Irrigation Management

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Outline

Facing Page: *Sprinklers on hardwood beds. (Photo by Jackie Robbins.)*

Irrigation Basics

Irrigation is used in bareroot hardwood nurseries to enhance both germination percentages and uniformity, and to grow seedlings with well-developed root systems that have good survival and growth when outplanted. Irrigation can be used to prepare beds for root pruning and for harvesting. Sometimes irrigation is used for micro-climate control, to limit heat and freeze injury. When limited or withheld, irrigation can condition ("harden-off") seedlings for harvesting and to withstand cold weather. Although not common in bareroot nurseries, irrigation can be used to apply fertilizers (fertigate) or pesticides and other additives, including soil sterilants (chemigate). Sometimes sprinkler irrigation systems are used to move surface-applied materials into the soil and to wash materials from seedling foliage. Except for freeze protection, which requires 50 to 100 gallons per minute per acre (gpm/ac) (468 to 935 liters per minute per hectare [Lpm/ha]), each of these uses of irrigation can be fully met with a pumping flow rate of less than 10 gpm (38 Lpm per minute) per acre of the entire area (Ae) irrigated by a system.

Several terms are critical to the understanding and discussion of irrigation systems. Many of these terms are defined in appendix 5-1. Three terms essential to understanding the design, operation, and performance of irrigation systems are precipitation rate (PR), irrigation efficiency (IE), and application uniformity (AU).

Precipitation rate is how fast an irrigation system applies water to an irrigation zone, usually reported as inches per hour. Table 5.1 shows the recommended maximum sprinkler precipitation rate for various soil textures. In those few cases when sprinkler systems apply water at rates exceeding the soil infiltration rates, surface runoff from the nursery beds can be controlled by providing sufficient surface storage to allow adequate time for the water to infiltrate. Tillage practices that create small reservoirs in the beds to capture and hold the water can increase infiltration time. Placing permeable mulches such as straw on the beds increases surface storage and helps maintain a high infiltration rate. Equation 1 provided in appendix 5-2 is used to calculate precipitation rate.

Irrigation efficiency is the amount of irrigation water stored in the crop's root-zone that is available for beneficial use by plants divided by the total amount of all the irrigation water pumped (assuming the crop's root zone covers all the area being irrigated). IE accounts for all losses of the irrigation water in getting it to where it is available for plant uptake: (1) for water not being applied uniformly to the irrigation area; (2) for evaporation that occurs as water travels from the sprinklers to the irrigation area and from wetted plant and soil surfaces; (3) for water falling outside of the irrigation area; and (4) for water moving out of the crop's root-zone via surface runoff and deep percolation. The water ending up where it is not crop-available may carry materials such as fertilizers, which are subsequently lost. If IE were 75 percent, an additional one-third (100/75 = 1.33) of irrigation water would have to be pumped to meet the needs of plants located in the irrigated area that receives the least water.

Application uniformity is a measure of how evenly irrigation water is applied over the irrigation area. AU is often the largest component of IE but only deals with the part of the irrigation water that is applied rather than pumped. If AU were 80 percent, an additional 25 percent (100/80 = 1.25) of irrigation water would have to be applied to meet plant needs.

Bareroot Nursery Layouts

Irrigation systems for bareroot hardwood nurseries are the same as those used to produce bareroot conifer tree seedlings. Often both hardwood and conifer seedlings are produced in the same nursery, using the same or very similar irrigation scheduling criteria. Layout, equipment, and cultural practices have become somewhat standardized over the past 70 or so years to use solid-set, impact sprinkler irrigation systems and components similar to those pictured in figures 5.1, 5.2, 5.3, 5.4, and 5.5. The essential components of such systems are: (1) a pressurized water source, (2) a piping network of main lines, control valves, laterals, and sprinkler risers, (3) impact sprinklers, and (4) monitoring equipment including pressure gauges, flow meters, and soil moisture status indicators, such as tensiometers. Some systems include submains, which feed more than one lateral through a single control valve from the main line rather than each lateral being fed directly from the main. The following are some control items added on the sprinkler risers to improve the system performance.

- **Quick coupling/connect valves** (www.webstermatic.com, www.travispattern.com). These are placed between the laterals and the risers to allow the risers to be removed for repair even while the system is operating. They can also help prevent damage when the laterals are moved (fig. 5.4).
- **Spring loaded check valves.** These are placed under each sprinkler to prevent flow through the sprinklers at the beginning and end of each irrigation event, until the pressure is large enough (maybe 5 pounds per square inch [psi]) to make the sprinklers turn. They also maintain pressure in the laterals between irrigation events to keep the lateral coupler gaskets set and prevent unwanted drain-down/emptying of the system. They minimize bed erosion, puddling, and poor irrigation efficiency (fig. 5.4).

- **Part-circle shields.** These may be placed on the risers at the boundaries of the nursery to prevent throw of water beyond the beds from full-circle sprinklers; e.g., to prevent wetting roadways (fig. 5.5).
- **Pressure regulators.** These may be placed in each riser to limit discharge variations caused by different pressures at the sprinkler nozzles; they are particularly useful in fields with varying elevations and on systems that operate at lower pressures.

In a typical bareroot nursery, impact sprinklers are spaced 40 feet (ft) apart along sprinkler laterals. The laterals are assembled using lengths of aluminum tubing with integral, quick couplers. Sprinkler laterals are located with nine, 4-ft wide (1.2 meters [m]) beds between them. The beds are spaced 6 ft (1.6 m) on center (OC) except where sprinkler laterals are placed, whereby the OC spacing is increased by 4 ft (1.2 m), making the spacing between laterals 58 ft (17.7 m) (fig. 5.1). Note that in such a nine-bed layout, the beds cover only 36 ft (11 m) of the 58 ft (17.7 m) width, or 62 percent of the irrigation area. Because lateral layouts are not exact, the laterals are usually assumed to be spaced at 60 ft (18.3 m), and not 58 ft (17.7 m), when estimating the precipitation rate and how efficiently and uniform these systems operate.

Some nurseries space sprinkler laterals closer to assure adequate watering of beds midway between laterals and to increase application uniformity. For example, under a common set of no-wind operating conditions, a typical nine-bed layout with sprinklers spaced 40 ft by 58 ft (12.2 by 17.7 m) has an application uniformity of 77 percent. Under the same conditions, but with sprinkler nozzles changed to main-

Figure 5.1*—Typical layout of a bareroot hardwood nursery. Beds are 4 ft (1.2 m) wide and spaced 6 ft (1.8 m) on center. Where sprinkler laterals are placed between two beds, the spacing between beds is increased by adding 4 ft (1.2 m). With one lateral per nine beds, the spacing between the laterals is 58 feet (17.7 m). Usually the spacing of sprinklers along the laterals is 40 ft (12.2 m). (Photos by Chase Weatherly, ArborGen, Inc. 2011.)*

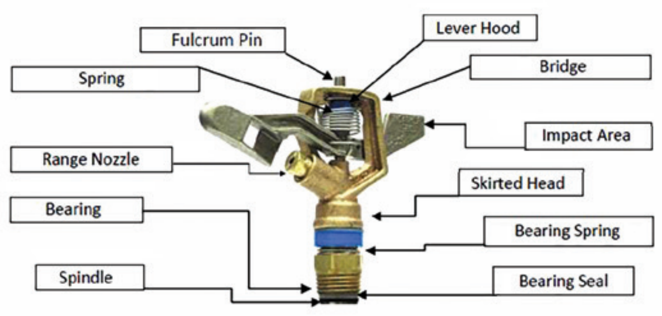

Figure 5.2*—Standard impact sprinkler: Some have a second outlet (for a spreader nozzle) that is usually plugged when used in bare-root hardwood nurseries. Some are part-circle to prevent applying water beyond the nursery (e.g., to roadways). Some are made of engineering grade plastic and others are brass. All should include stream straightener vanes (fig. 5.3) placed just before the nozzle to increase the throw distance. (Photo courtesy of WeatherTec, 2011.)*

Figure 5.3*—Sprinkler nozzle with stream straightener vanes installed. A sprinkler's throw distance will be increased by 3 to 4 feet (.9 to 1.2 m) and the application uniformity will be greater if the streamlines exiting the sprinkler nozzles are straight. (Photo courtesy of Irrigation-Mart. 2011.)*

tain the same precipitation rate, the application uniformity of a six-bed layout with sprinklers spaced 40 ft by 40 ft (1.2 by 1.2 m) is 86 percent. If the nozzles were not changed, the application uniformity would be 89 percent, but the precipitation rate would be 1.45 times greater. Note that the beds in the six-bed layout cover 60 percent of the irrigation area, or 24 ft of the 40 ft width (7.3 of 12.2 m), which is about the same as the 62 percent for the nine-bed layout. Under increasingly windy conditions, the application uniformity for a six-bed layout decreases less than that for a nine-bed layout, and this difference increases as the wind speed increases.

Sprinkler System Basics

Sprinkler System Limitations

The generic limitations of all sprinkler systems relate to several factors.

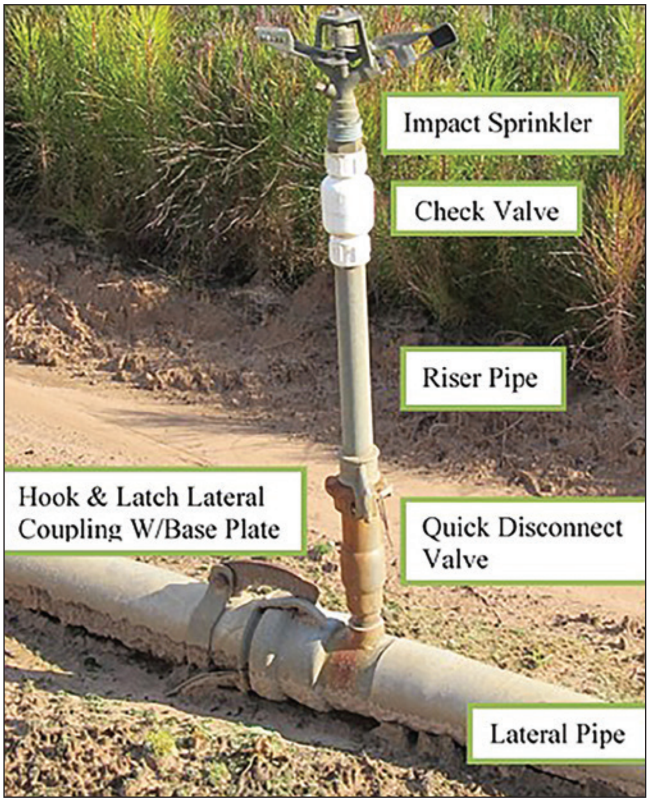

Figure 5.4*—Typical sprinkler riser with a quick disconnect valve and a check valve on an aluminum lateral with a hook and latch type quick coupler. Sprinkler risers should be vertical, even at the expense of adding stakes to support them; otherwise the distribution pattern will be skewed, and the application uniformity will be decreased. (Photo by Chase Weatherly, ArborGen, Inc., 2011.)*

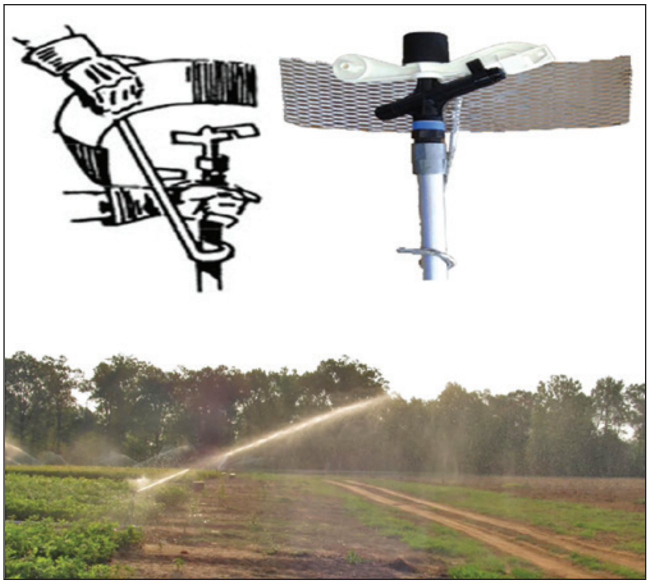

Figure 5.5*—Sprinkler shields can be used on full-circle sprinklers to prevent full-circle application. Some shields use solid splash plates and drop all the deflected water near the sprinkler, others use splash plates made of expanded metal to control overwatering near the sprinkler. (Photo courtesy of Irrigation-Mart and Chase Weatherly, ArborGen, Inc., 2011.)*

1. The entire plant and soil surfaces is wetted leading to significant evaporation losses, disease susceptibility, and removal of pesticides and other agricultural chemicals, and leaving of deposits on the seedlings that can reduce photosynthesis, growth, and marketability.
2. There are high power and energy requirements. These may be minimized by using low pressure and high irrigation efficiency systems. Decreasing the total dynamic head (pressure) of the irrigation system by one-half (e.g., from 70 psi to 35 psi, or 482 to 241 kilopascal [kPa]) lowers the power and energy requirement by 50 percent. Improving the irrigation efficiency from 65 percent to 75 percent not only saves 13 percent of the water needed to be pumped, but also lowers the amount of pumping plant energy required by more than 13 percent, depending on the efficiency of the pumping plant (pump and motor combined). (See also equations 3 and 4 in appendix 5-2.)
3. There are difficulties in obtaining uniform distribution, particularly in wind.
4. There is a high labor requirement. This may be reduced by mechanization and automation.
5. There is limited layout flexibility, which makes management changes difficult to implement.
6. Cultural practices may be hindered by wetted soils and by exposed system components that are subject to damage and must be worked around.

A major disadvantage of sprinkler irrigation in nursery operations is that water is applied to the entire irrigation area (A_e), and not just the bed area. This alone results in about 40 percent of the irrigation water being wasted (not available to the crop). Likewise, the same portion of any materials, such as fertilizers, carried by the water is wasted. Also, cultural practices must be delayed until the water applied between the beds has drained sufficiently to allow trafficking.

Nursery sprinkler irrigation efficiency (IE_N) is usually less than 50 percent. Even with the best design and no-wind conditions, irrigation efficiencies of more than about 90 percent are difficult to obtain for impact sprinkler systems. When system cost restraints are added, the solid-set sprinkler irrigation systems used in bareroot nurseries are generally established with irrigation efficiencies of less than 80 percent under no-wind conditions. With reasonable maintenance and scheduling, common in-field irrigation efficiencies are less than 70 percent under winds up to 8 mph. (Wind speeds greater than this are very common throughout the Eastern United States.) When using a realistic in-field irrigation efficiency of 67 percent and including the loss of all of the water applied between the nursery beds, only about 40 percent of the water pumped ends-up where it can be beneficially used by the crop.

Effect of Wind on Sprinkler Application Uniformity

Wind skews sprinkler distribution and is one of the most important factors governing the arrangement and spacing of sprinklers (and laterals). High wind conditions and winds from all directions should be assumed in the design of bareroot nurseries in the Eastern United States. Failure to do so has been one of the main causes of inadequate watering of beds midway between laterals and along the boundaries, and for low distribution uniformities and irrigation efficiencies in general.

Higher wind conditions require closer spacing of sprinklers to maintain a given level of application uniformity. The following is an example of recommended maximum spacing between fixed-location impact sprinklers as a percent of the sprinkler's diameter of throw for varying wind speeds:

no-wind	65 percent
0 to 4 mph (6.4 kph)	60 percent
4 to 8 mph (12.9 kph)	50 percent
over 8 mph (12.9 kph)	30 percent.

kph = kilometers per hour
mph = miles per hour

Whenever possible, laterals should be installed perpendicular to the wind direction; then just spacing sprinklers closer along the laterals, without spacing the laterals closer, maintains good application uniformity. Wind effects may be reduced by using pressure and nozzle combinations that produce larger droplets and/or using a single nozzle only, which concentrates all the sprinkler flow in just one nozzle stream. Sprinklers with lower discharge angles also limit the distortion of distribution patterns caused by wind.

Characteristics of Impact Sprinklers

Generally, bareroot nursery sprinkler systems use impact sprinklers because they provide larger diameters of throw than other overhead irrigation devices (e.g., jets, rotators, spinners, and off-center rotators) for a given set of operating conditions (pressure, discharge rate, discharge angle, etc.). Most impact sprinklers used in bareroot nurseries are a ¾-inch (in) (19 millimeters [mm]) base series with just one nozzle. They are installed on ¾- or 1-in (19 or 25 mm) diameter metal risers at regular intervals along the laterals (fig. 5.4). They are operated with pressure near 50 psi (345 kPa) at the nozzle, and they are nozzled to discharge 6 to 10 gpm (22.7 to 37.9 Lpm). Under a no-wind condition and with stream straightener vanes installed (fig. 5.3), the sprinklers have an effective throw radius of around 45 to 50 ft (13.7 to 15.2 m).

Impact sprinklers apply water in a stream as the head rotates either in a full- or part-circle. All other factors being the same (nozzle size, operating pressure, etc.), full- and part-circle sprinklers do not give the same precipitation rate because their areas of coverage are different. Therefore, to get good application uniformity, only full-circle sprinklers are recommended. Part-circle shields can be used on full-circle sprinklers at the ends of beds and along the boundaries of the nursery to prevent throw of water beyond beds if desired, such as to prevent wetting roadways (fig. 5.5).

Impact sprinklers with larger nozzles produce higher precipitation rates and require higher pressures to obtain a good distribution pattern. The application depth from a typical impact sprinkler decreases with distance from the nozzle. The flow rate and the distribution pattern of an impact sprinkler are governed by the size of the nozzle orifice and the operating pressure, with the shape of the nozzle (e.g., straight bore or taper bore) also having some influence. If the pressure at the sprinkler is adequate, the discharge pattern is approximated as triangular for one nozzle (a range nozzle) and elliptical for two nozzles (a range nozzle and a spreader nozzle). When the pressure is too low, the distribution pattern becomes donut shaped, which is unacceptable. When the pressure is too high, the portion of small droplets increases, increasing the depth of water applied closer to the sprinkler, evaporation, and the potential for skewing the application pattern by wind.

Impact sprinklers are available with trajectory angles ranging from 0 to 32 degrees, although some single-nozzle sprinklers have adjustable trajectory angles. The most common trajectory angles for range nozzles are from 21 to 27 degrees, and 5 to 7 degrees for spreader nozzles. For trajectory angles common to range nozzles, the diameter of throw will increase about one percent for each degree increase in trajectory angle upward from horizontal. Smaller trajectory angles result in higher precipitation rates. Sprinklers with larger trajectory angles reduce the impact of droplets on the soil and maximize coverage, but their distribution pattern can be greatly distorted by wind, especially by winds greater than 10 mph (16 kph). The distribution patterns of sprinklers with low trajectory angles are less distorted by wind, but their droplet impact on soil is more severe and their coverage is reduced.

Bareroot Nursery Irrigation Systems

Solid-set sprinkler irrigation systems used in bareroot hardwood nurseries are either permanent or nonpermanent, depending on whether the laterals are removable. Usually the main lines of both types and the laterals of permanent systems are polyvinylchloride (PVC) pipe and are installed underground. Outlets from the mains to the laterals include control valves. Permanent systems limit changes in nursery layout and they often require more time and expense to repair when damaged. Therefore, they are not very common in bareroot nurseries.

Nonpermanent sprinkler irrigation systems use portable, aboveground laterals that are placed in the field near the time of planting and not removed until the time seedlings are lifted. Although some moveable laterals are PVC or polyethylene (PE), most are made by coupling together 20-, 30-, or 40-ft (6.1, 9.1, or 12.2 m) lengths of aluminum tubing. The length of tubing is chosen to correspond to some multiple of sprinkler spacing along the laterals.

The thickness or gauge of the aluminum lateral tubing is chosen to withstand operating pressures. A 0.050-in (1.27-mm) wall thickness is common. Sprinkler spacing is typically held constant and all lateral tubing in a system is one diameter and one length. For example, a system might use 3-in (7.6 centimeters [cm]) diameter, 20-ft (6.1-m) long tubing with sprinklers spaced 40 ft (12.2 m) apart along the lateral. To save on material, laterals are often spaced further apart than the sprinklers along the laterals; e.g., laterals might be spaced 60 ft (18.2 m) apart, while sprinklers along the laterals might be spaced 40 ft (12.2 m) apart.

The diameter of the piping used in bareroot hardwood nursery irrigation systems is selected according to some predetermined design criteria which should be chosen to limit flow velocities to below 5 feet per second (fps) (1.52 meters per second [mps]) and pressure variations in sprinkler laterals due to friction and slope to less than some value, maybe 10 percent. Usually, the flow velocity restriction (5 fps maximum) (1.52 mps) governs for 4 in (10 cm) and larger pipes, while friction loss governs in smaller pipes. Many texts, tables, charts, calculators, and websites are available to aid in sizing pipe, including lateral pipe (chapter 7 of Stetson and Mecham 2011; USDA NRCS 2003, USDA NRCS 2008.)

Aluminum lateral tubing most often comes from the supplier with couplers attached. The couplers require gaskets, with fast-drain, slow-drain, and nondrain gaskets available for most coupler styles. Generally, nondrain gaskets should be used in nurseries to prevent drain-down of the laterals between irrigation events. Usually the couplers for aluminum lateral tubing are a hook and latch, quick-connect type, and include a threaded outlet for installing a riser pipe to serve a sprinkler; any outlet not needed is plugged. The couplers include a base or plate to help keep the riser and sprinkler upright. Risers may require additional support, however, to remain vertical and control skewing the sprinkler distribution (fig. 5.4).

System Capacity

System capacity addresses the ability of an irrigation system to deliver both the required rate (gpm, gpm/ac, inches/hour [in/h]) and volume (gal, acre-feet [ac-ft]) of water necessary to produce a crop, including the losses and inefficiencies encountered during the irrigation process. In other words, it is the gross amount of water the system must deliver and the rate at which it must be delivered.

Crop Water Requirement

The volume of irrigation water needed to produce a bareroot hardwood seedling crop in the Eastern United States is poorly known, extremely variable, and depends on numerous factors including weather. Equation 2 in appendix 5-2 may be helpful in estimating the volume of irrigation water that should be available, if needed, to assure a successful hardwood seedling crop. Equation 2 is only as good as the estimate of the volume of water needed to be supplied by irrigation during the entire growing cycle, and might best be based on meeting all of the crop’s gross water needs during a crop cycle assuming no rainfall, maximum evapotranspiration, and no contribution from stored soil moisture.

Pumping Rate Required

While the moisture stored in the soil and the rainfall during the growing season are important to determine the amount of irrigation water needed to produce a crop of seedlings, they are not factors involved in determining the required system pumping rate. Instead, evapotranspiration and irrigation efficiency are the key factors. A nursery irrigation system should have a large enough pumping rate to replenish the peak soil moisture use that occurs during the production cycle. Based on peak evapotranspiration, the minimum rate at which water is to be supplied by a nursery irrigation system is:

$Q_{min} = [k_3(A_e)(ET_{cp})/(T_i)(IE)]$ (Equation 3)

where:

Q_{min} = minimum pumping capacity or flow rate [gpm],

A_e = entire nursery area irrigated by the system [ac],

ET_{cp} = average peak evapotranspiration for the crop [in/day],

T_i = a decimal representing the portion of time that the system operates,

IE = a decimal representing the irrigation efficiency, and

k_3 = a constant: (27154 gal/ac-in) / [(24 h/day) (60 min/h)] = 18.86 gal-day/ac-in-min.

Equation 3 assumes that water losses during conveyance from the source to the emitting devices are negligible (i.e., no leaks).

The term A_e does not include any areas that receive irrigation water (sprinkled) beyond the defined irrigation boundaries. Irrigation water applied outside the nursery area is addressed through the IE term. In nursery sprinkler irrigation systems, A_e is the entire crop production area, including the area between the beds.

The term ET_{cp} is the average of the peak daily evapotranspirations that are expected to occur during the crop cycle. In hotter, dryer regions of the Eastern United States, evapotranspiration from irrigated hardwood seedling nurseries occasionally reaches 0.5 in/day (12.7 mm/day), and often reaches 0.3 in/day (7.6 mm/day) for a period of several days. In cooler and more humid regions, ET_{cp} may be as low as 0.2 in/day (5.1 mm). Absent better information and depending on region, 0.2 to 0.3 in/day (5.1 to 7.6 mm/day) is recommended as the minimum ET_{cp} value to use for design/planning purposes.

The operation of a nursery irrigation system is never continuous (i.e., T_i is less than 1.0) because of the need for downtime for system maintenance, to allow for cultural operations, or other reasons such as operator convenience. Still, for design purposes, one might use a T_i value of 1.0, assuming that irrigation will be continuous during the peak demand period.

If deficient irrigation is acceptable or if rainfall can be depended on to supply part of the water needed by the crop during the peak demand period, an irrigation system with a flow rate of less than Q_{min} would be adequate. However, before accepting such a system, a good appreciation is required of the rainfall frequency and amounts, the dependable amount and ease of soil moisture removal from the crop’s root zone, and the importance of meeting the peak water use of the seedlings. Also, a firm commitment to precise irrigation scheduling, plus overall good management (e.g., weed control), is needed to limit production losses under such irrigation schemes.

Equation 3 can be used to size pumps for nurseries. Assuming that a 10-ac (4 ha) irrigation zone uses an impact sprinkler system with an IE of 67 percent (a common value for a well-maintained and operated system with sprinklers spaced 40 ft by 58 ft [12.1 by 17.7 m]), and wind speeds under 8 mph (12.9 kph), a design ET_{cp} of 0.3 in/day (7.6 mm), and a $T_i = 1$ (i.e., irrigation will be continuous during the peak demand periods), then the minimum pumping rate needed, regardless of the number and size of zones involved, would be:

$$Q_{min} = (18.86 \text{ gal-day/ac-in-min}) (10 \text{ ac}) (0.3 \text{ in/day}) / (1) (0.67) = 85 \text{ gpm}$$

Even though ET_{cp} quite often exceeds 0.3 in/day (7.6 mm/day) during hot, dry periods throughout much of the Eastern United States for short periods, the damage caused by the deficit irrigation during these times may not justify the cost of a system with a larger pumping rate. Also note that if IE were increased to 75 percent (e.g., by spacing the sprinklers 40 ft by 40 ft, or 12.1 by 12.1 m), the Qmin would be decreased to 75 gpm (284 Lpm).

Example calculations of the power needed for pumping (equation 3) and the subsequent energy consumption (equation 4) are provided in appendix 5-2.

Irrigation Scheduling

Effective and efficient irrigation systems limit plant stress, seedling problems, pollution, and the wasteful use of energy, water, fertilizers and other resources. Such systems are capable of making applications so that watering can be correct with respect to: (1) when it is applied, (2) how much is applied during each event, (3) precipitation rate (the number of inches applied per hour), and (4) irrigation efficiency. For practical purposes, once a system is designed and installed, precipitation rate and irrigation efficiency are fixed. But when and how much to apply are operational and/or scheduling factors determined by the irrigator.

Irrigation scheduling plans (when and how much to irrigate) are an integral part of an irrigation system. Irrigation scheduling is governed by the crop water requirement (evapotranspiration, ET) and the ability of the soil to hold and release water. ET includes both the soil water that the crop and weeds transpire and soil water that is drawn from below the soil surface and evaporated. Numerous factors govern ET, including solar radiation, day length, air temperature, wind speed, humidity, crop species, crop growth stage, canopy size and shape, and leaf size and shape. The ability of a soil to hold and release water is related to texture, as indicated in table 5.1. Irrigation scheduling can be based on nonprecise methods such as observing the plants and/or feeling the soil. But even with years of well-developed experience, efficient and effective irrigation cannot be achieved without using some type of soil moisture measuring tool and monitoring technique.

The objective of irrigation based on soil moisture criteria is to keep soil moisture content between field capacity (FC) and some portion of plant available water (PAW). Soil moisture above field capacity will drain away due to gravity and may be harmful to the plant. The portion of PAW (e.g., 75 percent of PAW) is set by the nursery manager. Then, irrigation is managed and scheduled to maintain plant available water between these two levels. (Often the portion of PAW is imprecisely referred to as a portion of FC [e.g., 70 percent of PAW as 70 percent of FC], ignoring the amount of water that the soil contains at permanent wilting point [PWP].)

Frequent irrigation events are important to consistently maintain soil moisture near field capacity (FC) so that plant stress is kept at a minimum. This is particularly true for seedlings grown in soils with little water-holding capacity, such as the sandy soils so common to bareroot nurseries. Frequent applications are also needed to keep the seed moist during germination and the young seedlings turgid and cool during the early growth periods.

How much water to apply during an irrigation event is governed by the length of the event, because the precipitation rate is fixed. Over- and under-irrigating can definitely lower yield and quality and increase waste and the cost of production. Applying too little water per irrigation event increases the likelihood of stressing the crop and usually results in reduced efficiencies and the need for extra irrigation events. Applying too much water per event decreases irrigation efficiency because the excess water ends up wasted outside the crop's rootzone. Precisely timed applications are needed to assure that a high portion of the irrigation water ends up where it is readily available for beneficial use by the plants; e.g., with 50 percent ending up in the top 3 in (7.6 cm) of the bed and 30 percent in the 3 to 7 in (7.6 to 17.8 cm) zone, and with little deep percolation. See appendix 5-3 for an example of how to develop an irrigation schedule based on soil moisture.

Automated irrigation systems have been shown to be highly desirable in bareroot nursery production because of the need for frequent and precise irrigation events, the need to frequently vary the length of irrigation events in response to ET changes, the use of multiple irrigation zones, and the need to operate the systems for a high percentage of time during high water use periods. Continuous operation is

Table 5.1*—The impact of soil texture on the maximum depth of water to pump per irrigation event and maximum sprinkler precipitation rate (partially from Hoffman et al. 2007).*

Soil texture	Total plant available soil water at field capacity (Inches per foot of soil depth)	*Maximum amount of water to pump per irrigation event, based on 25% allowable depletion (Inches per foot of root-zone depth)	**Maximum precipitation rate using sprinklers (Inches per hour)
Coarse sand	0.60	0.15/IE	1.97
Fine sand	0.80	0.20/IE	1.57
Loamy fine sand	1.00	0.25/IE	1.38
Sandy loam	1.40	0.35/IE	0.98
Fine sandy loam	1.70	0.42/IE	0.79
Very fine sandy loam	1.80	0.45/IE	0.59
Loam	1.90	0.48/IE	0.51
Silt loam	2.00	0.50/IE	0.51
Sandy clay loam	1.80	0.45/IE	0.39
Clay loam	1.90	0.48/IE	0.31
Silty clayloam	1.90	0.48/IE	0.31
Clay	1.80	0.45/IE	0.20

IE = irrigation efficiency.

*The numbers in column 3 are 25 percent of those in column 2. Removal of this amount of plant available water (PAW) might be chosen by the irrigator as the driest acceptable soil moisture content for growing a crop. Dividing the numbers in column 3 by the irrigation efficiency, IE, gives the amount of water that must be pumped to bring PAW back to field capacity. Any additional water would be wasted. The same procedure may be used for other levels of allowable depletion.

**The rates in column 4 assume little or no soil slope. These rates should be reduced by at least one-half for bare or crusted soils or where plants are small.

common during peak irrigation demand periods. Experience has shown that manually operated systems are not operated as frequently and precisely as planned, especially on weekends and around holidays. Furthermore, more effort can be devoted to improving system monitoring, scheduling, inspection, and maintenance when an irrigation system is automated.

Monitoring

Irrigation monitoring is necessary to optimize bareroot nursery operations. Irrigation monitoring includes not only monitoring the performance of the physical irrigation system to determine how well the system is operating, but also monitoring soil moisture levels to determine when to irrigate and how much water to apply.

Monitoring System Performance

To help diagnose operational problems such as leaks, plugging, irrigation efficiency, and application uniformity, emphasis should be given to measuring both flow rate (gpm) and total flow (gal), as well as pressures at key locations throughout the system. When the flow rate, Q, is known, the length of irrigation gives the amount of water applied. Total flow records (volume pumped) are useful for further planning, water budgeting, and calculating irrigation efficiencies. Monitoring pressures throughout the irrigation system is helpful in determining where problems such as leaks, plugging, and nonuniform application exist.

Monitoring for Irrigation Scheduling

Irrigation scheduling addresses the issue of when to irrigate and how much water to apply. Quality seedling production can be obtained by basing irrigation scheduling on soil moisture monitoring alone. But adding weather data such as temperature, solar radiation, wind speed and direction, and in- and above-canopy humidity can improve irrigation scheduling. Weather data helps predict how fast the crop is using water and may give early indications of whether irrigation events are needed or should be delayed or even omitted. Augmenting soil moisture data with salinity and/or electrical conductivity readings may reveal additional information on where the irrigation water (and fertilizers, etc.) collect in the soil profile and whether it is available to the seedlings.

Soil moisture monitoring is necessary for scheduling irrigation and should include data from both within and below the crop's root zone. The root zone data is important when determining the need for more or less irrigation by revealing how much water is plant-available and the ease with which the plant can obtain it. Data from below the root zone reveals if the amount of water applied per event has been so much as to have caused excessive losses to deep percolation.

If the soil moisture status at just one location in the nursery is representative of the entire nursery and if the irrigation scheduling scheme is the same for all zones, monitoring just one site would be adequate. Otherwise multiple sampling sites should be established so that data is collected where soil moisture status and/or irrigation schemes differ. See May (1985) and chapter 3 of Stetson and Mecham (2011) for more discussion on the location of monitoring sites.

Soil moisture status is expressed as soil moisture content or soil moisture tension, depending largely on how it is measured. The dryer the soil, the lower the soil moisture content and the higher the soil moisture tension. Soil moisture content is the percent of water in the soil, which may be expressed on a weight basis (weight of water per weight of soil) or on a volume basis (the volume of water in a given volume of soil). Soil moisture tension expresses the energy level of water in the soil system, or the ease with which water can be removed by plants. It is the amount of suction needed to extract water from a soil. It is a pressure term and commonly measured and reported in centibars (cb). Soil water potential is another term expressing the same thing as soil water tension, but it has an opposite sign (e.g., a soil water tension of 9 cb is a soil water potential of -9 cb). A soil water retention curve (also called a soil moisture characteristic curve) gives the relationship between soil water content and soil water potential. This curve is unique for each type of soil. A good summary and discussion on the principles of soil moisture monitoring is provided by Shock and Wang (2011).

The standard method of measuring soil water status involves collecting a physical sample of the soil, weighing it before any water is lost, and drying it in an oven before weighing it again. This is relatively inexpensive and easy to conduct, and requires very simple field and laboratory equipment. However, it is also labor and time-consuming and leads to errors if the soil sample size is too small. Additionally, the sampling method is destructive, preventing repetitive measurements at the same location. Therefore, only indirect methods using instruments are routinely used for measuring soil moisture status in nursery operations, mainly because instruments require less labor and give frequent, reliable, and accurate data. Most give continuous readings and can be automated. Three reliable instruments recommended for use in bareroot nurseries are (1) tensiometers (e.g., Irrometer™), (2) electrical resistance-based sensors (e.g., Watermark™), and (3) capacitance-based sensors (e.g., TriSCAN™). See chapter 3 of Stetson and Mecham (2011) for more on these and other field monitoring methods to monitor soil water status.

Both tensiometers and electrical resistance-based sensors continuously measure soil moisture. They quantify the level of difficulty of removing water from soil. This is much like what a root senses. The data they provide can be collected manually or it can be collected automatically and transmitted electronically (fig. 5.6). Detailed information on how to use these instruments and the information they provide is readily available from many sources.

Capacitance-based sensors are commercially available in soil probes, which include multiple sensors set at different depths to measure the volumetric water content in the soil profile. Some probes include salinity sensors, which give data that is useful in tracking the movement of water and fertilizers in the soil profile. These sensors are often combined with weather and other sensors to make field stations (fig. 5.7). In addition to soil moisture and salinity sensors, field stations usually include in-canopy and above-canopy weather sensors (wind, solar radiation, humidity, and temperature) and irrigation line pressure sensors (indicating pressure and duration of irrigation). Sensors, probes, and field stations can be purchased or leased by the end user. The data from these can be collected automatically, transmitted electronically, and analyzed onsite or off-site. This allows the user to frequently and easily monitor soil moisture, site-specific weather events, and irrigation events from any location that has internet access. The number of individuals and companies that analyze the data and provide recommendations for irrigation scheduling via phone, email, and/or the internet is increasing (www.irrigation-mart.com, www.servitech.com).

Figure 5.6—*Field station automatically measuring and transmitting tensiometric soil moisture and other soil indices at various depths. (Photo courtesy of Irrigation-Mart, 2011.)*

Planning for an Irrigation System

The planning for a bareroot hardwood nursery irrigation system includes considerations of soil-plant-water relationships in addition to land slopes, hydraulics, weather and climate factors, economics, and system layout schemes, along with details on how the system is to be operated. Some items to address are: (1) amount of irrigation water that may be needed to produce the crop; (2) pumping rate and system pressure; (3) water quality; (4) amount of water to apply during each event, when to apply it, how fast to apply it, and the application uniformity and irrigation efficiency; (5) auxiliary uses of the system (e.g., fertigation, chemigation, and micro-climate control); and (6) how to monitor soil moisture (e.g., tensiometers) and system performance (water meters and pressure gauges). Comprehensive irrigation texts such as Hoffman et al. (2007) and Stetson and Mecham (2011) provide guidance for planning a system.

Also, a nursery irrigation system plan should consider possible expansion and changes. Failure to recognize and plan for how an irrigation system will be used in the future or how that usage may change over time, can lead

Figure 5.7—*Field station continuously measuring and transmitting volumetric soil moisture and salinity at various depths, in and out of canopy weather, and irrigation system pressure when irrigation is occurring. (Photo courtesy of Irrigation-Mart, 2011.)*

to excessive operational and modification costs, wasteful use of energy and other resources, inefficient labor utilization, and poor seedling production and quality.

The following outline lists factors that may have a bearing on the evaluation of irrigation system alternatives and the selection of a particular system. The outline can serve as a checklist to prevent overlooking important factors, and will be particularly helpful when dealing with regulatory agencies and irrigation providers such as consultants, designers, and dealers.

Physical considerations:

- **Seedling species and cultural practices**
- **Soils**
    - Texture, depth, and uniformity
    - Water intake or infiltration rate
    - Erosion potential
    - Internal drainage
    - Salinity
    - Bearing strength
- **Topography**
    - Slope percentages
    - Irregularities, such as ditches and wetlands
- **Water supply**
    - Source and delivery schedule
    - Quantity available and reliability
    - Quality
    - Chemical constituents
    - Suspended solids
- **Climate and microclimate**
- **Land value and availability**
- **Boundary constraints and obstructions**
- **Flood hazard**
- **Water table**
- **Pests**
- **Energy availability and reliability**

Economic considerations:

- **Capital investment required**
- **Credit availability and interest rate**
- **Equipment life and annualized cost**
- **Costs and inflation**
    - Energy, operation, and maintenance
    - Labor (various skill levels)
    - Supervision and management
- **Cash flow**
- **Efficiency factors**

Social considerations:

- **Legal and political issues**
- **Local cooperation and support**
- **Availability and reliability of labor**
- **Skill and knowledge level of labor**
- **Local and governmental expectations**
- **Level of automatic control desired**
- **Potential for damage by vandalism**
- **Health issues**

References

Hoffman, G.J.; Evans, R.G.; Jensen, M.E. [et al.]. eds. 2007. Design and operation of farm irrigation systems. 2nd ed. St. Joseph, MI: American Society of Agricultural Engineers (now American Society of Agricultural and Biolgical Engineers).

May, J.T. 1985. Soil moisture. In: Lantz, C.W., ed. Southern pine nursery handbook. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry.

McDonald, S.E. 1991. Irrigation in forest-tree nurseries: Monitoring and effects on seedling growth. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual. The Hague/Boston/Lancaster: Martinus Nijhoff / Dr. W. Junk Publishers.

Shock, C.C.; Wang, F. 2011. Soil water tension, a powerful measurement for productivity and stewardship. HortScience. 46(2): 178–185. http://hortsci.ashspublications.org/content/46/2/178.full.pdf

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

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2003. Conservation Practice Standard 442. Irrigation system, sprinkler. Washington, DC.

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2008. Sprinkle irrigation. In: National Engineering Handbook. Washington, DC. Section 15, Chapter 11.

Appendix 5-1

Commonly Used Irrigation Terms

Acre feet (ac-ft). A unit of volume, commonly used to designate the amount of water applied to an area. One ac-ft of water is 325,848 gallons, and the volume of water 1 foot deep covering 1 acre. (Metric conversion: 1 ac ft = 0.1233 ha m)

Acre inch (ac-in). A unit of volume, commonly used to designate the amount of water applied to an area. One ac-in of water is 27,154 gallons, and the volume of water 1 inch deep covering 1 acre. (Metric conversion: 1 ac in = 0.0103 ha m)

Allowable depletion. The amount of soil moisture depletion allowable between irrigation events that is set by the irrigation manager. It is the amount of soil water between field capacity (FC) and some portion of plant available water (PAW); it is usually reported just as a percent of PAW. Often the portion of PAW is imprecisely referred to as a portion of FC (e.g., 40 percent of PAW as 40 percent of FC), disregarding the amount of water the soil holds at PWP. When irrigation scheduling is based on soil moisture criteria (content or tension), the objective is to keep the soil moisture between the selected percent of PAW and FC. Then irrigation is to begin before the soil moisture is depleted beyond the selected percent of PAW, and to stop before the soil moisture exceeds FC. Note: the smaller the selected percent of PAW, the less energy the plant must use to get water and the less the plant is stressed.

Application uniformity (AU). A measure of how evenly irrigation water is applied over the irrigation area. Except in some nongermane cases of deficit irrigation, AU is a part/component of irrigation efficiency, often the largest. AU only deals with the part of the irrigation water that is applied rather than the gross amount, or amount pumped. If AU were 80 percent, an additional 25 percent (100/80 = 1.25) of irrigation water would have to be applied; e.g., if the plant available water needed were 0.7 in (17.8 mm), a total of 0.875 in (22.2 mm) would have to be applied; 0.175 in (4.4 mm) would be not available for beneficial use by the crop.

Centibar (cb). A unit of pressure, commonly used to quantify the energy level of water in the soil system or the ease with which water can be removed by plants. It is a unit of measurement for soil moisture tension and soil water potential. One cb is the same as one kPa, and is about 1/100 atmosphere.

Crop root zone. As used in irrigation matters, the volume of soil where plant-available soil moisture is stored; it usually increases in depth throughout the crop cycle as the crop grows.

Drain down. The partial or complete emptying of all or part of the irrigation system after an irrigation event.

Field capacity (FC). The maximum amount of water that a soil will hold under the force of gravity, or the water held in the soil after being saturated and allowed to freely drain for 2 or 3 days. At FC the soil contains 100 percent of plant available water (PAW), plus that held at permanent wilting point (PWP) which is not available for plant use. Soil moisture content near FC is ideal for plant growth.

Feet per second (fps). A unit of speed and velocity, commonly used to designate the speed of water flowing in a pipe. Metric conversion: 1 fps = 0.3048 mps (meters per second).

Gallons per minute (gpm). A unit of flow rate, commonly used to designate the flow rate of water in a pipe. Metric conversion: 1 gpm = 3.785 Lpm (liters per minute).

Impact sprinkler: A hydraulically operated mechanical device that rotates as it discharges pressurized water through a nozzle or nozzles. To cause rotation, momentum is transferred to the sprinkler body which is intermittently hit/impacted by a swinging, spring-loaded arm that gets its energy from contact with the water stream exiting a nozzle (fig. 5.2).

Irrigation area (A_e). The entire area desired/planned to be watered by an irrigation system.

Irrigation efficiency (IE). The amount of irrigation water stored in the crop's root zone that is available for beneficial use by plants, divided by the total amount of irrigation water pumped, assuming the crop's root zone covers all the area being irrigation. Thus, if the IE is 75 percent, an additional one-third (100/75 = 1.33) of irrigation water would have to be pumped. For example, if the plant available water needed were 0.7 in (17.8 mm), a total of 0.93 in (23.6 mm) would have to be pumped and 0.23 in (5.8 mm) would not be available for beneficial use by the crop, and would be wasted. Except for the portion of water applied between the beds in bareroot nurseries that would otherwise be crop-available if planted, IE accounts for all losses of the pumped water in getting it to where it is available for plant uptake. This includes: (1) water not applied uniformly to the irrigation area, (2) evaporation that occurs as water travels from the sprinklers to the irrigation area and from wetted plant and soil surfaces, (3) water falling outside of the irrigation area, and (4) water moving out of the beds via surface runoff and deep percolation.

Jet. A device that does not rotate as it distributes water through the air as a spray or streams after the water passes through a nozzle and strikes a pad.

Nozzle: A device with a hole/passageway through which pressurized water passes as the pressure is converted to stream velocity.

Nursery irrigation efficiency (IE_N). The same as irrigation efficiency (IE) when the crop root zone covers the entire irrigation area. When this is not the case, the irrigation efficiency is decreased by the portion of the irrigation area that has no crop, multiplied by IE. For bareroot hardwood nurseries that have no nursery plants between the beds, IE_N is less than IE by IE times the portion of the irrigation area that is between the beds; that is, $IE_N = IE [(1 - A_{bb}/A_e)]$, where A_{bb} is the area between the beds and Ae is the entire area. For example, if a bareroot nursery irrigation system has an IE of 0.75 and 40 percent of the irrigation area is between the beds, IE_N is [(0.75) (1 - 0.40)] = 0.45; that is, only 45 percent of the pumped water ends up available to the crop, and 2.22 times (100/45) as much irrigation water would have to be pumped to meet the needs of plants that receive the least water.

Off-center rotator. A sprinkler that distributes water through the air as rotating streams after the water passes through a nozzle and strikes a pad which rotates off-center (wobbles).

Permanent wilting point (PWP). The soil moisture content at which plants wilt to the extent that they will die. Even though the soil contains water at PWP, plants cannot remove it easily or fast enough to survive.

Plant available water (PAW). The amount of water held in the soil between field capacity (FC) and permanent wilting point (PWP), commonly reported as inches of water per foot of soil depth. Often a portion of PAW is imprecisely referred to as a portion of FC (e.g., 40 percent of PAW as 40 percent of FC), ignoring the amount of water the soil holds at PWP.

Precipitation Rate (PR): The rate at which an irrigation system delivers water to an irrigation area, usually reported as in/hr.

Range nozzle. The nozzle or the larger of multiple nozzles on a sprinkler. The range nozzle is used to throw water as far as possible (under the operating conditions), while any smaller, spreader nozzle(s) is used to apply water near the sprinkler, resulting in a more uniform application over the throw range of the sprinkler.

Riser. A length of pipe placed on an irrigation lateral to supply pressurized water to and to support a sprinkler.

Root zone. The same as the crop root zone.

Soil moisture tension. Expresses the energy level of water in the soil system, or the ease with which water can be removed by plants. It expresses how much suction is needed to extract water from a soil. It is a pressure term and commonly measured and reported in centibars (cb). Even though soil moisture tension is a negative pressure (suction), by convention it is usually reported as a positive value; i.e., a soil water tension of -9 cb is usually reported as 9 cb. Soil water potential is another term expressing the same thing as soil water tension, but it has an opposite sign; i.e., a soil water tension of 9 cb is a soil water potential of -9 cb.

Soil water retention curve. Also called a soil moisture characteristic curve, gives the relationship between soil water content and soil water tension. This curve is unique for each type of soil.

Spinner. A hydraulically operated mechanical device that rotates as it discharges water under pressure through a nozzle (or nozzles). Rotation is caused by directing the water stream exiting the nozzle through a curved path.

Spray head. A device that does not rotate as it distributes water through the air as a spray after the water passes through a nozzle and strikes a pad.

Spreader nozzle. One or more of the nozzles of a multiple-nozzle sprinkler. The smaller spreader nozzle(s) is used to apply water near the sprinkler, while the larger range nozzle is used to throw water as far as possible (under the operating conditions). This gives a more uniform application over the throw range of the sprinkler than would be possible with just one nozzle.

Sprinkler. A device that distributes water through the air as a stream(s) after it passes through a nozzle or nozzles, which converts water pressure to stream velocity.

System capacity. The ability of an irrigation system to deliver both the net required rate (gpm) and volume (gallons) of water necessary to meet a crop's needs, including all the losses that occur related to the irrigation process.

Appendix 5-2

Useful Calculations for Irrigation Management

Equation 1

Precipitation Rate of an Irrigation System:

$PRavg = [k_1(Q)/(Az)]$

where:

$PRavg$ = average precipitation rate in an irrigation zone [in/hr],

Q = flow rate at which water is applied to the zone [gpm],

A_z = area of the zone being irrigated [ft^2], and

k_1 = a constant: (60 min/hr)(12 in/ft)/(7.48 gal/ft^3) = 96.25 in-min-ft^2/gal-hr.

Equation 1 assumes that all the water is applied within the boundaries of the irrigation zone. Then, the average precipitation rate of a one-acre (43,560 ft^2) zone irrigated by an 85 gpm pump is:

$PRavg$ = [(96.25 in-min-ft^2/gal-hr) (85 gpm) / (43,560 ft^2)] = 0.188 in/hr.

Equation 2

Amount of Irrigation Water to Grow a Seedling Crop:

$V_{app} = [k_2(d_{ieu})(A_e)/(IE)]$

where:

V_{app} = volume of irrigation water needed to produce a crop of seedlings [gal],

d_{ieu} = amount/depth of irrigation water effectively used/evapotranspired to produce a crop of seedlings [in],

A_e = entire area irrigated by the system [ac], and

IE = a decimal representing the irrigation efficiency, and

k_2 = a constant: 27,154 gal/ac-in.

If an irrigation system with an IE of 0.67 is to supply 8 inches of water to be beneficially used by a crop of seedlings growing in a 10-ac nursery, the volume of irrigation water that must be supplied is:

V_{app} = [(27,154 gal/ac-in) (8 in) (10 ac)] / (0.67) = 3,242,268 269 gal. = 120 ac-in.

Thus, to apply the 8 inches of water for use by the seedling crop, 12 in must be supplied to the entire 10 ac nursery area.

Equation 3

Size of Power Source (Pump Motor)

The power required for irrigation depends on the rate water is pumped (Q), the efficiency of the pumping plant, and the total dynamic head of the system as follows:

$P = [(Q)(TDH)d/(Epp)k_4]$,

where:

P = pumping power (size of motor) required by the irrigation system [hp],

Q = flow rate at which water is supplied by the irrigation system [gpm],

TDH = total dynamic head (pressure) of the irrigation system [ft, 1 ft = 0.433 psi],

d = density of water [taken to be 8.33 lb/gal],

E_{pp} = a decimal representing the efficiency of the pumping plant (pump and motor combined), and

k_4 = a constant: 33,000 ft-lb/min-hp.

Assume that the TDH for a sprinkler system used for the 1-acre nursery zone previously discussed (Equation 1) is 139 feet (60 psi) and that the pumping plant has a 65 percent efficiency. Then the size of electric motor/power unit required to supply the 85 gpm flow rate is:

P = (85 gpm) (139 ft) (8.33 lb/gal) / (0.65 eff) (33,000 ft-lb/min-hp) = 4.6 hp, or 5 hp.

Equation 4

Irrigation Energy Consumption

$E = [k_5(P)(V_{app})/Q]$

where:

E = energy consumed/used by the pump to produce the crop [kilowatt hours (kW-hr)],

P = power used by the pumping plant [hp],

V_{app} = volume of irrigation water needed to produce a crop of seedlings [gal],

Q = flow rate at which water is supplied to/by the irrigation system [gpm],

k_5 = a constant: (0.745 kilowatts per horsepower [kW/hp]) / (60 min/hr) = 0.012417 kilowatts per horsepower kW-hr/hp-min.

So, the amount of irrigation energy needed to produce the 10-ac seedling crop previously discussed (Equations 1, 2, and 4) is:

E = (0.012417 kW-hr/hp-min) (4.6 hp) (3,242,268 gal) / (85 gal/min) = 2,178 kW-hr.

At an energy cost of $0.10/kW-hr, this amounts to $217.30, or $21.73 per acre.

Appendix 5-3

Example Calculations for Irrigation Scheduling Based on Soil Moisture

A sprinkler irrigation system with a pumping rate of **150 gpm** and an irrigation efficiency **(IE) of 0.73** is to irrigate a **10-ac** nursery crop using **five 2-ac zones**. The soil is **sandy loam** and the **crop's root zone is 6 in**. The allowable soil moisture depletion is chosen to be **25 percent of plant available water (PAW)**, meaning that irrigation will be initiated when soil moisture is depleted to 75 percent of PAW and continued until reaching field capacity (FC).

*What is the pumping rate in units of in/hr?

[150 gal/min / (2 ac) (27154 gal/ac-in)] [60 min/hr] = 0.1657 in/hr.

*What is the amount of plant available soil moisture between 75 percent of PAW and FC.

From column 3 of table 1, 25 percent of PAW is 0.35 in per foot of soil. Thus, the amount of plant available soil moisture between 75 percent of PAW and FC in the crop's 6-in root zone is:

(0.35in/ft) (6 in) (1/12 ft/in) = 0.175 inches

and, over the 10 acres this is:

(0.175 in) (10 ac) (27,154 gal/ac-in) = 47,519.5 gal.

*What is the volume of irrigation water to pump to replace the 25 percent depletion?

Since IE is 0.73,

(0.35/0.73 in/ft) (6 in) (1/12 ft/in) = 0.24 inches

and, over the 10 acres this is:

(0.24 in) (10 ac) (27,154 gal/ac-in) = 65,170 gal.

*What is the pumping time required to irrigate each of the 2-ac zones to replace the 25 percent depletion?

Using the pumping rate of 150 gal/min,

[(0.24 in) (2 ac) (27154 gal/ac-in)] / (150 gal/min) = 87 min.

*How often must irrigation occur not to exceed the allowable depletion of soil moisture if the **ET is 0.10 in/day**?

[(0.35 in/ft) (6 in) (1/12 ft/in)] / (0.10 in/day) = 1.75 days.

*But if a **frequency of irrigation** is chosen to be **once per day**, what is the total daily amount of water to pump for the 10 acres, and the length of the daily irrigation event for each 2-ac zone?

The amount to pump each day is:

(0.10 in/day) / (0.73) = 0.137 in/day,

or (0.137 in/day) (10 ac) (27,154 gal/ac-in) = 37,197 gal/day.

The length of the irrigation event per day for each 2-ac zone is:

[(0.137 in/day) (2 ac/zone) (27154 gal/ac-in)] / (150 gal/min) = 50 min/zone-day.

However, if the **ET were 0.33 in/day**, the frequency of irrigation would need to be more than once per day because the daily ET is greater than the allowable depletion of soil moisture, 0.175 in. If two irrigation events per day were chosen and the length of each event were the same, the volume of irrigation water to pump would be:

[(0.33) / (0.73 in/day) (2 ac/zone)] / (2 events/day)]= 0.45 ac-in/event-zone,

or (0.45 ac-in/event-zone) (27,154 gal/ac-in) = 12,275 gal/event-zone,

and for the entire 10-ac nursery:

(12,275 gal/zone) (5 zones) = 61,375 gal/event,

and the daily amount to pump for the 10 acres would be:

(61,375 gal/event) (2 events) = 122,750 gal.

The pumping time required per event per day for each zone would be:

(12,275 gal/zone) / (150 gal/min) = 82 min/zone;

The pumping time required for one event on the entire 5-zone nursery would be 409 min, or 6 hr and 49 min. And the total pumping time for the two events per day would be 13 hr and 38 min.