, which reflects the influence of dissolved salts, and MP, which measures the attraction of water molecules for the surfaces and small pores in the growing medium (table 4.2.1). The OP of the growing medium solution increases (becomes more negative) as the soil water content decreases due to evaporation or transpiration and the salinity of the growing medium solution increases-a reduction of 50% in the soil water content will approximately double the salt concentration (Bunt 1976). (The effects of high salinity on seedling growth are discussed in section 4.2.4.2.)

The MP reflects the energy with which the water in the growing medium is held by matric forces and is related to the size of pores in the growing medium. The pore volume of a growing medium is a function of particle size and arrangement and is composed of air and water, which change in inverse proportion to one another. After irrigation, excess water is drained out of the container by gravitational forces, leaving the growing medium essentially saturated; this point is termed "container capacity;" which differs from the traditional field capacity due to the effect of the container (see section 4.3.2.2). At container capacity, the MP is very high (moisture stress is very low) and water is readily available to the seedling. As the growing medium loses water through evaporation and transpiration, the large pores drain first and are filled with air. The pores never drain completely, however, as an increasingly thinner film of water surrounds the growing medium particles. The thinner the water film layer, the lower the MP (the higher the moisture stress) and the less water that is available to the seedling. The smaller pores are the last to lose their water. Eventually, the water content of the medium (and the MP) will be so low that the seedling is unable to obtain water as fast as it is lost to transpiration and the seedling will begin to lose turgor and wilt. The *permanent wilting point* occurs when the seedling is unable to recharge its moisture reserves overnight and remains flaccid (Bunt 1976).

The GMWP and PWP are closely related; the PWP pattern for a seedling that starts out in a moist growing medium (high GMWP) but is not irrigated is shown in figure 4.2.6. As the growing medium dries out, the GMWP gradually decreases. The normal PWP curve occurs each day (fig. 4.2.4A), but the PWP decreases to a lower level on each subsequent day because the seedling is not able to recharge its moisture supplies from the increasingly drier growing medium. The PWP becomes more and more negative until ultimately the seedling is unable to recover.

Most traditional soil moisture instruments measure only MP and ignore the OP, which can be a significant component in heavily fertilized soils such as greenhouse media (fig. 4.2.7). The MP can be measured directly with a pressure membrane in a testing lab or with a tensiometer at the nursery. The best method of measuring GMWP appears to be the small-wire thermocouple psychrometer technique. These small psychrometers are encased in porous bulbs and are attached to electrical

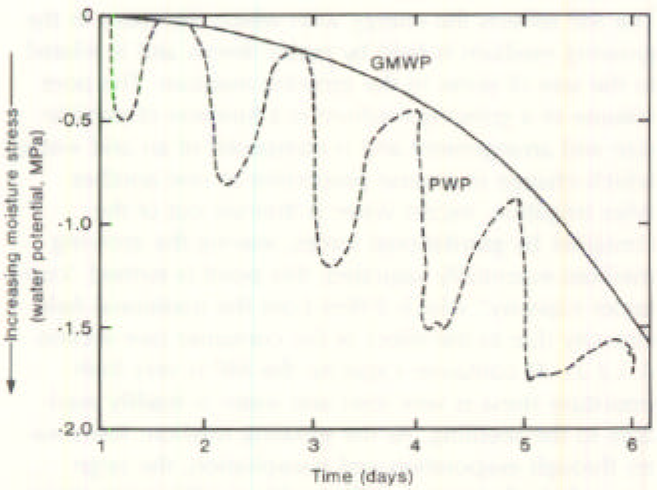


Figure 4.2.6—*The relationship between plant water potential (PWP) and growing medium water potential (GMWP) in a container without irrigation: the diurnal pattern of PWP gradually decreases as the growing medium dries out and the GMWP decreases (adapted from Slatyer 1967).*

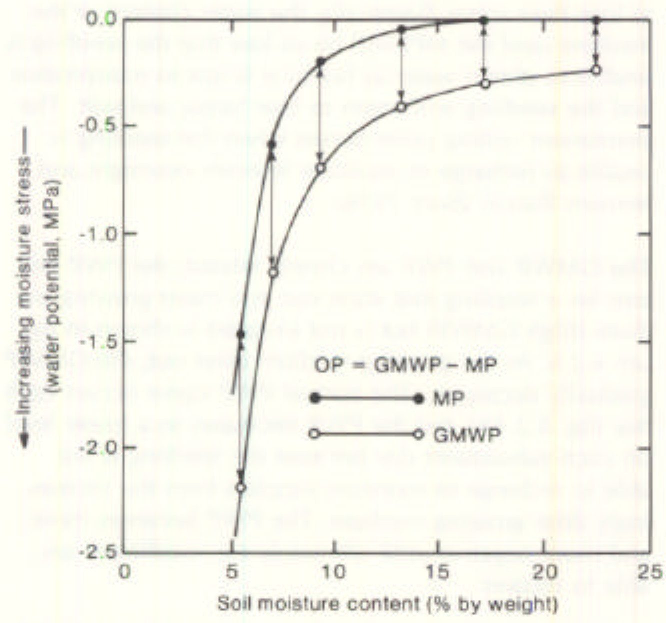


Figure 4.2.7—*Heavy fertilization of a container growing medium produces a significant osmotic potential (OP), which increases at lower moisture contents. OP is the difference between the growing medium water potential (GMWP) and the matric potential (MP). (Adapted from Newman 1966.)*

leads and the GMWP can then be measured directly with a microvoltmeter (Kramer 1983). These psychrometers could be placed within the growing medium inside the container and the GMWP measured easily and instantaneously. This technique was not being used operationally at any of the nurseries that responded to the Container Nursery Survey but may hold promise as a way to monitor soil moisture in containers. (Current ways of operationally monitoring irrigation are discussed in section 4.2.6.)

4.2.3 Factors Affecting Water Availability in Containers

4.2.3.1 Unique aspects of artificial growing media
The use of "artificial soil" composed of materials like peat moss and vermiculite affects many properties of water in the growing medium, such as water holding capacity and water movement.

High water-holding capacity. Most of the growing media used in container tree seedling nurseries, such as a mixture of peat moss and vermiculite, have the ability to absorb and retain a much higher percentage of water than the mineral soils of bareroot nurseries. The most accurate way to illustrate this difference is with a soil moisture retention curve that shows the relationship between gravimetric soil moisture and MP. Soil moisture retention curves are developed in a soil-testing lab using a pressure plate apparatus; separate curves must be developed for each type of soil or growing medium because the relationship changes significantly based on physical characteristics, particularly texture and structure. Figure 4.2.8 shows two soil moisture retention curves for a typical silty loam soil for a bareroot nursery soil and a 1:1 peat-vermiculite growing medium; note that the peat-vermiculite growing medium retains considerably more water over the entire range of MP The properties of peat-vermiculite media are discussed further in the chapter on growing media in volume two of this series.

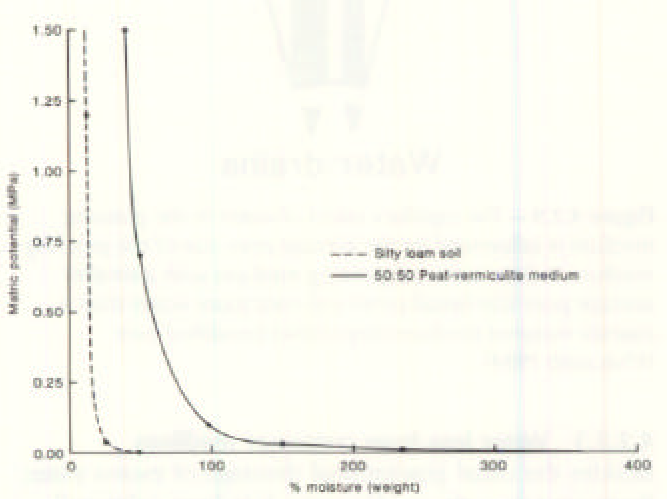


Figure 4.2.8—*A comparison of the soil moisture retention curves for a typical silty loam bareroot nursery soil and a peat-vermiculite growing medium shows that the artificial growing medium holds considerably more water at all matric potentials.*

Water movement in artificial growing media. The infiltration rate and capillary conductivity of peat-vermiculite growing media change with water content. When irrigation water is applied to the surface of a container, the rate at which it is absorbed into the growing medium is termed the infiltration rate. The infiltration rate for peat-vermiculite media is relatively high because most growing media have good porosity. If a medium is allowed to dry out, however, the infiltration rate can be severely restricted because dry peat particles actually repel water and become hydrophobic (Furuta 1978). Wetting agents (surfactants) are commercially available that can be applied to the growing medium and increase the infiltration rate; these chemicals are detergents that break down the surface tension of water and cause it to penetrate the medium much more easily. Wetting agents are often used during the hardening period to resaturate the growing medium after it has been allowed to dry out to induce seedling water stress (see section 4.2.7.3).

Capillary conductivity refers to the rate of water movement in the growing medium, especially in response to plant uptake. During irrigation, the capillary conductivity of peat-vermiculite media is high in a downward direction due to gravity, but after irrigation, capillary conductivity may be limited in very porous media (Furuta 1978). Hanan and others (1978) studied the capillary conductivity of two growing media with different textures and found that seedlings growing in very porous mixes could experience severe water stress even though water could still be squeezed from the mixture by hand. Water movement in growing media can be increased by using components that provide a mixture of particle sizes and by insuring that the medium is firmly tamped into the container during loading. Use of a growing medium that is too fine or excessive tamping, however, can cause waterlogged conditions and seriously reduce seedling growth.

4.2.3.2 Container effects
Water in a container behaves differently than water in an unconfined soil; this fact should be understood by container nursery managers because it affects water management and resultant irrigation practices. The application of a given amount of water to a fixed amount of growing medium in a small container produces a different water content, different moisture movement, and therefore a different plant response than the same amount of water applied to the same volume of unconfined soil (Furuta 1978).

When irrigation is applied to a filled container, the water percolates downward under the influence of gravity until it reaches the bottom of the container; at this point, water flow ceases because the force of gravity is less than the combined forces of adhesion and cohesion within the water column. Drainage from the bottom of the container only occurs when the force due to the height of the water column is sufficient to overcome these adhesive and cohesive forces. The biological significance of this drainage pattern is that a zone of saturated growing medium always exists above the medium/ air interface at the bottom of the container (Furuta 1978). The depth of this saturated layer is a function of the growing medium texture as shown in figure 4.2.9. The depth of this saturated zone will be greater for a fine-textured medium than for a coarse-textured one because capillary forces are greater in smaller pores.

The height of the container determines the proportion of freely draining growing medium that it contains, assuming that the growing medium texture is the same (Whitcomb 1984). A 10.2-cm (4 inch)-high container will have the same depth of saturated medium as a 25.4-cm (10-inch; container, but the shorter container will have proportionately less freely drained growing medium (fig. 4.2.10). This "capillary fringe" effect is independent of container diameter or shape. For a given container, the only way to modify the depth of this saturated layer is to change the growing medium texture to a coarser mix (Furuta 1978). The presence of this saturated layer has serious implications for the aeration of the growing medium; Bunt (1976) showed that changing the container height from 5 to 20 cm (2 to 7.9 inches) increased the air volume in the container from 4 to 8% (fig. 4.2.11).

The containers that are used in many container tree seedling nurseries have a relatively small top opening and limited volume. The small top opening 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 seedlings become larger and their foliage begins to intercept irrigation before it can reach the top of the container. Foliage interception is particularly serious for broadleaved species. Because small containers have a corresponding small volume of growing medium, they have limited moisture reserves and require frequent irrigation, especially in times of high evapotranspirational losses (Furuta 1978).

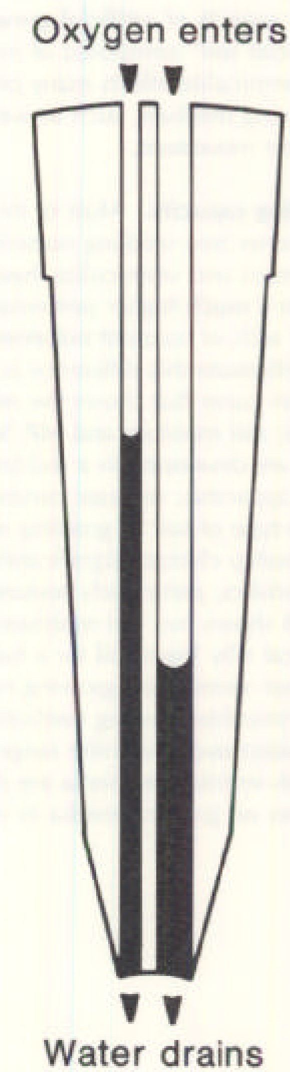


Figure 4.2.9 — *The capillary effect of water in the growing medium is influenced by the average pore size of the growing medium. A finer-textured growing medium with a smaller average pore size (small tube) will hold more water than a coarser-textured medium (large tube) (modified form Whitcomb 1984).*

4.2.3.3 Water loss from container seedlings

Besides the usual gravitational drainage of excess water, there are two pathways for water loss from solid-wall containers in a container tree seedling nursery: evaporation from the growing medium surface and seedling transpiration. Evapotranspiration rates are related to energy input, mainly sunlight in a greenhouse, and several studies have correlated water loss to solar input. Evapotranspiration increases with higher temperatures, lower

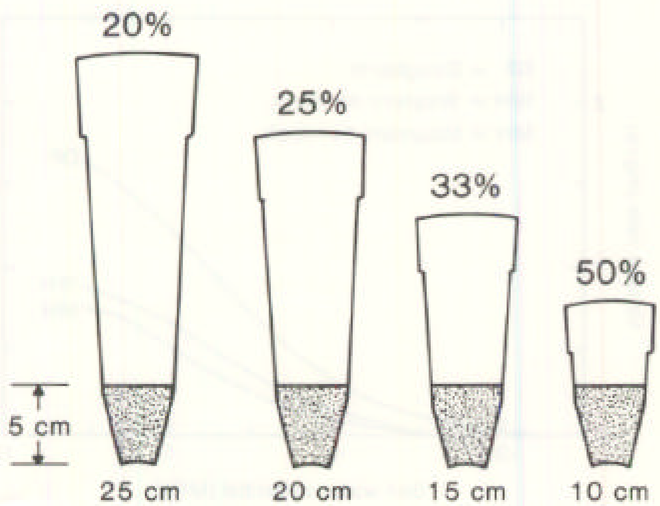


Figure 4.2.10—*The depth of the saturated growing medium layer at the bottom of the container is proportionately greater in shorter containers, given the same type of growing medium (modified from Whitcomb 1984).*

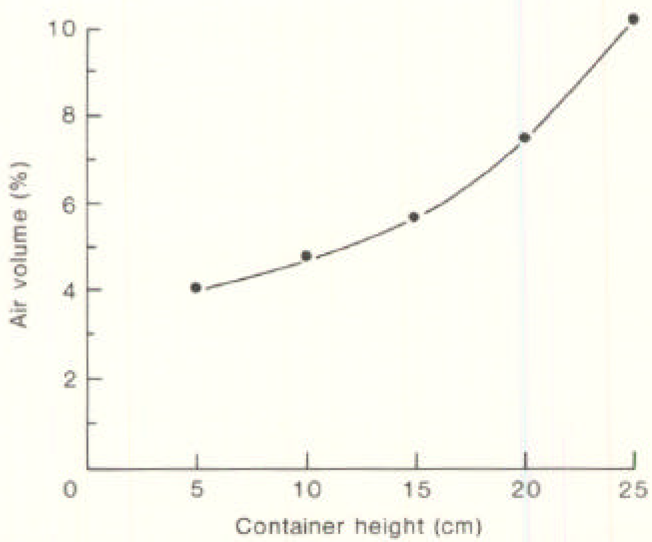


Figure 4.2.11—*The relative volume of air space (aeration porosity) in a growing medium increases with container height (Bunt 1976).*

humidities, and increased air movement. Seedling water losses are greatest, therefore, when high temperatures cause the vents to open in an enclosed greenhouse. High temperatures and drying winds can also increase water use in semi-controlled structures. Although many equations have been developed to predict mathematically the amount of water loss from climatic factors for agricultural crops, they are too imprecise to have much practical usefulness for irrigation management in operational container tree seedling nurseries.

Evapotranspiration losses in container nurseries can be divided into two general time periods. Evaporation from the growing medium surface is the major loss early in the growing season (fig. 4.2.12A). As seedlings become larger, however, foliar transpiration is responsible for a greater proportion of water loss because the root system

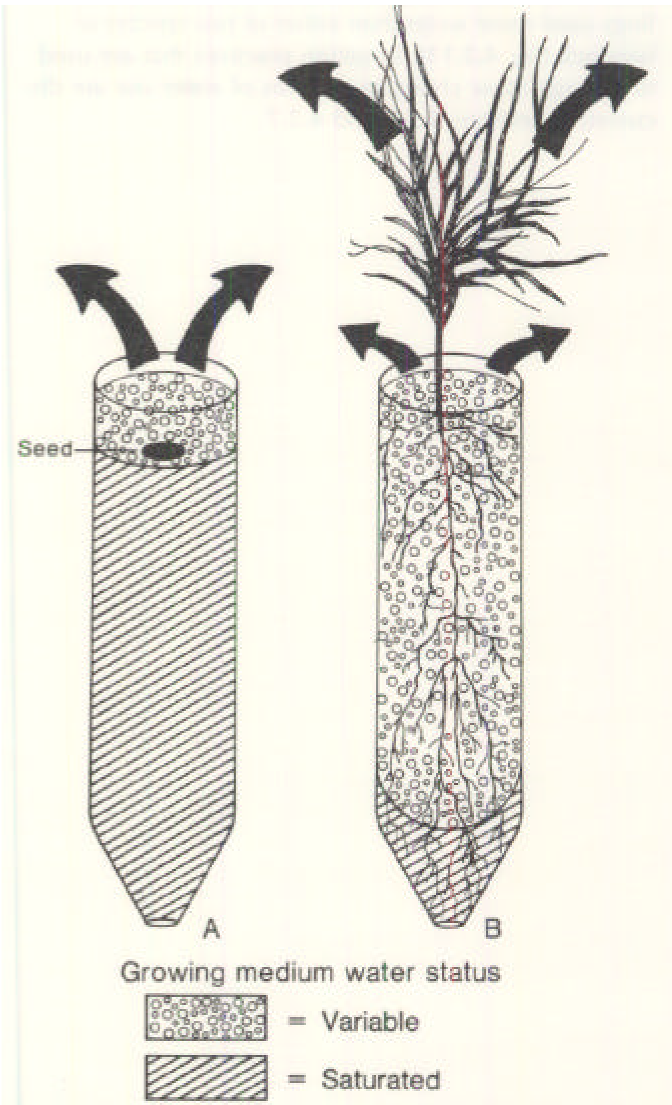


Figure 4.2.12—*There are two stages of evapotranspirational water loss in container nurseries. Evaporation (**A**) is the primary force during seedling germination and emergence, but transpiration (**B**) becomes dominant after seedling occupancy of the container.*

can extract water from throughout the growing medium; at the same time, the foliage shades the surface of the growing medium, which reduces evaporation (Furuta 1978). This change in type of water use affects the water status of the growing medium and resultant irrigation practices. During germination and emergence the medium dries out only in the surface layer, whereas later in the growing season, the growing medium moisture will be depleted throughout the container (fig. 4.2.12). Different species of seedlings use water at different rates; Ballard and Dosskey (1985) found that Douglas-fir seedlings used more water than either of two species of hemlock (fig. 4.2.13). Irrigation practices that are used to manage these changing patterns of water use are discussed in sections 4.2.6 and 4.2.7.

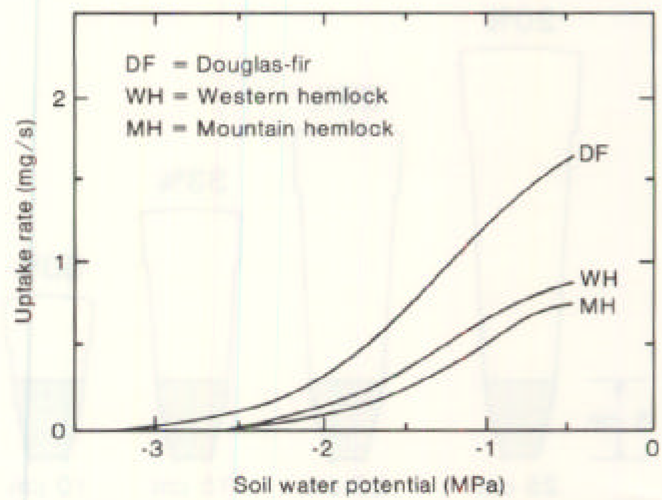


Figure 4.2.13—*Different species of seedlings are able to take-up water at different rates (Ballard and Dosskey 1985).*

4.2.4 Quantity and Quality of Irrigation Water

Because water is considered to be the most important biological factor controlling plant growth, the quantity and especially the quality of irrigation water is the single most important environmental factor in the operation of a container tree nursery. A successful container nursery must have an ample supply of high-quality irrigation water available throughout the growing season. Gartner (1981) stresses the importance of water quality in nursery site selection and discusses the characteristics of different irrigation water sources. Both the quantity and quality of water from potential sources should be checked thoroughly prior to the establishment of a container nursery. (Site selection criteria are discussed in volume one of this series.)

4.2.4.1 Quantity of water required for container nurseries

There are basically two sources of irrigation water for use in container tree nurseries: groundwater and surface water. Both sources have been used successfully, although surface water from streams, reservoirs, or lakes is more likely to be contaminated with pests such as fungal pathogens or weed seeds.

The primary consideration in selecting an irrigation water source is to insure that enough water is available throughout the growing season for all the possible uses at the nursery. Water availability is often a problem during the early spring and late fall if irrigation is needed for frost protection in outside growing compounds or overwintering areas. The availability of surface water may be more variable than that of well water, although the reliability of any irrigation source should be well-researched before the nursery is constructed.

The amount of water necessary to produce a crop of container tree seedlings depends on many factors, such as climate, type of growing structure, type of irrigation system, growing medium, and seedling characteristics. Matthews (1983) calculated that 1,000 conifer seedlings in Styroblock 2® (41 cm^3 = 2.5 cubic inch capacity) containers require up to 45.4 liters (12 gallons) of water per week, depending on type of irrigation system. At Mt. Sopris Nursery in Colorado, a crop of 1,000 conifer seedlings in 164- cm^3 (10-cubic-inch) Ray Leach Single Cell® containers required from 56.8 liters (15 gallons) early in the season to over 189.3 liters (50 gallons) per week during mid-summer. The University of Idaho Forest Research Nursery in Moscow, ID, uses 42.6 to 54.7 liters (11.2 to 14.4 gallons) of irrigation water per week for 1,000 conifer seedlings in 65 cm^3 (4 cubic inches) Ray Leach Pine Cell® containers. The Colorado State Forest Nursery in Ft. Collins uses 75.8 to 94.6 liters (20 to 25 gallons) of irrigation water per week for a thousand of their large 492- cm^3 (30-cubic-inch) Styrofoam® containers.

4.2.4.2 Water quality

The quality of irrigation water is another important factor in the selection and management of a container tree seedling nursery. Water quality should be a primary consideration in the site evaluation for a new nursery because there is no inexpensive way to improve poor-quality irrigation water.

The term water quality means different things to different people because quality is dependent on intended use. For domestic purposes, factors such as color, taste, turbidity, odor, and toxic ion concentrations determine water quality, whereas for irrigation purposes, water quality is determined by two factors:

1. The concentration and composition of dissolved salts (total salinity and individual toxic ions).
2. The presence of pathogenic fungi, weed seeds, algae, and possible pesticide contamination.

***Effects of salts on irrigation water quality*.** Salinity is considered to be the primary factor in the determination of agricultural water quality (Richards 1969). For our purposes, a salt can be defined as a chemical compound that releases charged particles called ions when dissolved in water: for example, potassium nitrate (KNO_3) releases two ions, one a positively charged cation (K^+) and the other a negatively charged anion (NO_3^-). Salts can be either beneficial or harmful, depending on the characteristics of the specific ions involved, as well as the total salt concentration. KNO_3 is a fertilizer salt and both K^+ and NO_3^- are nutrient ions, whereas other salts, such as sodium chloride (NaCl), consist of harmful ions (Na^+ and Cl^-) that can damage or even kill plant tissue. A list of the major ions that affect irrigation water quality is provided in table 4.2.3.

Many terms and units have been used to describe salinity (table 4.2.4). Because an aqueous solution of dissolved ions conducts electricity, salinity is traditionally expressed as electrical conductivity (EC); the higher the salt concentration, the higher the EC reading. EC is measured in units of electrical conductance over a specific distance (usually 1 cm) and at a standard temperature

Table 4.2.3—*Cations and anions commonly found in irrigation water that affect water quality*

Ion name	Chemical symbol	Equivalent weight
Cations		
Calcium	Ca^{2+}	20
Magnesium	Mg^{2+}	12
Sodium	Na^{+}	23
Potassium	K^{+}	39
Anions		
Bicarbonate	HCO_3^{-}	61
Carbonate	CO_3^{2-}	30
Chloride	Cl^{-}	36
Sulfate	SO_4^{2-}	48
Boron[1]	—	—

[1] Boron occurs in several different ionic forms in irrigation water and therefore a specific ionic formula or equivalent weight cannot be given.
Source: California Fertilizer Association (1985).

[25 °C (77 °F)]. The most commonly used units in irrigation water quality are micromhos per centimeter (abbreviated mho and pronounced "micromows") and the SI 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 publication.

Another older system for reporting the total salt content of irrigation water is total dissolved solids (TDS), which can be determined by evaporating a known weight of water and weighing the resultant salt deposit (California Fertilizer Association 1985). TDS in parts per million can be estimated by multiplying the EC (in microsiemens per centimeter) by 0.64 (table 4.2.4).

Specific ions are generally described in units of milliequivalents per liter (meq/l) or parts per million (ppm) (table 4.2.4). The former are the preferred units for water quality purposes, whereas the latter are more practical for fertilizer calculations, so both should be requested in irrigation water quality tests. Although the exact conver-

Table 4.2.4—*Terms and units used to describe salinity effects on water quality*

Units	Abbreviations	Conversion factors
Total salts		
Electrical conductivity (EC)		
mhos system		
mho/cm at 25 °C	mho/cm	—
millimho/cm	mmho/cm	1 mmho = 10^{-3} mho
micromho/cm	µmho/cm	1 µmho = 10^{-6} mho
mhos/cm × 10^{-5}	mhos/cm × 10^{-5}	—
siemens system*		
millisiemens/cm	mS/cm	1 mS = 1 mmho
microsiemens/cm	µS/cm	1 µS = 1 mcmho = 10^{-3} mS
decisiemens/m	dS/m	1 dS/m = 1 mS/cm
Total dissolved solids (TDS)		
parts per million	ppm	TDS (ppm) = (µS/cm) × 0.64
milligrams per liter	mg/l	1 ppm = 1 mg/l
Specific ions		
milliequivalents per liter	meq/l	For total salts: 1 meq/l = µS/cm divided by 100
milligrams per liter	mg/l	1 ppm = 1 mg/l
parts per million	ppm	ppm = meq/l × EW
equivalent weight	EW	EW = atomic weight divided by valence
grains per gallon	gpg	gpg × 17.2 = ppm

* Siemens units are the SI standards and microsiemens per centimeter (µS/cm) are the preferred units for irrigation water quality.

sion will vary with the ions involved, 1,000 µS/cm of salinity equals approximately 640 ppm of total salts and the meq/l of total salts can be estimated by dividing the EC in /AS/cm by 100 (table 4.2.4) (California Fertilizer Association 1985).

The topographic location of a container nursery can have an effect on irrigation water quality because of local climatic or geologic influences. Irrigation water may be contaminated by saltwater intrusion in coastal areas. In arid or semi-arid climates where evapotranspiration exceeds precipitation, salts naturally accumulate in the soil, and geologic deposits and groundwater irrigation sources are often high in salt content. Matthews (1983a) reported that irrigation water quality was much better in coastal container nurseries in British Columbia than in nurseries in the interior of the province. Hallett (1987) tested 32 irrigation water sources in the relatively humid Maritime Provinces of Canada and found an average EC of 170 1tS/cm compared to an average EC value of 507 µS/cm for 15 nurseries in the semi-arid interior West of the United States (Landis 1982). There is a significant amount of local variation, however, because the EC values ranged from 19 to 787 µS/cm in the Maritimes and from 58 to 1,460 µS/cm in the western United States.

Effects of salinity on seedling growth. Soluble salts can affect plant growth in several different ways. Fuller and Halderman (1975) discuss four effects: 1) total salinity can reduce water availability, 2) sodium ions decrease soil permeability, 3) certain specific ions are directly toxic, and 4) availability of other mineral nutrients is altered. Another, nonbiological effect of dissolved salts is the unsightly effect of salt crusts on the foliage, which may affect the salability of seedlings. The specific ions involved and the evaluation criteria for these five categories of seedling injury are listed in table 4.2.5.

Table 4.2.5—*Excess soluble salts affect seedling growth in five ways*

Effect	Ions involved	Evaluation criteria
Water availability	All	Electrical conductivity (EC)
Soil permeability	Sodium Calcium Magnesium Carbonate Bicarbonate	Adjusted sodium adsorption ratio (ASAR)
Direct toxicity	Sodium Chloride Boron	Ion concentration (ppm) Ion concentration (ppm) Ion concentration (ppm)
Nutrient availability	Iron Phosphorus Calcium Magnesium	No specific tests No specific tests Ion concentration (ppm) Ion concentration (ppm)
Foliar staining	Iron Bicarbonate Calcium Magnesium	Ion concentration (ppm) Ion concentration (ppm) Total hardness (ppm)

Effect of salinity on water availability. The total salinity of a water source, as measured by the EC, exerts an osmotic effect in the growing medium solution, which can reduce the water available for plant growth. Salts decrease the osmotic potential and therefore the water potential in the growing medium solution: a value of 3,000 µS/cm represents an osmotic force of 0.1 MPa. Although this may not seem particularly high, it may become significant during critical times such as seed germination, especially if the growing medium is allowed to dry out, which can greatly increase the osmotic concentration. Whitcomb (1984) reported that the soluble salt level doubles when growing medium dries from 50 to 25% moisture content. The high fertilization rates used in container nurseries can add to the salinity problem. The OP becomes an increasingly more significant factor of the total GMWP as the water content of the growing medium decreases (fig. 4.2.7).

Most woody plant seedlings, and conifers in particular, are extremely sensitive to salinity damage. The principal damage of high salinity is reduced growth rate, which usually develops before more visible foliar symptoms become evident. Very sensitive species, such as blue spruce and Douglas-fir, can suffer growth reductions as high as 50% when the EC of the growing medium is as low as 2,500 µS/cm (table 4.2.6). The symptoms of salt injury vary with species and may include one or more of the following: foliar tip burn (fig. 4.2.14A), scorching, or bluish color; stunting; patchy growth; and eventual mortality. Water with high salt levels can also cause whitish deposits on the leaf surfaces (fig. 4.2.14B) that, although not directly damaging, may reduce the sale-ability of the crop. Salt deposits may also accumulate on sprinkler nozzles and reduce their efficiency.

Salinity rating guidelines for irrigation water for container tree nurseries are provided in table 4.2.7. The EC

Table 4.2.6—*Salinity (measured as electrical conductivity) of growing medium that produced 0 to 50% reductions in growth rate (RGR)*

Salinity tolerance class	Representative species	Conductivity of medium ($\mu S/cm$)[a]			
		0% RGR	10% RGR	25% RGR	50% RGR
Very sensitive	Blue spruce Douglas-fir	1,000	1,400	1,800	2,500
Sensitive	Eastern redcedar Magnolia	1,400	2,000	3,000	4,600
Moderate tolerance	Ponderosa pine Green ash	2,500	3,400	4,800	7,000
Tolerant	Russian olive Allepo pine	4,500	5,800	8,000	12,000
Very tolerant	Saltbush River-oak casuarina	8,000	10,000	13,000	18,000

[a] = Electrical conductivity of a saturation extract (ECe) of the growing medium, measured in microSiemens per centimeter (= micromhos per centimeter).

Source: modified from Ayers (1977) and Handreck and Black (1984).

4.2.14A

4.2.14B

Figure 4.2.14—*Dissolved salts, whether from natural sources or from added fertilizers, can affect seedlings in several ways: necrosis of foliar margins, or "tip burn"* (**A**) *or leaf spotting* (**B**).

can easily be checked at the nursery using a conductivity meter, and salinity tests should be run at least every month because water quality can change significantly over the course of a year. The EC and pH of the irrigation water at a California nursery was monitored monthly, and the values were found to vary considerably because of differences in water quality between different irrigation wells (fig. 4.2.15). Although there is no inexpensive way to remove salts from irrigation water, cultural practices such as increasing the porosity of the growing medium and leaching more frequently can help alleviate the effects of saline water.

Table 4.2.7—*Irrigation water quality standards for container tree seedling nurseries*

Quality index	Units	Quality rating: Good	Marginal	Poor
Salinity	µS/cm (µmhos/cm)	0–500	500–1500	>1500
Sodium effect on soil permeability[1]	ASAR	0–6	6–9	>9
		Toxicity thresholds		
Toxic ions				
Sodium	ppm	50		
	meq	2.2		
Chloride	ppm	70		
	meq	2.0		
Boron[2]	ppm	0.75		
	meq	—		
Nutrient ions				
Calcium	ppm	100		
	meq	5.0		
Magnesium	ppm	50		
	meq	4.2		
Sulfate	ppm	250		
	meq	5.2		
Foliar staining ions				
Bicarbonate	ppm	60		
	meq	1.0		
Total hardness (Ca + Mg)	ppm	206		
Iron	ppm	0.1		

[1] ASAR is not important in container nurseries unless soil is used in the growing medium

[2] Boron exists in several ionic forms and so milliequivalents cannot be precisely determined.

Source: modified from Ayers (1977), Bunt (1976), Swanson (1984), Fitzpatrick and Verkade (1987), Vetanovetz and Knauss (1988).

Although highly saline irrigation water is not desirable, very pure irrigation water can also cause problems; in fact, distilled or deionized water is not recommended for irrigating growing tree seedlings. Water with a very low level of dissolved salts will leach fertilizer ions as it passes through the growing medium. Vetanovetz and Knauss (1988) define "too pure" irrigation water as having a low total soluble salt level (EC < 200 µS/cm), and low calcium and magnesium contents. They state that use of very pure water with artificial growing media may leach out the nutrients from incorporated fertilizer amendments, such as limestone and dolomite, resulting in a calcium or magnesium deficiency. This will not be a serious problem, however, if container tree seedling nurseries add fertilizer salts to the irrigation water through liquid fertilizer injection.

Sodium effect on growing medium permeability. Although sodium (Na^+) is directly toxic to seedlings, this ion has an equally serious effect on growing medium structure. An excess of Na^+ ions relative to the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions can cause clay particles to disperse and seal up the pores, which seriously reduces permeability and gas exchange. This sodium effect is usually measured in terms of the sodium adsorption ratio (SAR), which gives a relative index of the concentration of Na^+ to Ca^{2+} and Mg^{2+} ions. Actually a revision of the SAR index, called the adjusted sodium adsorption ratio (ASAR), is row preferred because it also considers the effect of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions (table 4.2.5). ASAR standards for nursery irrigation water are provided in table 4.2.7. Fortunately, sodium-induced permeability problems only affect natural soils and should therefore not be a problem in the "artificial" growing media (those that do not contain soil) that are commonly used in most container tree seedling nurseries.

Toxicity of specific ions. The third effect of salinity is the direct toxicity of certain ions, especially sodium, chloride, and boron, to seedling growth (table 4.2.5). Individual plant species vary considerably in their sensitivity to these ions, but all container seedlings should be considered very susceptible because of their small size and succulence. Ayers (1977) provides water quality guidelines for either root or foliar absorption of these three potentially toxic ions, and Bunt (1976) also published water quality standards (table 4.2.7). Other ions, including any of the heavy metal ions such as manganese or zinc, can also be toxic if present in high enough concentrations. These problems should be identified in the initial irrigation water quality tests, however.

Mineral nutrient availability. Excesses of certain ions for example, calcium and magnesium-in the irrigation water can produce nutrient imbalances in the growing medium solution and lead to problems with nutrient uptake and utilization in some plants (Fitzpatrick and Verkade 1987) (table 4.2.5). Vetanovetz and Knauss (1988) state that, if irrigation water contains over 100 ppm Ca^{2+}, this mineral nutrient may accumulate in the

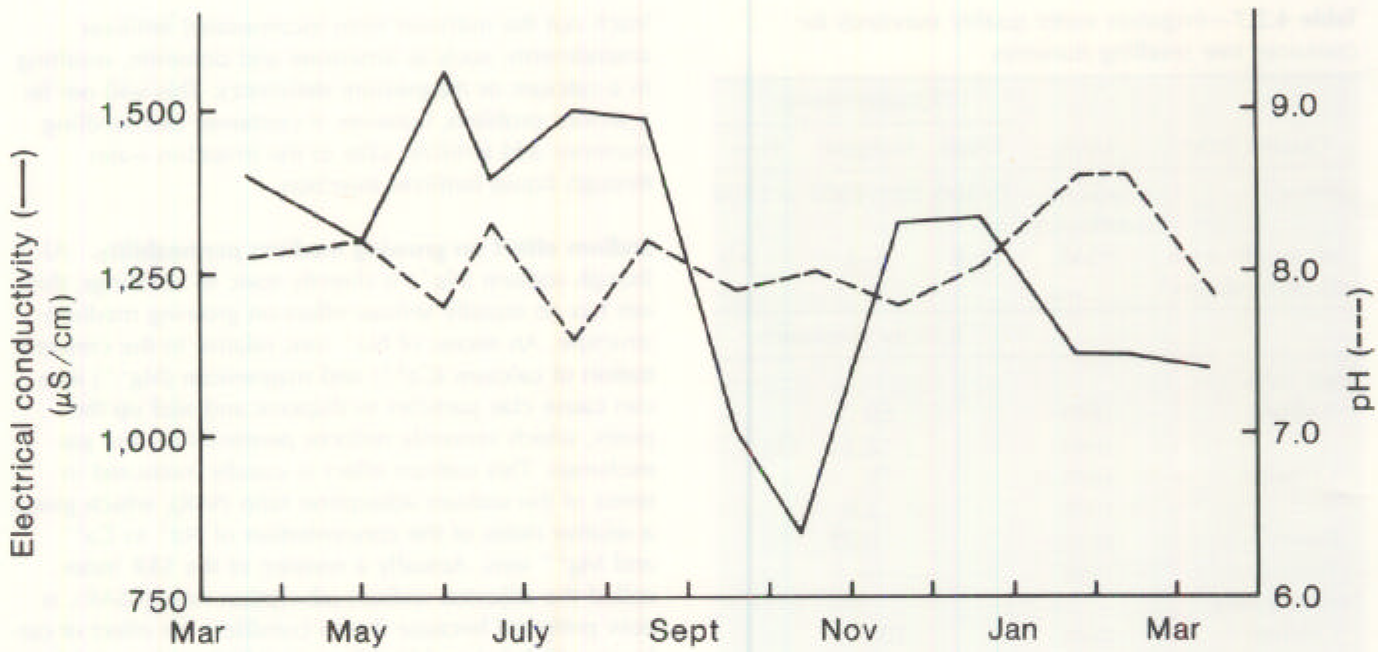


Figure 4.2.15—*Irrigation water quality, as measured by electrical conductivity and pH, can vary significantly during the year, as demonstrated by these data from a California container nursery.*

growing medium and cause deficiencies of Mg^{2+} or iron. Greater than 50 ppm of Mg^{2+} in the water can also cause deficiencies of other mineral nutrients, such as Ca^{2+} and potassium (table 4.2.7). These nutrient imbalances are complicated and particularly difficult to diagnose, but should not be a problem in container tree seedling nurseries that use artificial growing media and a well-balanced fertilization regimen.

Foliar residues. Certain compounds, such as iron and calcium carbonate, can cause discoloration or spotting of seedling foliage (table 4.2.5, fig. 4.2.14B). Although these cosmetic blemishes do not directly affect seedling growth, they do affect customer appeal. Some well waters contain dissolved iron in the ferrous form; when these waters are applied through sprinkler irrigation, the ferrous iron is converted to the ferric form, which has a typical rust color that can stain foliage (Swanson 1984) or clog irrigation nozzles (Fitzpatrick and Verkade 1987). "Hard" irrigation water contains high levels of calcium, magnesium, carbonate, or bicarbonate ions. When this irrigation water is sprinkled on plant foliage, it produces white deposits of calcium carbonate or magnesium carbonate upon evaporation. These carbonate deposits can also build up on irrigation nozzles. Water quality standards for foliar staining ions are listed in table 4.2.7.

Pests in irrigation water. Container nurseries that use irrigation water from surface water sources such as ponds (fig. 4.2.16), lakes, or rivers may encounter problems with biotic pests, that is, weeds, pathogenic fungi, moss, algae, or liverworts (Baker and Matkin 1978). Surface water that originates from other nurseries or farmland is particularly likely to be contaminated with water-mold fungi, such as *Pythium* and *Phytophthora*, that can cause damping-off (Whitcomb 1984). Recycled nursery irrigation water should also be suspect. Water-mold fungi can be isolated from nursery irrigation water sources using "baits" of green fruit such as pears or apples (McIntosh 1966). 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. Irrigation water was considered to be the source of a blue-green algae problem in a British Columbia container nursery (Vance 1975).

Water-borne pests can be killed with chlorination, and some specialized filtration systems can remove many disease organisms from irrigation water. (See the follow-

Figure 4.2.16—*Surface water sources, such as this pond, can be a source for waterborne nursery pests, including weed seeds, algae, and pathogenic fungi.*

ing section for more information on chlorination and filtration.)

Pesticide contamination. Irrigation water, especially in agricultural areas, may have become contaminated with residual pesticides. Urbano (1987) reports that pesticide contamination of groundwater is becoming an increasingly serious problem in the United States. In 1979, the active ingredient (aldicarb) of the herbicide Temik® was identified in well water in Long Island, NY, and groundwater contamination is considered a potential threat in many other areas. Herbicides applied to adjacent cropland or to control aquatic weeds in reservoirs can affect irrigation water quality. Vance (1975) reported substantial losses of container seedlings due to herbicidal control of aquatic weeds in a nursery irrigation reservoir. Potential sources of irrigation water should be tested for pesticide contamination when a site is being evaluated prior to development.

Water quality tests. Ideally, water quality tests are performed during nursery site selection and at regular intervals thereafter, but many container tree seedling nurseries 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 milliequivalents per liter (meq/liter) and parts per million (ppm) (table 4.2.8). For a small additional fee, it is possible to test for the remaining nutrient ions at the same time. In addition to the ion concentrations, the testing

Table 4.2.8—*Components of an irrigation water quality test for soluble salts*

Water test parameter	Reporting units
Quality indexes	
Electrical conductivity (EC)	µS/cm
Adjusted sodium adsorption ratio (ASAR)	None
pH	None
Specific ion concentrations	meq/l & ppm
Sodium	
Calcium	
Magnesium	
Chloride	
Carbonate	
Bicarbonate	
Sulfate	
Boron	
Fertilizer concentrations	ppm
Ammonium nitrogen	
Nitrate nitrogen	
Phosphorus	
Potassium	
Micronutrients	

lab should report three standard water quality indices: electrical conductivity, adjusted sodium adsorption ratio, and pH. EC and pH can be measured directly from the water sample and the ASAR can be computed from the specific ion concentrations in milliequivalents per liter (table 4.2.9).

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. Due to the different chemical structures of the 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.

Fitzpatrick and Verkade (1987) discuss the proper procedure for collecting a sample for irrigation water testing: use a clean plastic bottle with a firm lid, let the water

Table 4.2.9—*Calculation of adjusted sodium adsorption ratio (ASAR)*

$$ASAR = \frac{Na}{\sqrt{(Ca + Mg)/2}} \bullet [1 + (8.4 - pHc)]$$

Na = sodium ion concentration in milliequivalents per liter (meq/l)
Ca = calcium ion concentration in meq/l
Mg = magnesium ion concentration in meq/l

pHc, which is a relative index calculated from the following ion concentrations, is the sum of **A+B+C:**

Ca + Mg + Na (meq/l)	A	Ca + Mg (meq/l)	B	CO_3 + HCO_3 (meq/l)	C
0.5	2.11	0.05	4.60	0.05	4.30
0.7	2.12	0.10	4.30	0.10	4.00
0.9	2.13	0.15	4.12	0.15	3.82
1.2	2.14	0.20	4.00	0.20	3.70
1.6	2.15	0.25	3.90	0.25	3.60
1.9	2.16	0.32	3.80	0.31	3.51
2.4	2.17	0.39	3.70	0.40	3.40
2.8	2.18	0.50	3.60	0.50	3.30
3.3	2.19	0.63	3.50	0.63	3.20
3.9	2.20	0.79	3.40	0.79	3.10
4.5	2.21	1.00	3.30	0.99	3.00
5.1	2.22	1.25	3.20	1.25	2.90
5.8	2.23	1.58	3.10	1.57	2.80
6.6	2.24	1.98	3.00	1.98	2.70
7.4	2.25	2.40	2.90	2.49	2.60
8.3	2.26	3.14	2.80	3.13	2.50
9.2	2.27	3.90	2.70	4.00	2.40
11.0	2.28	4.97	2.60	5.00	2.30
13.0	2.30	6.30	2.50	6.30	2.20
15.0	2.32	7.90	2.40	7.90	2.10
18.0	2.34	10.00	2.30	9.90	2.00
22.0	2.36	12.50	2.20	12.50	1.90
25.0	2.38	15.80	2.10	15.70	1.80
29.0	2.40	19.80	2.00	19.80	1.70
34.0	2.42				
39.0	2.44				
45.0	2.46				
51.0	2.48				
59.0	2.50				
67.0	2.52				
76.0	2.54				

Source: modified from Ayers (1977).

run for several minutes, and rinse the sample bottle well before collecting the sample. Chu (1986) states that a 500-ml (about 1-pint) sample is sufficient for most water tests but that 1,000 ml (about 1 quart) is needed for pesticide testing. Label the sample bottle properly with a waterproof marker before sending it to the analytical laboratory. The sample should be tested as quickly as possible but can be stored under refrigeration for short periods, if necessary. Water quality parameters can change over time, however, and Chu (1986) reports that the values for some test parameters, such as pH and chlorine, can change after only a few hours (table 4.2.10).

***Corrective treatments for irrigation water*.** Any irrigation water treatment system requires significant initial expense, making it prudent to determine irrigation water quality before a nursery is developed. Sometimes, however, there is no other option because it is less expensive to treat the irrigation water than to attempt to relocate an already established nursery. There are six standard water treatment procedures.

Acidification. Irrigation water is often treated with acid to lower the pH level to the ideal range of 5.5 to 6.5. Phosphoric and sulphuric acid are most commonly used, although other acids such as nitric or acetic acid have also been utilized. Acidification will not change the salinity of irrigation water, but it does remove the carbonate and bicarbonate ions, as reflected by the lower pH. Phosphoric acid was used to acidify the irrigation water in a Canadian container tree seedling nursery; the pH was lowered from 8.8 to 6.1 but the total salinity, as reflected by the EC readings, was not changed appreciably (table 4.2.11). (Acidification is also discussed in section 4.1.3.3.)

Reverse osmosis. This treatment consists of forcing irrigation water through a semipermeable membrane so ,hat the salt ions are left behind. The process is relatively expensive, but systems are available for nurseries. As an example of the costs involved, a California container tree seedling nursery recently purchased a reverse osmosis system, at an initial cost of over $50,000, designed to produce 40,000 gallons per day of treated water at an operating cost of approximately $0.80 per thousand gallons. This system is designed to significantly improve irrigation water quality from an initial pH of 8.1 and EC of 2,218 µS/cm to a pH 5.8 and an EC of 312 /µS/cm. Reverse osmosis systems require regular maintenance but are a practical irrigation water treat-

Table 4.2.10—*Pretreatments, storage time, and storage methods for irrigation water samples*

Water test parameter	Pretreatment	Storage method	Maximum storage time
pH	None	Analyze immediately	2 hr
Electrical conductivity	None	Refrigerate	28 days
Chlorine	None	Analyze immediately	2 hr
Boron	None	Refrigerate	28 days
Nitrogen—Total, ammonium, or nitrate	Add sulfuric acid to lower pH below 2.0	Refrigerate	28 days
Phosphorus	Add sulfuric acid to lower pH below 2.0	Refrigerate	3 days
Sulfate	None	Refrigerate	30 days
Pesticides	None	Refrigerate	7 days

Source: modified from Chu (1986).

Table 4.2.11—*The chemical effects of irrigation water acidification with phosphoric acid on water quality indexes and individual ions*

Water quality parameter	Levels in irrigation water	
	Untreated	Acidified
pH	8.8	6.1
EC	377	348
SAR[1]	15	15
RSC[1]	3.84	0.28
Ca (ppm)	3.4	3.8
Mg (ppm)	0.43	0.39
Na (ppm)	117	118
CO_3 (ppm)	24	0
HCO_3 (ppm)	198	31
B (ppm)	0.06	0.08

[1] The SAR (sodium adsorption ratio) is unchanged because it does not consider CO_3 or HCO_3 levels, whereas the RSC (residual sodium carbonate) index and the adjusted sodium adsorption ratio (ASAR), which was not given, do.

Source: R.D. Hallett, Canadian Forestry Service, Fredericton, NB.

ment system for container tree seedling nurseries if the initial cost can be justified.

Deionization. Deionization is an effective yet costly method to remove unwanted salts from water and would only be practical for crops of very high value (Furuta 1978). The process consists of passing water over ion-exchange resins that are charged with either H^+ or OH^- ions; these ions are exchanged for the Ca^{2+}, Cl^-, or other charged ions in the irrigation water, resulting in chemically pure water. Boron salts are not removed by deionization, although all ions can be removed by reverse osmosis (Hartnrann and Kester 1983). Another drawback to this process, in addition to the high cost, is that it is relatively slow, and treated water must generally be accumulated and stored to supply the volume needed by large container tree seedling nurseries.

Water softeners. This water treatment is included only for completeness and should *never* be used for treating irrigation water at container tree seedling nurseries. Water softeners do not improve the salinity level of water, but merely convert "hard" water, which contains an abundance of Ca^{2+} and Mg^{2+} ions, to "soft" water, which is predominated by Na^+ ions; this additional Na is much more injurious to plants than the Ca and Mg that was replaced (Whitcomb 1984). The primary benefit of softened water is that it makes soaps and detergents clean more effectively.

Chlorination. Chlorination is a viable water treatment for nurseries that have a problem with fungi, bacteria, algae, or liverworts that are introduced through the irrigation system. The two most common ways of introducing chlorine into the irrigation water are:

1. liquid sodium hypochlorite (household bleach, NaOCl) or powdered calcium hypochlorite [$Ca(OCl)_2$] can be added to the water, and

2. pressurized chlorine gas (Cl_2) can be injected into the irrigation system.

Chlorine gas is the most common and cheapest way to chlorinate water but is relatively dangerous to use, compared to sodium or calcium hypochlorite. When chlorine is added to water, it interacts to produce hypochlorite (HOCl) and chlorite ions (OCl^-), which are powerful oxidizing agents and responsible for the disinfectant action of the solution. In actuality, only part of the applied chlorine (called the *free residual chlorine*) is effective because some of the chlorine ions combine with organic substances (combined chlorine) and are essentially inactivated (Tchobanoglous and Schroeder 1985). The various forms of chlorine used in chlorination should not be confused with the chloride ion (Cl^-), which is an important irrigation water quality ion, but has no disinfectant properties (Green 1987).

There are five aspects of operational chlorination: 1) initial contact, 2) contact time, 3) form and concentration of disinfectant, 4) species and concentration of pathogens, and 5) environmental factors, particularly pH and temperature (Tchobanoglous and Schroeder 1985). For example, when exposed to warm temperatures and sunlight, hypochlorite decomposes and loses its disinfectant properties (Green 1987). The engineering aspects of a chlorination system are too complicated to be discussed here but suffice it to say that, to be effective as a disinfectant, a critical concentration of free residual chlorine must be maintained for a specified time period. Baker and Matkin (1978) report that 1 ppm free residual chlorine will kill zoospores of *Phytophthora cinnamomi in* 1 minute but that the mycelium of the fungus is much more resistant.

A chlorination system, whether chlorine gas injection or hypochlorite addition, should be designed so that the chemical is thoroughly mixed with the irrigation water and has enough time to act. Because chlorine is deactivated by suspended organic matter, irrigation water should be filtered before treatment. Chlorine gas is also very hazardous and corrosive and, therefore, a chlorination expert should be consulted when designing a chlorine injection system. The chlorine level in the applied irrigation water should be periodically monitored to make certain that the chlorination system is working properly; this can be done with a commercially available swimming pool test kit or with a Hach® kit (Frink and Bugbee 1987).

Chlorination is routinely being used in some forest and ornamental nurseries. Standard household bleach (5.25% sodium hypochlorite) at a rate of 20.4 cm^3 per 1,000 liters of water (2.6 fluid ounces per 1,000 gallons) will produce approximately 1 ppm chlorine (Baker and Matkin 1978), and the authors recommend a minimum contact time of 4 minutes. Bunt (1976) recommends adding enough sodium hypochlorite to produce a chlorine content of 5 to 20 ppm, but states that a chlorine concentration as low as 0.5 ppm can be effective if the treated water is stored. Handreck and Black (1984) recommend adding enough bleach to give 2 ppm chlorine. Daughtry (1984) discusses an operational chlorination system using injected chlorine gas that produces a concentration of 0.3 ppm residual free chlorine and a contact time of about 25 seconds within the irrigation line.

Many plants are sensitive to chlorine, and Bunt (1976) reported no problems with water containing 5 ppm of chlorine. Injected chlorine at 5 to 10 ppm was not found to be phytotoxic to a wide range of plant species and the higher level partially controlled liverwort (Scott 1980, as reported in Whitcomb 1984). Many domestic water supplies are chlorinated to control human pathogens but this treatment usually produces a relatively low chlorine level (about 1 ppm) that is not injurious to most plants (Frink and Bugbee 1987).

Filtration. Filters can be used to remove suspended or colloidal particles, such as very fine sand, that can damage irrigation or fertilization equipment or plug irrigation nozzles. In addition to removing suspended inorganic particles, filters can be used to remove some unwanted pests, such as weed seeds or algae, from the irrigation system (figure 4.2.17).

Two general types of filters are commonly used in water treatment: granular medium filters and surface filters. 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 (Tchobanoglous and Schroeder 1985). 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

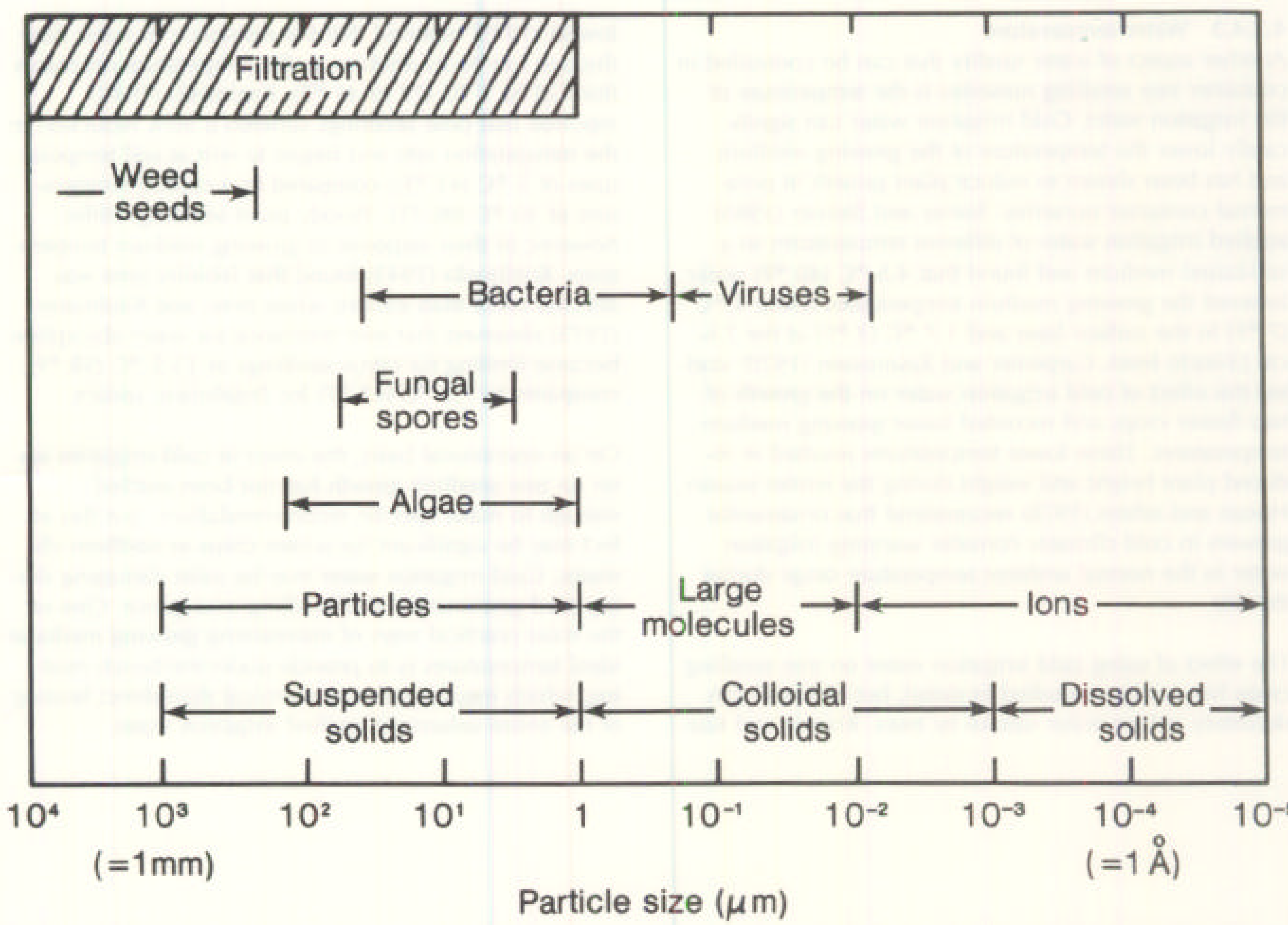


Figure 4.2.17—*Many different sizes of inorganic particles and some biological pests can be carried in irrigation water. Irrigation water for container tree seedling nurseries should be filtered to remove these unwanted materials (modified from Tchobanoglous and Schroeder 1985).*

material; screens must be physically removed and cleaned whereas cartridge filters are not reusable and must be regularly replaced (Sprinkler Irrigation Association 1983).

Filtration is recommended for container tree seedling nursery irrigation water, and filters should be installed before the water passes through the nutrient injector to intercept sand particles that can cause excessive wear or plug valves.)ones (1983) recommends cartridge filters because they are easy to change. Back flushing of screens or granular medium filters is not practical with many nursery irrigation systems. The installation of a 25-/Am cartridge filter is recommended for the Smith Measuremix® liquid fertilizer injector. Handreck and Black (1984) recommend using filters small enough to remove particles greater than 5 µm in diameter, which will take care of most suspended materials (fig. 4.2.17). The types of filters used for swimming pools are capable of removing suspended particles greater than 50 µm in diameter. Specialized filtration systems, such as the Millipore©, can remove particles around 1 /µm in diame ter; such a system is therefore capable of removing some disease organisms as well as most suspended solids (fig. 4.2.17). Unfortunately, these sophisticated filtration systems are relatively expensive and require frequent maintenance (Jones 1983).

4.2.4.3 Water temperature

Another aspect of water quality that can be controlled in container tree 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. Seeley and Steiner (1965) applied irrigation water of different temperatures to a soil-based medium and found that 4.5 °C (40 °F) water lowered the growing medium temperatures about 4 °C (7 °F) in the surface layer and 1.7 °C (3 °F) at the 7.6cm (3-inch) level. Carpenter and Rasmussen (1970) studied the effect of cold irrigation water on the growth of two flower crops and recorded lower growing medium temperatures. These lower temperatures resulted in reduced plant height and weight during the winter season. Hanan and others (1978) recommend that ornamental growers in cold climates consider warming irrigation water to the normal ambient temperature range during the day.

The effect of using cold irrigation water on tree seedling crops has not been studied in detail, but cold soil can definitely reduce water uptake by trees. Kramer and Kozlowski (1979) reported that the resistance to water flow through tree roots doubles as the temperature decreases from 25 to 5 °C (77 to 41 °F). Kozlowski (1943) reported that pine seedlings suffered a 50% reduction in the transpiration rate and began to wilt at soil temperatures of 5 °C (41 °F), compared to a control temperature of 30 °C (86 °F). Woody plant seedlings differ, however, in their response to growing medium temperatures. Kozlowski (1943) found that loblolly pine was affected more than eastern white pine, and Kaufmann (1975) observed that root resistance for water absorption became limiting for citrus seedlings at 13.5 °C (58 °F), compared to 7.5 °C (45 °F) for Engelmann spruce.

On an operational basis, the effect of cold irrigation water on tree seedling growth has not been studied enough to make specific recommendations, but this effect may be significant for winter crops in northern climates. Cold irrigation water may be most damaging during seed germination and seedling emergence. One of the most practical ways of maintaining growing media at ideal temperatures is to provide under-the-bench heating, which may be more economical than direct heating of the entire volume of applied irrigation water.

4.2.5 Types of Irrigation Systems

The method of applying irrigation water in container tree seedling nurseries depends on the size of the operation and the characteristics of the crop species. Most large nurseries use some sort of mechanical irrigation system; based on the Container Nursery Survey, only 2% of the respondents used hand watering. Hand watering, however, is often necessary for small container tree seedling nurseries or for nurseries producing species with radically different water requirements (fig. 4.2.18).

Furuta (1978) lists three major types of irrigation systems used in ornamental container nurseries: overhead sprinkling, individual container (including drip irrigation), and subirrigation. Overhead sprinkling is the only one used in container tree seedling nurseries because the containers are too small for drip irrigation of individual containers, and subirrigation would prohibit air root pruning at the bottom of the containers.

4.2.5.1 Overhead irrigation systems

The basic design consideration of any irrigation system used in container tree seedling nurseries is that water must be applied evenly to many individual containers that have a relatively small top opening in relation to their volume. To complicate matters, each container houses a growing seedling that will eventually produce enough foliage to intercept a significant proportion of the applied irrigation and prevent it from reaching the growing medium surface. Overhead systems are also very wasteful of water, for only a limited percentage of the applied water ever reaches the roots of the seedlings.

Figure 4.2.18—*Hand watering is the only way to irrigate small lots of water-sensitive plants, such as many native plant species.*

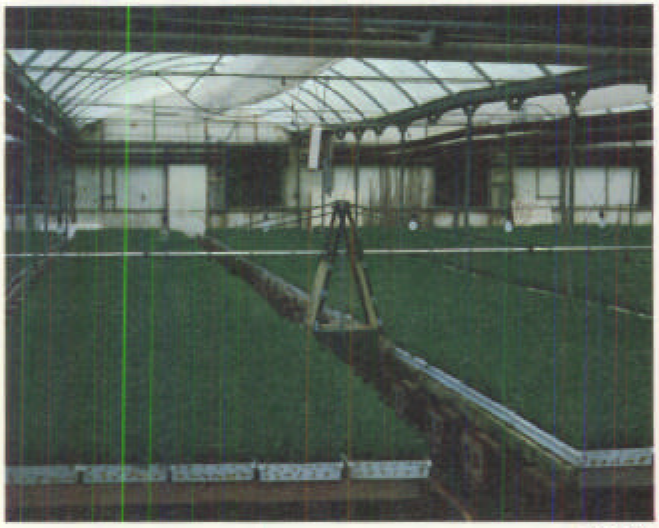
Weatherspoon and Harrell (1980) studied the efficiency of different irrigation methods for ornamental container plants and found that only 13 to 26% of the irrigation water applied through overhead sprinklers was retained by the growing medium. On the positive side, the artificial growing media used in container tree seedling nurseries have high infiltration capacities compared to most natural agricultural soils, and wind drift is not a problem in completely enclosed greenhouses.

There are many types of overhead irrigation systems, but in container tree seedling nurseries they can be divided into mobile and fixed systems. Mobile systems consist of a traveling irrigation boom, and 59% of the nurseries surveyed in the Container Nursery Survey used this type of irrigation system. Fixed irrigation systems consist of regularly spaced irrigation nozzles and were used in 31 % of the surveyed nurseries, whereas the remaining 10% used some combination of watering systems.

Mobile irrigation booms. This popular irrigation system consists of a horizontally oriented boom that carries a distribution pipe containing a series of regularly spaced nozzles. The boom is mechanically drawn along the length of the growing area by an electric motor, usually covering one or more benches (fig. 4.2.19). The boom is reversed mechanically when it reaches the end of the bench and the seedlings are irrigated from the opposite direction. A number of passes is usually required to completely saturate the containers. The booms can be supported from a ceiling track, or on a floor-mounter cart; the connecting hose is pulled along underneath in a supporting carriage or trails on the floor.

Irrigation boom systems distribute water very evenly compared to fixed systems because they supply a moving curtain of water with none of the distribution problems inherent with circular pattern sprinklers. They are relatively expensive, however, and because they are mechanical systems, are susceptible to breakdown. Shearer (1981) points out that moving sprinklers are not efficient for frost protection because they move too slowly to provide continuous coverage of all the growing areas.

A variety of nozzle types has been used on irrigation booms including circular, cone, and flat fan, although the majority of nurseries use some variety of the flat fan nozzle (fig. 4.2.20A). If possible, a relatively coarser spray nozzle than that used for pesticides should be used for irrigation to minimize misting, insure good penetration through seedling foliage, and apply the re-



4.2.19A

4.2.19B

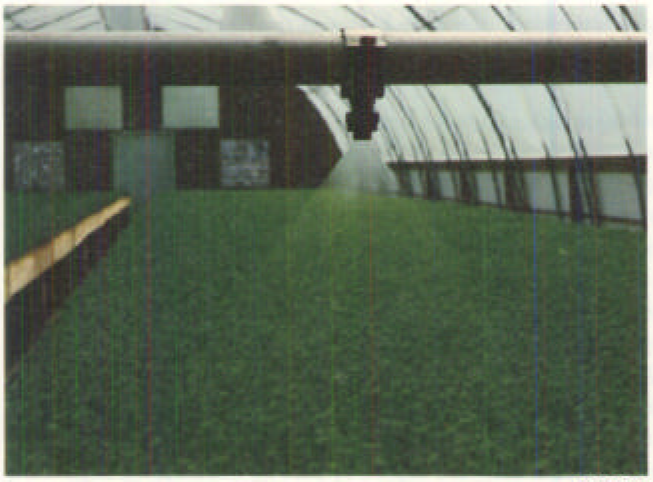
Figure 4.2.19—*Mobile irrigation boom systems: floor-mounted carriage that covers two greenhouse benches* (**A**) *and rail-mounted carriage in an outdoor growing compound* (**B**).

quired amount of irrigation water in a short time. Some nurseries have three different types of irrigation nozzles mounted on parallel booms: a flat fan nozzle for irrigation (fig. 4.2.20A), a misting nozzle (fig. 4.2.20B), and a hollow cone nozzle for applying pesticides. Once the irrigation nozzle has been selected, irrigation coverage is dependent on: 1) the spacing of the nozzles on the boom, 2) the distance of the nozzle above the containers, 3) the water pressure at the nozzle, and 4) the speed of the irrigation boom. The spacing of the nozzles along the boom and the proper distance above the bench can be determined from the nozzle performance specifications supplied by the manufacturer. Hallett (1982a) recommended Teejet 8003® nozzles mounted on 31-cm (12.2-inch) centers on a boom set at 40 to 50 cm (15.7 to 19.7 inches) above the seedlings. Willingdon (1987) states that Teejet 8008® are the most commonly used irrigation boom nozzles in British Columbia nurseries. Nozzle pressure can be directly measured from the irrigation nozzle with a pressure gauge equipped with a pitot tube. Be aware that the water pressure reading at the nutrient injector or in the headhouse can be significantly different from the actual delivered pressure at the nozzle; to monitor irrigation nozzle efficiency, therefore, water pressure must be measured at or near the nozzles. The final factor controlling irrigation coverage is the speed of the irrigation boom itself. A rate of approximately 2.4 to 3.1 m/min (8 to 10 feet per minute) has proven effective in an Idaho container tree seedling nursery (Myers 1987).

Many commercial irrigation booms are equipped with variable speed motors so that the speed can be adjusted for each nursery situation.

Fixed overhead sprinklers. This type of irrigation system consists of a series of parallel irrigation lines, usually constructed of plastic PVC pipe, with sprinklers spaced at uniform intervals to form a regular grid pattern. Overhead sprinklers apply water at a fairly rapid rate compared to the irrigation boom system and are relatively inexpensive to install and operate (Davidson and Mecklenburg 1981). Fixed irrigation systems generally do not apply water as evenly as mobile systems but will do an acceptable job if properly designed and maintained.

Generally, the growing structure is divided into irrigation "bays" 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 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 of differing wa-



4.2.20A

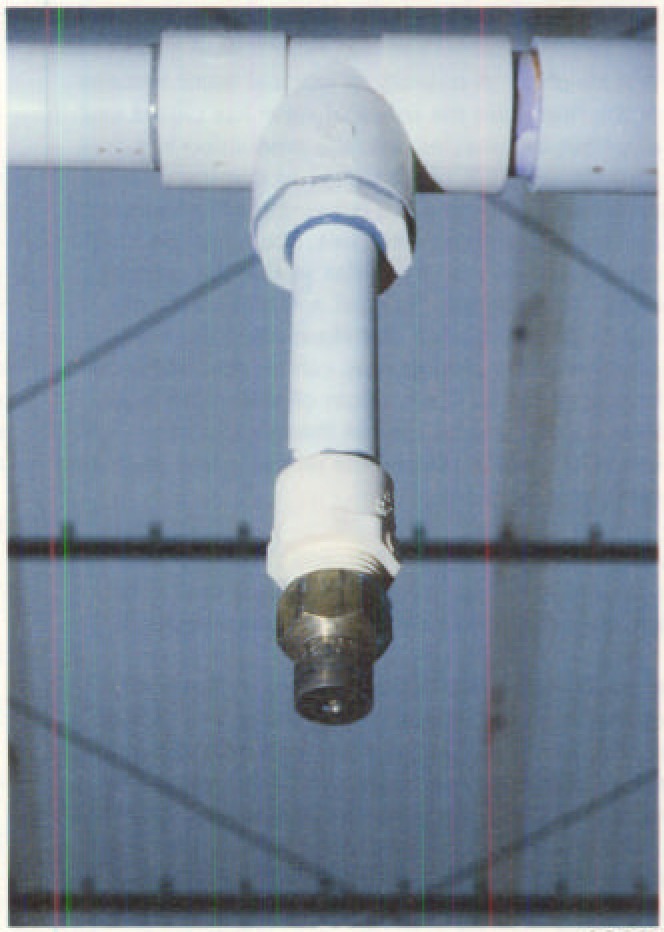
4.2.20B

Figure 4.2.20—*Types of nozzles used for mobile irrigation booms: flat fan nozzle for routine irrigation* (**A**) *and misting nozzle for light surface irrigation and maintaining humidity* (**B**).

ter 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 insure that the system is balanced in terms of coverage and water pressure.

Several types of irrigation 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 4.2.21A). Stationary nozzles (fig. 4.2.21 B) have no moving parts but distribute water in a circular pattern; these nozzles also come in half-circle and quarter-circle patterns. Mist nozzles are also sometimes installed on overhead irrigation lines. Mist nozzles are primarily used during the germination period and for cooling and humidity con-

4.2.21A



4.2.21B

Figure 4.2.21—*Types of irrigation nozzles used in fixed overhead irrigation systems: "spinner-type" nozzle equipped with an anti-drip valve* (**A**) *and stationary irrigation nozzle* (**B**).

trol because they do not supply water at a fast enough rate for normal irrigation.

Some drawbacks of fixed overhead irrigation systems are:

1. *Lack of uniform coverage:* This problem can be avoided by proper design of the irrigation system, ensuring proper overlap between nozzles (see section 4.2.5.2 for irrigation design considerations).

2. *Waste of irrigation water*: Because irrigation water is applied to the entire growing area, including aisles and walls, considerably more water is wasted than with boom systems. This is less of a problem in arid climates, however, because evaporation of this water adds to the humidity in the growing structure.

3. *Nozzle drip*: A quantity of residual water remains in the lines after the solenoid valve has closed and drips out the nozzles onto the production benches, washing seed out of containers or causing disease problems by keeping the growing medium saturated and the foliage constantly wet. The irrigation lines can be located over the aisles so that the nozzles drain on to the floor. Special anti-drip valves (fig. 4.2.21A) are available that close when the water pressure drops, or drip lines can be attached to the bottom of the nozzle to drain off the excess water. Residual water remaining in the irrigation lines also can be a problem during the winter, when freezing can break the pipes.

Furuta (1978), Langhans (1980), and Davidson and Mecklenburg (1981) present good discussions of the design and operation of overhead irrigation systems.

***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 (fig. 4.2.22A). The main type of sprinkler nozzle is the rotating-impact type (fig. 4.2.22B); these sprinklers rotate slowly due to 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 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. Stationary sprinklers can also be used on basal irrigation systems.

One major 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. Impact sprinklers typically have larger droplet sizes compared to boom or overhead systems and can result in splash damage on germinating seed. Residual water drains back down the irrigation riser, although nozzle splash can still be a problem (fig. 4.2.22B). All of the irrigation lines must run along or under the floor, however, creating obstacles for workers and making it difficult to operate machinery. Basal irrigations systems also are typically not as effective as moving systems in applying water uniformly; proper design and maintenance can produce an acceptable system, however.

4.2.5.2 Fixed irrigation system design principles

The efficiency of an irrigation system is primarily dependent on its original design, and there are few operational procedures that can improve a poorly designed system. 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. Therefore, it is important to consult an irrigation engineer during the planning stages. An excellent general reference for sprinkler irrigation system design is available from the Irrigation Association (Pair and others 1983).

Uniform water application is a function of five factors:

1. Design of the nozzle

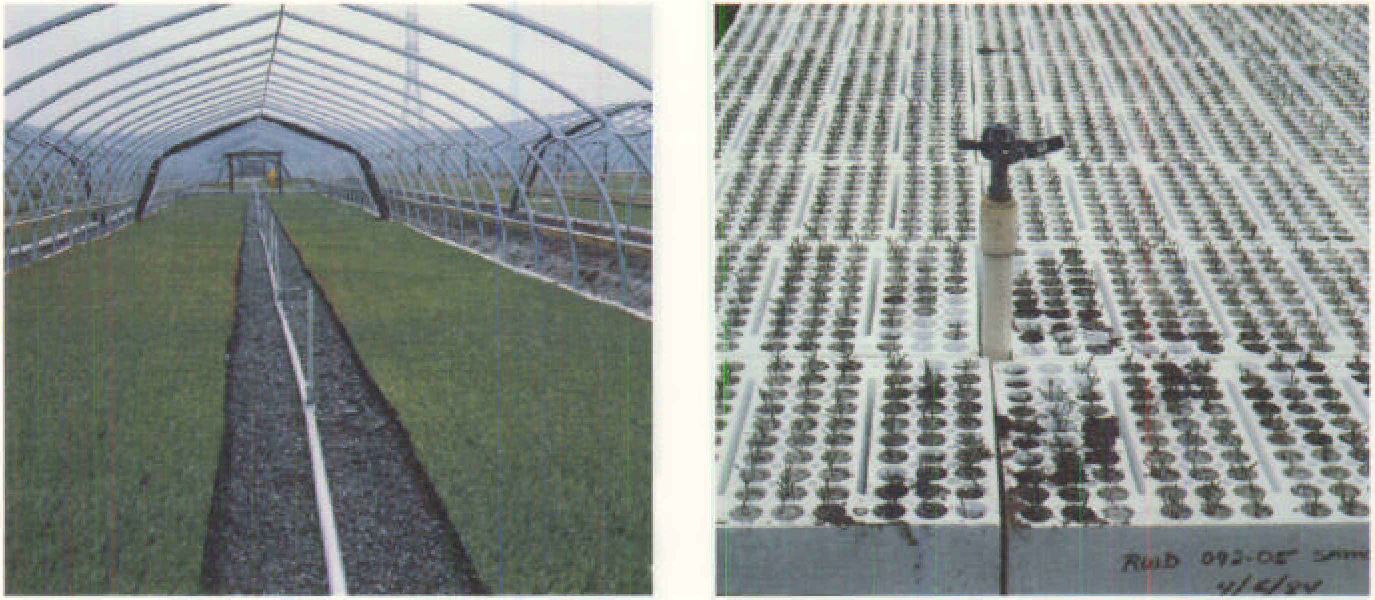
2. Size of the nozzle orifice

3. Water pressure at the nozzle

4. Spacing and pattern of the irrigation nozzles

5. 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 seedling foliage and minimize wind drift but not large enough to create splash problems.



4.2.22A 4.2.22B

Figure 4.2.22—*Basal irrigation systems consist of either fixed or movable irrigation lines* (**A**), *fitted with regularly-spaced nozzles, such as the rotating-impact type* (**B**).

The water pressure at the nozzle has a major effect on sprinkler function and efficiency and must be considered during initial planning. Performance specifications for each sprinkler type can be obtained from the manufacturer. The water pressure should be *regularly* monitored with a gauge permanently mounted near the nozzles (fig. 4.2.23) 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 furthest 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 distribution patterns such as the "doughnuts" or strips shown in figure 4.2.24. (Compare the doughnut pattern in figure 4.2.24A with the computer diagram of water distribution in figure 4.2.28A.)

Both the type of nozzle and the water pressure affect the irrigation droplet size, and the average droplet size decreases as nozzle size decreases and water pressure increases. Droplets that are too large can cause physical splash damage to germinating seeds, whereas very small droplets from "misting" nozzles are subject to wind drift and evaporation losses in exposed growing areas. Handreck and Black (1984) estimate that as much as 90% of the water from a misting nozzle can be lost on a hot windy day. Misting irrigation nozzles can be corrected by reducing the water pressure or changing the size of the nozzle orifice. A simple procedure for measuring droplet size involves exposing a dish of SAE 90 oil under the irrigation shower and measuring the size of the droplets. An irrigation droplet with a diameter in the range of 1.0 to 1.5 mm (0.04 to 0.06 inches) is recommended for most container nursery situations (Handreck and Black 1984).

The spacing and pattern of the sprinklers in fixed irrigation systems is related to sprinkler function and the effect of wind. Regardless of the type of sprinkler used, water distribution is never completely uniform over the stated coverage area, and so irrigation systems should be designed to provide adequate overlap between sprinklers. This is especially important in shadehouses or outdoor growing areas where wind drift can be a problem (figs. 4.2.19B and 4.2.25). Furuta (1978) states that the maximum spacing between rotating impact sprinklers should range from 65% of the spray diameter with no wind to 30% in winds of greater than 8 miles per hour. Fixed sprinklers should not be spaced any further than 50 to 65% of the sprinkler coverage diameter. Spacing of a spinner sprinkler should be no more than 40% of the spray diameter in the row and 60% of the diameter between rows (fig. 4.2.26) and should produce effective irrigation coverage in the wind conditions normally en-

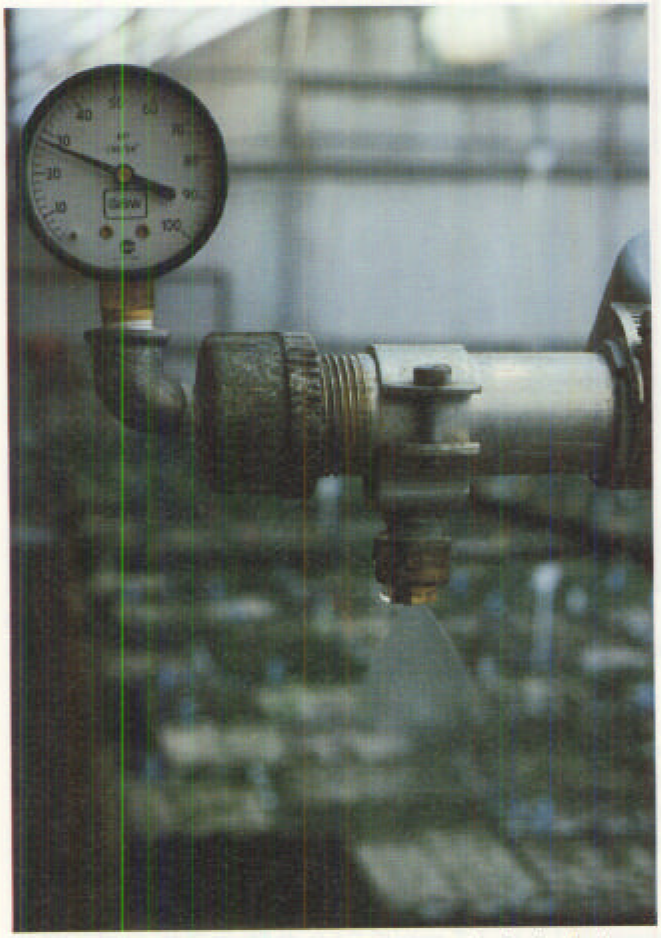
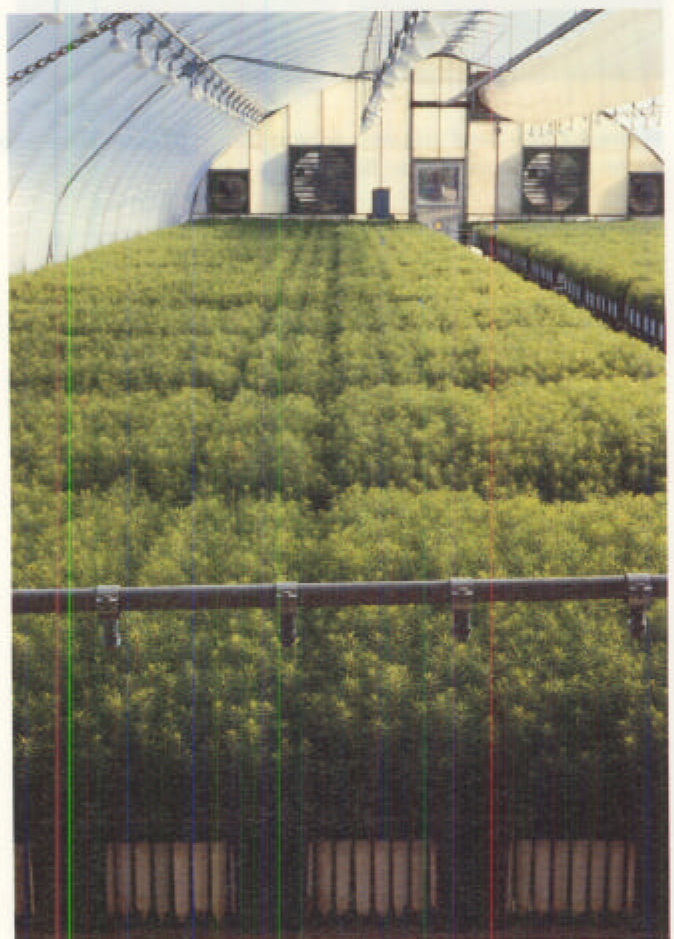


Figure 4.2.23—*Water pressure should be regularly checked at, or near, the irrigation nozzle.*

4.2.24A



4.2.24B

Figure 4.2.24—*Low water pressure or improperly adjusted nozzles can cause irregular water distribution patterns, such as "doughnuts" with fixed systems* (**A**) *or strips with movable irrigation systems* (**B**).

countered in container tree seedling nurseries. Very often sprinklers are spaced at greater intervals in a cost-saving effort, but this is false economy considering the profound effect of water and injected nutrients on seedling growth.

The two common sprinkler patterns for fixed irrigation systems are the box (rectangular) and diamond (triangular) pattern. Shearer (1981) concluded that there is no real difference between the standard rectangular sprinkler pattern and the triangular pattern under normal conditions.

4.2.5.3 Testing the efficiency of irrigation systems

Both new, and existing irrigation systems should be tested periodically to see if they are performing properly. Many nursery managers assume that a new system will perform according to the engineering specifications, but

Figure 4.2.25—*Any irrigation system should be designed to provide overlap between individual sprinkler heads, particularly in outdoor growing areas where wind interference is likely.*

this should be checked under normal operating conditions. Fischer (1987) found that theoretical irrigation patterns differed from operational patterns and attributes this discrepancy to two factors:

1. The theoretical patterns assume that the water pressure will be identical at each nozzle, which is impossible because of pressure losses within the lateral distribution lines.

2. Droplet collision between adjacent sprinklers will affect distribution.

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.

Irrigation systems can be easily checked by running a "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 (fig. 4.2.27). Containers for cup tests should have a circular opening that has a narrow rim; the shape of the container below the opening is not important as long as the cup is stable and deep enough to hold several centimeters of water without any splashing losses. For any such container, the amount of water collected can be converted to precipitation rate in inches per hour by the following formula (Furuta 1978):

Specifications for Roberts ® #4 Nozzle

Nozzle pressure (MPa)	0.11	0.14	0.16	0.19	0.22	0.25	0.28	0.30
(psi)	16	20	24	28	32	36	40	44
Spray diameter (m)	7.9	8.2	8.5	9.2	9.4	9.8	10.1	10.4
(ft)	26	27	28	30	31	32	33	34
Water discharge (lpm)	2.72	3.18	3.60	3.97	4.28	4.54	4.81	5.07
(gpm)	0.72	0.84	0.95	1.05	1.13	1.20	1.27	1.34

Recommended spacing:

In-row 40% spray diameter

Between-row 60% spray diameter

Example:

Nozzle pressure (measured) = 0.19 MPa

Spray diameter (chart) = 9.2 m

9.2 m × 0.40 = 3.7 m In-row (124% overlap)

9.2 m × 0.60 = 5.5 m Between-rows (84% overlap)

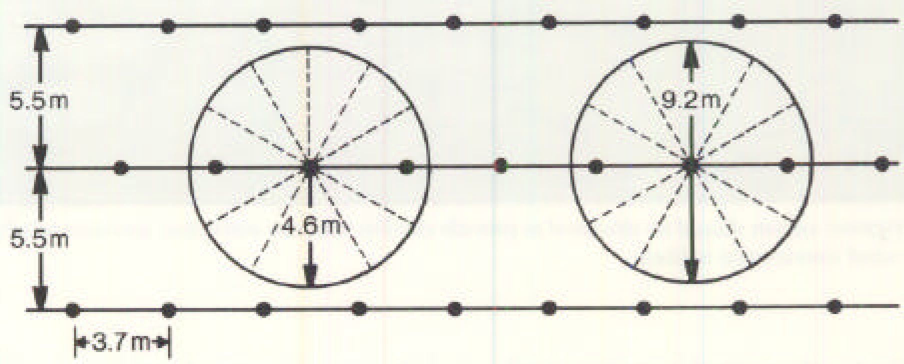


Figure 4.2.26—*Sample calculations for determining proper sprinkler overlap with fixed irrigation systems, using specifications for one type of irrigation nozzle.*

$$P = (C \times 7620) / (D^2 \times T)$$

Where:
- P = irrigation water applied per hour (centimeters)
- C = water "caught" in can (milliliters)
- D = inside diameter of can opening (millimeters)
- T = time of irrigation period (minutes).

A classic method for determining the variability in irrigation application was developed by Christensen (1942) by calculating a numerical index that he called the coefficient of uniformity (CU). The CU is calculated by running a cup test and using the data in the following formula (Furuta 1978):

$$CU = 100\,[1.0 - (B / A)]$$

Where:
- CU = coefficient of uniformity (%)
- B = sum of deviations of individual values from the mean value
- A = sum of the individual values

A completely uniform irrigation pattern will produce a CU of 100%, and the lower the CU, the more variable the irrigation. The standard target for most agricultural irrigation systems is a CU of 85% (Zimmerman 1966), which also is the minimum acceptable value that Shearer (1981) suggests for tree nursery crops.

A computer program for modeling sprinkler irrigation distribution patterns has recently been developed at the University of California at Davis, using water depth in-

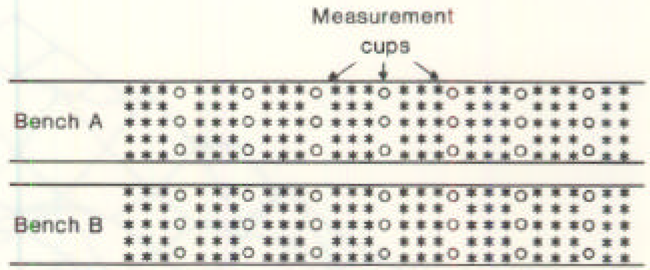


Figure 4.2.27—*The actual efficiency of an irrigation system should be periodically checked with a "cup test," which consists of measuring water depth in a series of measurement cups arranged in a regular grid system on the production benches.*

formation from actual cup tests to generate three-dimensional graphs (Fischer 1987). Using this information, water distribution problems can be easily identified, such as "doughnuts" from low water pressure at a single nozzle (fig. 4.2.28A) or the "breadloaf" pattern (fig. 4.2.28B) that is characteristic of poor water distribution around the perimeter of the growing area.

4.2.5.4 Automatic 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 (Hanan et al. 1978). This equipment allows the nursery manager to preprogram periods of irrigation and is a great time-saver in terms of labor. The prudent grower, however, will never become completely reliant on automatic systems and will continue to directly monitor irrigation efficiency and its effect on seedling growth on a regular basis.

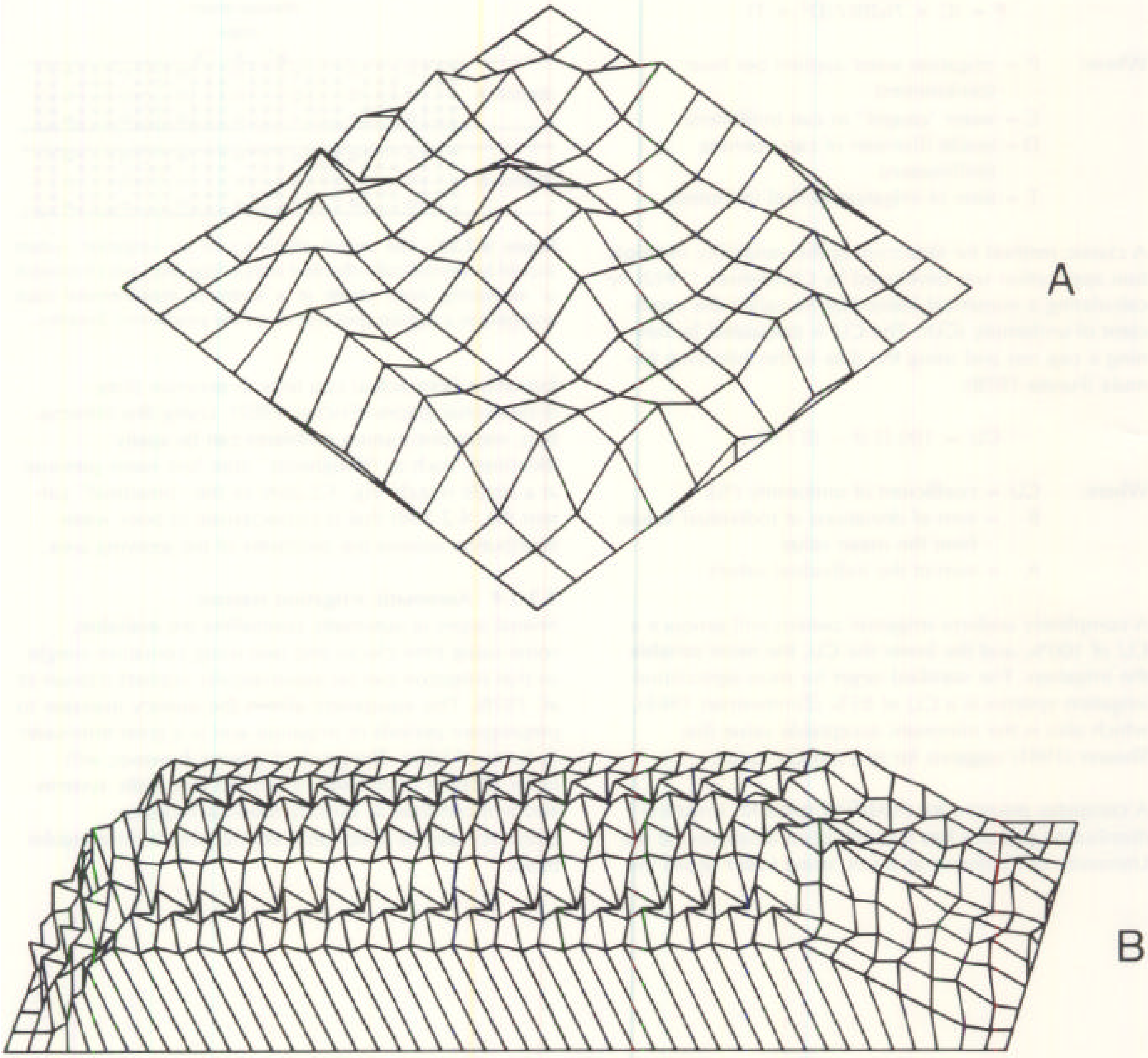


Figure 4.2.28—*Sprinkler distribution patterns can be modeled on computers, using cup test data. These 3-dimensional graphs illustrate two common problems encountered with fixed overhead sprinkler systems: a "doughnut" pattern, resulting from low water pressure at a single nozzle (**A**), and a "breadloaf pattern," which is characteristic of poor sprinkler overlap and wind effects around the perimeter of the growing area (**B**) (Fisher 1987).*

4.2.6 Monitoring Water in Containers Determining When to Irrigate

Determining the moisture status of the growing medium in most of the containers used in container tree seedling nurseries is a problem 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, a definite advantage. In spite of the operational difficulties, it is absolutely necessary to regularly monitor the moisture status of container growing media because the limited volume of moisture reserves in small containers means that critical moisture stresses can develop quickly.

Hanan et al. (1978) and Furuta (1978) discuss several moisture monitoring techniques that can be used in ornamental container nurseries. White (1964) evaluated two standard methods, tensiometers and electrometric instruments (gypsum blocks), for container crops and concluded that they were not appropriate for three reasons: 1) lack of response above field capacity, 2) deterioration due to frequent fertilization, and 3) their relatively large size, which prohibited their use in small containers. Hanan et al. (1978) concluded that there is no inexpensive, yet accurate, instrument that can measure growing media moisture content in containers; any method must be supported by actual observation and the grower's experience.

Two surveys of irrigation monitoring have been conducted in recent years. McDonald (1978) surveyed container tree seedling nurseries in the western United States and found that 60% used a *visual and tactile examination* of the growing medium and seedling condition, 22% *monitored container weight*, and the remaining 18% used other methods, including the *pressure chamber*. The Container Nursery Survey found that most container tree seedling nurseries in the United States and Canada used some sort of irrigation monitoring system including: container weight (48%), visual and tactile methods (33%), commercial moisture meters (8%), and a combination of methods, including the pressure chamber (11 %); 13% of the nurseries reported no irrigation monitoring system.

4.2.6.1 Visual and tactile examination

This technique consists of direct observations of the growing medium and seedling condition to determine irrigation need. McDonald and Running (1979) describe a system to estimate the moisture content of bareroot nursery soils using the "feel or appearance" of the soil but these guidelines are not applicable for artificial growing media. 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 seedling appearance and growth; 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.

4.2.6.2 Container weight measurement

Based on the results of the Container Nursery Survey, measuring container weight is now the most popular moisture monitoring technique in container tree seedling nurseries. The basic principle behind this technique is simple: because water is relatively heavy in relation to the other container components, the moisture content of a tray or block of containers can be monitored by weight. The weight of the container decreases between irrigations as the water in the growing medium is lost through evaporation and transpiration, and the seedling crop is irrigated when the container weight reaches some predetermined level (fig. 4.2.29).

The weight of a tray of containers varies with many factors such as container type, type of growing medium, degree of medium compaction, crop species, and stage of seedling development, but one of the most significant is moisture content. Matthews (1983b) reported that a saturated Styroblock 2A®, containing growing medium compacted to an average density of 0.1 g/ml (ovendry weight), will weigh between 7.00 and 8.25 kg. By developing a series of container weights that correspond to available water content and seedling condition, a container nursery manager can use these predetermined weights to determine when to irrigate and even to manipulate seedling growth and development.

The only piece of equipment needed to determine container weights is an accurate scale (fig. 4.2.30); some nurseries use more than one scale, leaving the containers on the scale in the growing area so that they can be read quickly. Containers should be weighed at approximately the same time after irrigation so that the results can be accurately compared. The container weight procedure must also adjust for seedling weight. As the seedlings grow larger, they will have an increasingly more significant influence on container weight (as much as 10 to 15% of the total container weight). New con-

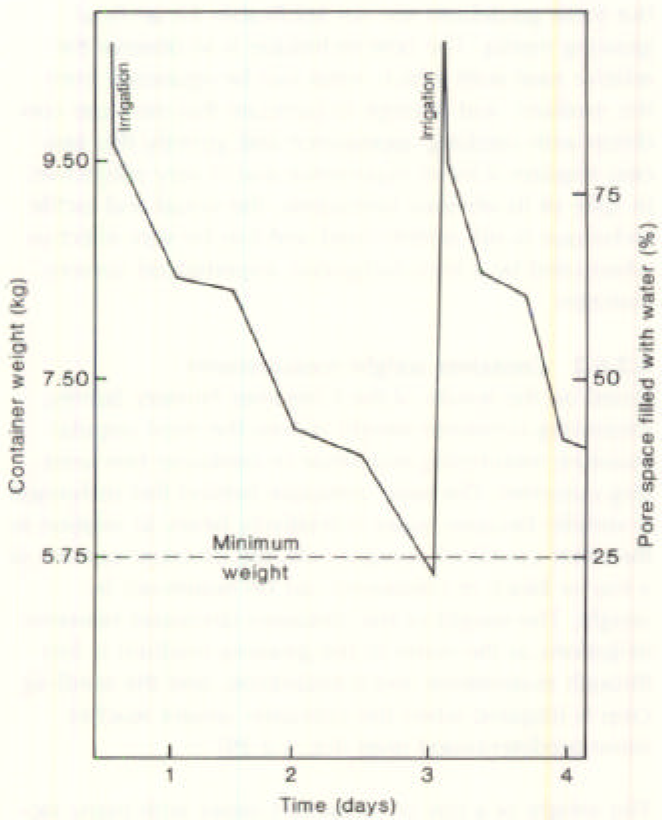


Figure 4.2.29—*Container weight decreases after irrigation until it reaches some predetermined minimum weight, at which point irrigation is applied (courtesy of Tony Willingdon, Surrey Nursery, BC).*


Figure 4.2.30—*Because of the relatively heavy weight of water, irrigation can be monitored through repeated weighing of selected containers to determine water weight loss.*

tainer wet weights that take seedling weights into consideration should be calculated at regular intervals during the growing season.

Container irrigation weights will vary significantly between seedling species due the physiological response of different species to moisture stress. Matthews (1983b) developed a detailed container weight scale for British Columbia container tree seedling nurseries for three different "seedling groups" (table 4.2.12). He further distinguished between three different types of containers and three moisture stress "levels": low stress for the rapid growth phase, moderate stress for slowing growth, and drought stress for inducing dormancy during the hardening phase. Drought-stressing is effective on some species, such as Douglas-fir, Sitka spruce, western larch, and western redcedar (group 3), that are very sensitive to over-irrigation and will produce excessive top growth at the expense of caliper and root growth. Other species, such as western hemlock, mountain hemlock, true firs, and white/Engelmann spruce (group 1), may be permanently injured by indiscriminate drought stressing (table 4.2.12). Krizek (1985) concluded that the procedure of withholding water to induce plant moisture stress is very difficult to control operationally because of the difficulty of reaching and maintaining a specified level of growing medium moisture availability.

There are two ways to develop a scale for relating container weights to irrigation demand: 1) through experience and 2) using measurements of growing medium matric potential. Before a container weight scale can be developed, however, certain terms need to be defined:

Table 4.2.12—*Container weights for British Columbia tree species[a] based on water weight loss*

Type of container	Container weight (kg)								
	Seedling group 1			Seedling group 2			Seedling group 3		
	Low stress	Moderate stress	Drought stress	Low stress	Moderate stress	Drought stress	Low stress	Moderate stress	Drought stress
Styroblock 2A®	1.50	1.75	2.25	1.75	2.00	2.50	2.00	2.25	2.75
Styroblock 4A®	2.00	2.50	3.00	2.25	2.75	3.15	2.75	3.00	3.25
Spencer-Lemaire 5®	—	—	—	0.80	0.90	1.00	0.90	1.00	1.10

[a] Seedling group 1 = Pacific silver fir, mountain hemlock; seedling group 2 = interior Douglas-fir (dry belt), lodgepole pine, ponderosa pine, Alaska-cedar, grand fir, western hemlock, white/Engelmann spruce; seedling group 3 = coastal Douglas-fir, interior Douglas-fir (wet belt), western larch, Sitka spruce, western redcedar.
Source: Matthews (1983b).

wet weight = the weight of a filled and sown container after it has been completely saturated and allowed to drain freely. The medium will be at "container capacity;" which is conceptually the same as field capacity in a natural soil

irrigation weight = the container weight when irrigation is needed. This value will vary with seedling size and cultural objectives.

Developing a container weight scale through experience. The first step is to measure container weights at several times following irrigation and attempt to correlate these weights with the available moisture content of the growing medium, and seedling condition. 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 seedling turgor during these measurement periods.

When enough information has been gathered on container weights, the data can be converted into a container weight scale, which shows the irrigation weight as a percentage of the wet weight. McDonald and Running (1979) suggest that the irrigation weight be set at around 75 to 80% of the wet weight. With enough experience, a comprehensive scale can be developed so that irrigation timing can be scheduled at various growth stages during the growing season and even into packing and storage (table 4.2.13). Each nursery should develop its own container weight scale, however, because there will be variation between types of growing medium, container characteristics, and individual seedling response.

Developing a container weight scale using growing medium matric potential. A more scientific, yet time consuming way to determine the irrigation weight of a container is based on the growing medium matric potential (GMMP), which is a measure of the energy required to absorb moisture from the growing medium. GMMP values can be obtained from soil moisture retention curves that depict the relationship between percent soil moisture by weight and GMMP (See section 4.2.2 for further discussion on water potential terminology and section 4.2.3.1 for more information on soil moisture retention curves.) Although this technique is unable to adjust for media compaction and the effect of the container, it is

Table 4.2.13—*A container weight scale developed for conifer seedlings in the Pacific Northwest*

Seedling growth stage	Irrigation weight (% of wet weight)
Germination	90
Rapid growth	80
Hardening	65–70
Post bud set	75
Packing and storage	80–85

Source: James Sedore, Washington Department of Natural Resources, Webster Forest Nursery, Olympia, WA.

the most empirical method of estimating GMMP in small containers at the present time. Future technology may produce sensors small enough to directly monitor GMMP within the container.

A typical soil moisture retention curve for a growing medium of 50% peat moss and 50% vermiculite is shown in figure 4.2.8. Once the curve is established, the GMMP values having biological significance ("target values") can be read from the curve, along with the corresponding growing medium water contents; the exact water contents for specific GMMP values can also be determined by the testing laboratory during the development of the curve. The target GMMP values given in table 4.2.14 were developed from recommendations in the literature. Day (1980) gives an excellent discussion of irrigation monitoring in bareroot nurseries and recommends maintaining a GMMP of between - 0.010 to - 0.0.'5 MPa to ensure a good balance of aeration and moisture. McDonald and Running (1979) recommend that a growing medium be irrigated between - 0.050 and - 0.080 MPa, compared to a recommendation of less than - 0.055 MPa for a medium coarse peat growing medium (Puustjarvi and others 1972, as reported in Hallett 1982b). Based on these recommendations, the target irrigation limits were set at - 0.010 MPa for the wet weight and - 0.050 MPa for the irrigation weight (table 4.2.14).

Once the target GMMP values and growing medium water contents have been set (table 4.2.14), the water weight losses of the container at each of the points can be calculated using the following relationship, which is also the basis for the soil moisture retention curve:

$$\% \text{ Water content} = \frac{\text{weight of water}}{\text{weight of ovendry medium}}$$

Once the water weight losses have been calculated for each of the target values, a sensitive container weight scale can be developed that is specific for each container type (table 4.2.14). For the Super Cells, seedlings in the rapid growth phase should be maintained between - 0.01 and - 0.05 MPa of growing medium MP, which converts to a water weight loss of between 4.04 and 5.77 kg. To induce moisture stress (-0.10 MPa) during the hardening period, the container weights can be allowed to drop below the ideal medium moisture conditions, approximately 6.26 kg for the Super Cells (table 4.2.14). It is impossible to precisely prescribe a growing medium MP for hardening, however, because seedling moisture stress is a function of evaporative demand and seedling physiology in addition to soil moisture levels (see section 4.2.7.3).

Developing a container weight scale requires a significant amount of effort and record keeping, but container weight is one of the few objective, nondestructive, 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 the seedlings are large enough to show moisture stress or use in the pressure chamber.

4.2.6.3 Monitoring plant water potential with a pressure chamber. Plant water potential (PWP) readings are the most accurate way to determine the water status of a tree seedling, and predawn measurements with a pressure chamber (fig. 4.2.5) can give an excellent indication of the need for irrigation (see Section 4.2.2.3 for basic information on PWP). Day (1980) recommends that every container nursery obtain and use a pressure chamber; McDonald (1978) reported that pressure chambers were being used in 10 to 15% of forest nurseries in the Western United States.

The major restriction to this technique is that it is destructive, and seedlings must be large enough to fit easily in the pressure chamber, which means that it cannot be used early in the growing season. With larger seedlings, individual needles or needle fascicles can be used; Ritchie (1984) illustrates a pressure chamber modification that accommodates single conifer needles that would permit several measurements of PWP on the same seedling. McDonald and Running (1979) describe a method for relating pressure chamber readings to seedling water requirements and the difficulty of interpreting midday PWP values.

Day and Walsh (1980) developed a comprehensive manual for the use of pressure chambers in nursery and reforestation work, which includes procedures for handling sample material and operating a pressure chamber:

1. Seedling stems or other plant parts to be tested should be cut cleanly, and should not be recut.

2. The bark around the seedling stem should be removed prior to testing; a standard length of 2 cm (0.8 inch) is recommended.

Table 4.2.14—*A container weight scale for two types of containers developed from a soil moisture retention curve for a growing medium of 50% peat moss/50% vermiculite*

Target values		Water weight loss (kg) from tray of containers		
Growing medium matric potential (MPa)	Growing medium water content (%)	Ray Leach Pine Cells®	Ray Leach Super Cells®	Seedling condition and irrigation guidelines
0.00	482	0.00	0.00	Saturated medium—*too wet*
−0.01	235	3.49	4.04	Upper limit for rapid growth phase—*wet weight*
−0.05	130	4.94	5.77	Lower limit for rapid growth phase—*irrigation weight*
−0.10	98	5.40	6.26	Hardening phase—*moisture stress*
—	0	6.76	7.89	Ovendry medium

Source: Burr (1982).

3. The plant part should not protrude through the pressure chamber lid more than 1 to *2* cm (0.4 to 0.8 inch).

4. PWP measurements should be made within 5 minutes of cutting the seedling stem.

5. The compressed gas should be applied at a constant rate of *0.04* to 0.07% MPa *(5* to 10 psi) per second.

6. Plant parts should be only measured once and then discarded.

Despite the suitability of the pressure chamber technique for monitoring irrigation in container tree seedling nurseries, there are few published standards for nursery managers to use. A generalized chart of seedling response to a range of *predawn* PWP values is given in table *4.2.15.* Predawn pressure chamber readings should always be used whenever possible because they represent the most stable indication of the moisture status of the seedling. Some scientists recommend midday readings, but these values are too variable to be useful on an operational basis (see figure *4.2.4* for typical diurnal PWP patterns). Although there are significant differences between species, a general rule would be to irrigate when predawn PWP values exceed - 0.*5* MPa. Cleary et al. (1978) state that periods of slight moisture stress (around - 0.*5* MPa) promote sturdier and better-conditioned seedlings compared to over-irrigated stock. Seedling moisture stress should never be allowed to exceed - 1.0 MPa unless reduced growth or dormancy induction is desired.

Table 4.2.15—*Growth response and cultural implications of inducing moisture stress in western conifer seedlings in Northwest nurseries*

Plant water potential (predawn)		Moisture stress rating	Seedling response/ cultural implications
MPa	Bars		
0.0 to − 0.5	0–5	Slight	Rapid growth
− 0.5 to − 1.0	5–10	Moderate	Reduced growth/ best for overall hardening
− 1.0 to − 1.5	10–15	High	Restricted growth/ variable hardening results
− 1.5 to − 2.5	15–25	Severe	Potential for injury
< − 2.5	>25	Extreme	Injury or mortality

Source: modified from Cleary et al. (1978).

4.2.7 Irrigation as a Cultural Treatment
Determining How Much to Irrigate

Once the decision has been made that irrigation is required, the next step is to determine how much water should be applied per irrigation event. The amount of water can be described in terms of water depth (centimeters) or water volume (liters) per unit area, and estimates of how much water to apply is given in section 4.2.4.1. On an operational basis, however, irrigation events are normally controlled by clock timers for fixed irrigation systems or number of passes with the irrigation boom in mobile systems. Both of these need to be determined empirically for individual nursery conditions.

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. Due to the unique properties of artificial growing media in containers (see section 4.2.3.2), enough water must be applied to the surface to force the air out of the medium pores. Because irrigation in container tree seedling nurseries is only applied from overhead, this "front" of water moves downward through the growing medium as long as the irrigation continues; if the irrigation period is too short, the water will never reach the bottom of the container and result in a perched water table with a layer of dry growing medium underneath. Because of this, it is important not to partially irrigate a crop of container seedlings because only the top part of the medium will be wetted (Nelson 1978).

If the growing medium throughout the container is not completely saturated after every irrigation, the tree 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." The general rule of thumb is to apply approximately 10% more water than is needed to completely saturate the entire growing medium profile at each irrigation. The best procedure is to actually check to make sure that drainage is occurring during or immediately after irrigation by direct inspection, or attaching a vial or plastic bag to the bottom of the container itself to collect the leachate. (More information on salinity and a procedure for determining proper leaching, see sections 4.1.3.4 and 4.1.9.2.)

The amount of irrigation to apply varies during the growing season in a container tree seedling nursery due to the stages of seedling development and the cultural objectives of the nursery manager. Because water is so essential to plant growth, the irrigation regime can be manipulated to control seedling growth.

4.2.7.1 Irrigating during the establishment phase

Immediately after the sown containers are placed in the growing area, the growing medium should be completely saturated. Prior to seed germination, the major water loss is by evaporation from the top of the container (fig. 4.2.12A). Irrigation during this period, therefore, must be applied so as to replenish the moisture in this thin surface layer, which is best accomplished by frequent mistings or light irrigation. Too-infrequent irrigations will allow the seed to dry out and may decrease germination, whereas over-irrigation may cause excessively wet conditions around the seed and promote damping-off.

Irrigation can also be used to control the temperature around the germinating seed. Germinants, particularly those with dark-colored seed coverings, can be injured by high growing medium temperatures. Matthews (1983b) recommends irrigation if surface temperatures exceed 30 °C (86 °F).

4.2.7.2 Irrigating during the rapid growth phase

Once the seedling root system becomes established, the pattern of water use changes and transpiration gradually replaces evaporation as the major source of water loss (fig. 4.2.12B). When the seedling becomes large enough to completely shade the top of the container, surface evaporation declines and becomes insignificant compared to transpiration. Due to the "container effect" (see section 4.2.3.2), a small zone of saturated medium may exist at the bottom of the container, the depth of which will depend on the porosity of the growing medium (fig. 4.2.9) and container height (fig. 4.2.10). Because the available water will be removed from the top of the container first, the salinity will become higher in the small reservoir of growing medium solution at the bottom, which underscores the need for frequent leaching. In fact, one of the apparent signs of a salinity problem is a salt crust around the drainage hole of the container.

Most of the existing container manuals (Carlson 1983, Tinus and McDonald 1979) recommend maintaining the growing medium at "field capacity" to maximize growth rates. Some nursery scientists, however, believe that regular periods of slight moisture stress will result in sturdier seedling growth. Cleary and others (1978) recommend inducing periods of a "mild moisture stress" between waterings for coastal Douglas-fir seedlings, letting the PWP reach up to 0.5 MPa before irrigation. This concept is reflected in the recommended PWP ranges in table 4.2.15. Matthews (1983b) advocates an irrigation program of alternative wet-dry periods to minimize the buildup of moss, algae, and liverworts. Nursery managers should be aware, however, that each seedling species reacts differently to any cultural practice, so operational tests should be conducted before moisture stressing is adopted as a standard practice.

One other factor that must be considered when scheduling irrigation is the effect of foliage interception. Although the foliage of a young seedling is limited in coverage, the leaves of larger seedlings, especially broadleaf species, can cause a significant reduction in the amount of irrigation that reaches the growing medium surface. The duration of the irrigation period must, therefore, be adjusted periodically during the growing season to account for interception losses.

4.2.7.3 Irrigating during the hardening phase

Manipulation of the irrigation regimen in container tree seedling nurseries has been found to be one of the most effective ways to initiate the hardening of seedlings prior to storage or shipment. Because seedling growth is so critically tied to moisture stress levels, a grower can reduce height growth, induce bud set, or initiate development of cold hardiness in many species of container seedlings by culturally inducing water stress (fig. 4.2.31). This "drought stressing" procedure consists of withholding irrigation for short period of time until the seedlings can be seen to wilt or some predetermined moisture stress is reached. After this stress treatment, the crop is returned to a maintenance irrigation schedule. Matthews (1983b) recommends a drought stress treatment to induce bud set after adequate height growth is attained (table 4.2.12); this drought stress period may last up to 14 days depending on species. Timmis and Tanaka (1976) found that moisture-stressed seedlings were smaller in diameter and had lower root and shoot dry weights compared to unstressed seedlings but had significantly more terminal buds, which were also formed earlier in the season. They also concluded that mild moisture stress levels increased the ability of the seedling to cold-harden.

In a recent review of the effects of water stress on seedling quality, Joly (1985) listed two physiological and morphological effects of water deficit on bareroot seedlings that may be useful to container nursery managers:

Figure 4.2.31—*Water stress can be used to control shoot growth of some container tree seedlings although this cultural practice can be difficult to apply uniformly.*

1. Increasing moisture stress can be used to *induce seedling dormancy* during early to mid-summer (Zaerr et al. 1981).

2. Mild PWP values (-0.5 to - 1.0 MPa) during midsummer will initiate the sequence of events leading to *cold hardiness* (Blake et al. 1979).

Two more effects can be added:

3. Moderate moisture stress levels (-1.0 to -1.5 MPa) can be used to *retard unwanted late-season shoot growth* (lammas or proleptic growth), although this treatment reduced cold hardiness (Blake et al. 1979).

4. Christersson (1976) demonstrated that both pine and spruce container seedlings could be *drought-hardened* by imposing a period of moisture stress and that these hardened seedlings could tolerate a more severe drought stress (-3.5 MPa) than unhardened seedlings (-2.5 MPa).

Moisture stress as a cultural treatment can be affected by other environmental conditions. Blake et al. (1979) pointed out that the effects of moisture stress treatments on seedling hardening are affected by photoperiod. Mild moisture stress was only effective under the long days of summer or the equivalent extended photoperiod in a greenhouse environment.

It is also important to realize that irrigation cultural treatments can have detrimental results. Continued frequent irrigation into late summer can delay the normal development of frost hardiness (Lavender and Cleary 1974). Applying a moisture stress treatment under a short photo period may actually inhibit the development of frost hardiness (van den Driessche 1969).

One problem with operationally implementing moisture stress as a cultural practice is that there can be considerable variation in growing medium moisture between adjacent containers. Due to differences in irrigation application and seedling water use, it is hard to achieve a uniform average level of seedling water potential in a greenhouse. Another operational problem is that, if the growing medium is allowed to dry too far, it can become hydrophobic and difficult to rewet even if wetting agents are used.

Most of the research on these techniques has been done with coastal Douglas-fir or other coastal species, so nursery managers should interpret these findings accordingly. Matthews (1986) recently reported that drought stressing does not work well with interior species of spruce in British Columbia nurseries, and concluded that this cultural practice should still be considered "more of an art than a science." Growers should conduct their own trials of operational moisture stressing to determine the effect on their own species in their respective growing environments. In spite of these caveats, induction of mild moisture stresses such as those in table 4.2.15 should be considered as a cultural technique to manipulate seedling physiology and morphology. A further discussion of the hardening process, including moisture stress, is provided in the chapter on hardening in volume six of this series.

4.2.7.4 Irrigating for frost protection

Container seedlings that are raised in outdoor growing areas or stored in sheltered storage may require protection against freezing temperatures in the fall or spring in climates with cold overwinter temperatures. Proper hardening procedures will help protect the shoot against frost injury, but unusually cold weather can sometimes occur suddenly before the seedlings have had time to harden sufficiently. Roots do not achieve a high degree of cold hardiness and should always be insulated if seedlings are to be stored under exposed conditions. (More information on hardening procedures can be found in the hardening chapter in volume six of this series.)

An excellent discussion of using sprinkler irrigation for frost protection in bareroot tree seedling nurseries is provided by McDonald (1984), and the same basic principles apply in container nurseries. 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 value. The main protection comes from the heat released from the freezing water, however, and 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. Some nurseries test their seedlings for frost hardiness and base their determination 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 -8 °C (17 °F). The amount of water to apply for frost protection varies with temperature and wind velocity, however. Some suggested irrigation application rates are provided in table 4.2.16 (Hansen and others 1979).

Table 4.2.16—*The amount of irrigation necessary for frost protection varies with temperature and wind velocity (three ranges from 0 to 5 km/hr are shown)*

Seedling temperature (°C)	Irrigation rate (mm/hr)		
	0–0.05 km/hr	1.0–2.5 km/hr	3.0–5.0 km/hr
− 3	2.5	2.5	2.5
− 4	2.5	3.5	5.5
− 5	3.0	5.0	—
− 6	3.5	6.5	—
− 8	5.0	—	—

Source: Hansen et al. (1979).

4.2.8 Irrigation Wastewater Disposal

4.2.8.1 Sprinkler irrigation efficiency

The sprinkler irrigation that is typically used in most container tree seedling nurseries is very inefficient. Handreck and Black (1984) estimated that less than a third of the sprinkler irrigation water applied to containers actually reaches the growing medium. No published data exist for forest nurseries, but Weatherspoon and Harrell (1980) compared overhead sprinkler and drip irrigation in an ornamental nursery: impulse sprinklers had an irrigation efficiency (that is, the percentage of applied water retained by the growing medium) of 26%, and spinner sprinklers had an even less efficient rate of 13%. Boom irrigation may be more efficient than fixed irrigation systems because the water is applied only to the seedlings, rather than to the entire growing area. Irrigation efficiency will gradually decrease during the growing season as the seedling crowns intercept and shed an increasingly greater proportion of the applied irrigation water. Many ornamental container nurseries have converted to drip or subirrigation to increase their irrigation efficiency, but the small containers used in forest nurseries and the need to air prune roots make these irrigation systems impractical.

4.2.8.2 Managing nursery wastewater

The problem of poor irrigation efficiency involves more than simply wasted water, however, 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 leaching of excess salts. Most pesticides are applied in a water 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.

Recent testing has revealed that excess fertilizer nutrients and pesticides are leaching downward and contaminating groundwater supplies. Originally it was thought that the soil filtered out impurities and therefore underground water supplies were pure, but this theory has recently been refuted. A Government Accounting Organization (GAO) survey found that 29% of the 65,000 community water systems in the United States are unable to meet federal minimum drinking water standards. The Environmental Protection Agency (EPA) is currently conducting a national survey of pesticides in drinking water that should provide some good data on the scope of the problem (Urbano 1987).

Two fertilizer elements, nitrogen and phosphorus, have been identified as particularly harmful to the environment or human health. Nitrate-nitrogen (N03-) is particularly harmful: water containing more than 10 ppm N03- can cause a disease of infants called methemoglobinemia, which involves an inability to use oxygen (Rosen and others 1986). Wastewater from container tree seedling nurseries will undoubtedly contain significant amounts from excess nitrogen fertilizer, as the anion N03- is not adsorbed by the growing medium and leaches from the containers with the irrigation water. Much of the applied liquid fertilization solution is shed by the foliage of large container seedlings or falls on noncrop area and goes directly into the wastewater. Urbano (1987) reports that one-third to half of the nitrates applied as fertilizers are ending up in groundwater supplies. Phosphorus leached into lakes can cause a buildup of algae or water weeds, a process called eutrophication. Whether the amount of fertilizer P leaching from container tree seedling nurseries is a serious problem is unknown, because P becomes fixed and immobilized in the soil. A study of storm runoff into lakes in Minneapolis, MN, found that the P content did not increase with P fertilization (Rosen and others 1986).

Urbano (1987) reports that the amount of herbicides and pesticides reaching the groundwater is much smaller (0.1 %) than the amount of fertilizer nutrients, but the toxicity of many of these chemicals is unknown. The problem is not hypothetical because, in 1979, irrigation well contamination with the herbicide Temik© (aldicarb) was found to be extensive in Long Island, NY, and groundwater contamination with this pesticide has been suspected in other states (Urbano 1987).

The implications of excess fertilizer and pesticides in irrigation wastewater are obvious, but no acceptable standards have been established for many pesticides. Some quality standards for discharge waters have been established in southern California (table 4.2.17). Florida has one of the most stringent groundwater monitoring programs in the United States, testing for 129 different chemicals. The most recent state action that will affect nursery managers is California's Proposition 65 (the "toxics initiative"), which will require regulation of more than 200 potentially harmful chemicals (Urbano 1987).

Accepting the fact that considerable irrigation waste exists, container nursery managers are beginning to consider ways of dealing with the problem. The focus of any

Table 4.2.17—*Water quality standards for irrigation wastewater set by the Los Angeles Water Quality Control Board*

Water quality parameter	Limit *	
Total dissolved solids	750	ppm
Nitrate-nitrogen	10	ppm
Chloride	175	ppm
Chloride and sulfate	500	ppm
Chromium	0.01	ppm
Suspended solids	75	ppm
Biological oxygen demand	30	ppm
Oil and grease	15	ppm
Surfactants	0.50	ppm
Chlorinated hydrocarbons	0.004	ppm
Turbidity	75	ntu
Settleable solids	0.2	ml/l

* 1 ppm = 1 mg/l; ntu = nephrotometer turbidity unit.
Source: Skimina (1986).

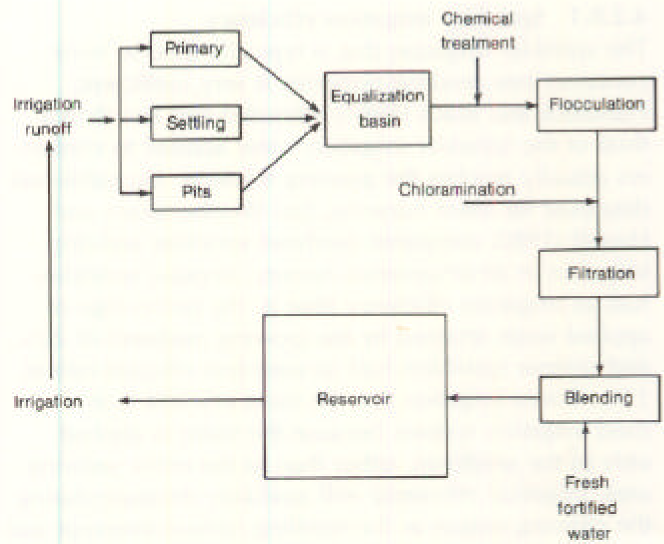


Figure 4.2.32—*Schematic for an irrigation water treatment and recycling plant in use at a California nursery (Skimina 1986).*

control program should be on prevention, because there is no way to remove the chemicals once they have contaminated the groundwater (Urbano 1987). Skimina (1986) studied three alternatives for handling irrigation wastewater in a California container nursery: discharging into sewers, denitrification, and recycling. He found that the recycling was the only practical option and designed a water treatment facility (fig. 4.2.32) that produces water "pure enough to drink." The recycled water was tested on 106 ornamental plants and most of the test plants had better growth than the plants grown on the original irrigation water; it is not, however, used operationally on cuttings and some sensitive species. The treatment plant cost $1.3 million to build and operating costs were $0.08 per kl ($0.30 per gallon) (Skimina 1986). The treatment program has also produced several side benefits, such as fertilizer reclamation, but one of the most significant benefits has been the good community relations that have resulted from the recycling project (Urbano 1987).

Most container tree seedling nurseries are not located in heavily populated areas and wastewater disposal may not be a serious concern at the present time. Undoubtedly, however, the problem of irrigation wastewater disposal will become more significant in the future, and nursery managers should be prepared to deal with the wastewater problem.

4.2.9 Conclusions and Recommendations

Because of the overriding importance of water to plant growth, water management through irrigation is one of the most critical cultural operations in container tree seedling nurseries. An understanding of basic seedling-water relations is helpful in container nursery management; the water status of a tree seedling can best be described in terms of water potential. Water potential is the most practical way to describe seedling water status because the principles and units remain the same from the growing medium, through the seedling, and into the atmosphere. The water potential in the growing medium, or the seedling itself, can be separated into components that the grower can manage to achieve the proper quantity and quality of seedling growth.

Water must be managed differently in container tree seedling nurseries, than in a bareroot operation. 'Artificial soil;' composed of materials such as peat moss and vermiculite, has different physicochemical properties than native 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 the selection and operation of a container tree seedling 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. Tree seedlings are very sensitive to soluble salts, and so water should be tested at all stages of the irrigation process at regular intervals during the growing season.

Container tree seedlings are typically irrigated with some type of overhead sprinkler irrigation system, from either fixed sprinklers or sprinklers on a moving boom. Mobile irrigation booms provide more uniform coverage but are subject to mechanical failure. Several different types of stationary sprinklers are available and will perform satisfactorily if properly designed and maintained. Any irrigation system must be tested periodically to insure 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 the small containers used in container tree seedling 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. When the seedlings become larger, a pressure chamber can be used to directly measure plant water potential. Due to 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 is a function of the growth stage of the seedlings and the environmental conditions. In addition to promoting rapid germination and seedling growth, water can be used as a cultural tool to help harden the seedlings and induce dormancy. In cold climates, irrigation can also be used for frost protection of seedlings in open growing compounds.

Because of the excess amounts of irrigation required and the poor efficiency of most sprinkler systems, disposal of wastewater is a important consideration in container 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 problem in nurseries located in urban areas.

4.2.10 References

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