# Chapter 11
# Water Management
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## Abstract


**Water is managed in forest-tree nurseries to (1) control available soil moisture and foster germination, growth, and specific physiological responses, (2) provide solutions for transporting and infiltrating water-soluble fertilizers and leaching excessive salt concentrations, (3) protect crops from extreme drought, soil heating, freezing, or frost heaving, (4) promote germination of weed seed on fallow land for herbicide-free weed control and regulate growth of cover crops, (5) minimize potentially polluting losses of fertilizers and biocides, and (6) limit the amount of water to the optimum needed for crop production. A nursery's water requirements for all water-management purposes must be determined either with tables or by calculation from climatic data. Water quality (salinity level) must be acceptable for adequate crop growth. The quantity of the water supply or of stored water must be sufficient for all needs, even in the driest years. Although "ditch and flood" type methods have been used for irrigation over the years, most modern nurseries rely on sprinkler irrigation; a fully permanent, semipermanent, or solid set rotating sprinkler system Is recommended. System design must be carefully tailored to water resource, soil depth and type, irrigation need, pressure head, friction loss, sprinkler layout, land elevation, and local winds. Nursery managers should consult an irrigation engineer to plan the best irrigation system their budgets will allow, recognizing the likely need for future expansion.**


## 11.1 Introduction

Water management may be defined as "the scientific regulation of water for the production, conditioning, and protection of bareroot nursery crops." The term **water management** is to be preferred over others such as "irrigation" or "supply with water" [9] because it embraces many water-management techniques in addition to irrigation.

In forest-tree bareroot nurseries, water may be managed [15]:

- To control available soil moisture to promote the germination, establishment, and growth of the crop-or to slow or stop that growth, if necessary-and to foster root-regeneration potential, bud formation, frost hardiness, or other physiological responses.
- To provide solutions for transporting and infiltrating water-soluble fertilizers and leaching excessive salt concentrations.
- To protect the crop from excessive atmospheric drought, soil heating, freezing, or frost heaving.
- To promote the germination of weed seed on fallow land before cultivation as a herbicide-free weed control measure.
- To promote the germination and establishment and regulate the growth of cover crops on fallow land and noncrop areas.
- To minimize potentially polluting losses of fertilizer and biocides.
- To limit the amount applied to the optimum needed forcrop production.

This chapter acquaints nursery personnel with the principles, practices, and methods of modern water management. Because forest-tree nurseries are most efficiently irrigated by sprinklers, water-management systems associated with sprinkler irrigation will be stressed.

## 11.2 History of Water Management

Water management is an ancient procedure. The earliest evidence of irrigation is a water storage dam in Egypt dating to 5,000 B.C. [23, 30]. Perhaps the earliest water managers were


**In** Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

the priests of ancient Egypt, who built conduits connecting the temples of the river gods to the Nile and used "Nilometers" (graduated pillars) to forecast the floodcrest and the success of each season's irrigation and deposit of fertile silt. In Pliny's time (1st century B.C.), floodcrests marking the Nilometers at 12, 13, 15, and 16 cubits (18.0, 19.5, 22.5, and 24.0 ft) were taken to indicate famine, scarcity, safety, and plenty, respectively.

The history and development of early man seem closely related to the development of water-management technology not only for the Egyptians of the Nile valley but also for civilizations in four other principal river valleys: the Mesopotamian of the Tigris-Euphrates valley, the Indian of the Indus valley, the Chinese of the Yellow River valley, and the Andean of the coastal river valleys of Peru [23]. Because the principles of irrigation technology are basic and few, their worldwide coevolution should not be surprising—regardless of whether or not contact was made between the early irrigators [4]. Common features of ancient and modern irrigation systems are types of water sources (streams, rivers, and wells), storages (storage dams and cisterns), diversion dams, and methods for lifting and transporting water and applying it to the land.

# 11.3 Planning A Water-Management Program

## 11.3.1 Determining nursery water requirements

Before a new nursery is established, it is essential to estimate or calculate the **water requirements** for all potential water-management purposes. This can be done either by consulting tables showing the average water requirements in various regions or by obtaining climatic data from a station at or near the proposed nursery site and computing seasonal and annual water requirements.

### 11.3.1.1 Water requirements from tables

Because the average amount of water needed to produce forest-tree nursery crops in any region is approximately similar to that needed for agricultural crops, tables giving the average annual irrigation requirements of agricultural crops may be obtained from local agricultural extension agencies and the information applied to nursery production. Table 1 compares the average annual water requirements for agricultural crops in broad regions of the United States [ 17].

### 11.3.1.2 Water requirements from climatic data

Computing the water requirements of a bareroot nursery from climatic data recorded at or near the nursery site is preferable to relying on annual tables used for agricultural crops (see 1 1.3.1.1). To do this, it is best to obtain the monthly means of precipitation and temperature for as many previous years as possible, or at least for mean and extremely dry years.

The **irrigation need**—the principal component of the water requirement-is the amount of water required to maintain nursery soil within an optimum range of available soil-moisture levels throughout the growing season each year [2]. The irrigation need for a given bareroot nursery can readily be estimated by computing water balances for all (or just the mean and extremely dry) years in the past by the Thornthwaite method [27, 28]. Although methods described by Blaney and Criddle [3] or Penman [18] could be used for the same purpose, in this chapter all examples of estimating irrigation need will be by the Thornthwaite method.

For example, Figure 1 a shows the monthly Thornthwaite water balance for the Ontario Ministry of Natural Resources Thunder Bay Forest Station, based on climatic data recorded from 1947 to 1978 (a 32-year average). In an "average" year, potential evapotranspiration (PET) exceeds precipitation (P) in May, June, July, and August; thus, these months will require irrigation. In such a year, PET - P = 0.62 inches in May, 0.81 inches in June, 2.03 inches in July, and 0.59 inches in August, for a total of 4.05 inches (15.7, 20.6, 51.6, and 15.0 mm, for a total of 102.9 mm). Therefore, the total amount of irrigation water needed to maintain soil moisture close to field capacity would approximately equal 4.05 inches (102.9 mm). Water needed for purposes other than irrigation will of course increase this amount.

The problem with using estimates of irrigation need based on an average year is that an average year never occurs. For example, the monthly Thornthwaite water balance for the Thunder Bay Forest Station in the extremely dry year of 1975 (Fig. 1 b) showed that PET exceeded P from May through September, 1 month more than in an average year; PET - P = 3.27 inches in May, 0.47 inches in June, 2.58 inches in July, 2.73 inches in August, and 0.04 inches in September, for a total of 9.09 inches (83.1, 1 1.9, 65.5, 69.4, and 1.0 mm, for a total of 230.9 mm). The irrigation need in the dry year of 1975 was more than double that of the average year. Obviously, nursery staff must be ready to provide for all irrigation needs and water requirements of the crop in the driest years if an effective water-management program is to be developed. To

**Table 1. Average annual irrigation-water requirements by region in the United States (adapted from [17]).**

| Region | (a) Net required by crop, in.[1] | (b) Application efficiency, % | (c) a x 100/b, in. | (d) Storage delivery efficiency, % | (e) c x 100/d, in. | (f) Estimated recovery of losses, % | (g) Total water requirements [e - (c x f)/100], in. |
|---|---|---|---|---|---|---|---|
| **Eastern U.S.** | | | | | | | |
| Moistest region | 2.43 | 60.0 | 4.05 | 60.0 | 6.75 | 20.0 | 5.94 |
| Driest region | 5.25 | 60.0 | 8.75 | 65.0 | 13.46 | 20.0 | 11.71 |
| Mean | 4.07 | 60.0 | 6.78 | 62.0 | 10.94 | 20.0 | 9.58 |
| **Western U.S.** | | | | | | | |
| Moistest region | 5.62 | 50.0 | 10.52 | 60.0 | 17.53 | 55.0 | 11.74 |
| Driest region | 8.59 | 45.0 | 19.10 | 55.0 | 34.71 | 55.0 | 24.21 |
| Mean | 8.45 | 46.0 | 18.37 | 52.0 | 35.33 | 56.0 | 25.04 |
| **Addenda** | | | | | | | |
| Pacific Northwest | 4.04 | 60.0 | 6.73 | 60.0 | 11.22 | 20.0 | 9.87 |
| Western Lake States[2] | 6.88 | 17.2 | 60.00 | 17.2 | 28.67 | 60.0 | 18.35 |

[1]To convert in. to cm, multiply by 2.54.

[2]Western Lake States are Minnesota and Wisconsin.

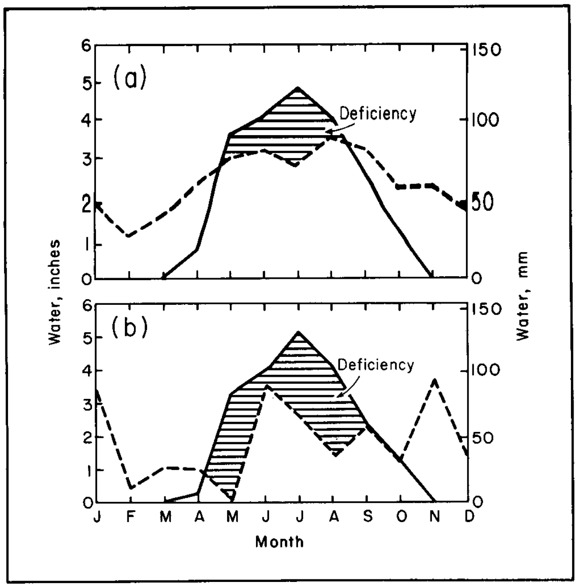



**Figure 1. Precipitation (P, dashed line) and potential evapotranspiration (PET, solid line) for the Thunder Bay Forest Station for (a) an average year [mean deficiency, or PET - P = 4.05 inches (-103 mm)] and (b) an extremely dry year [acute deficiency, or PET - P = 9.09 inches (- 231 mm)].**

evaluate the water requirements for a bareroot nursery in detail, it is also essential for nursery staff to estimate the irrigation need for dry periods not indicated by monthly means and to be sure that adequate water supplies will be available for all water-management purposes at such times. The severity of dry periods can best be identified and assessed by computing a daily water balance for past years by the Thornthwaite method [5].

Calculating the percentage probability of monthly or periodic irrigation-water requirements during the time in which irrigation is needed each year is also very useful. This tells the nursery staff how often they are likely to have to supply specific quantities of irrigation water. For example, the percentage probability of monthly irrigation-water requirements at the Thunder Bay Forest Station was computed by the Thornthwaite method from climatic data recorded over the 32-year period noted in Figure 1 (Table 2). At Thunder Bay, the probabilities of an irrigation-water requirement of more than 1 inch (2 5.4 mm) in May, June, July, August, September, and October are 12, 35, 63, 38, 16, and 6%, respectively. In the hot summer months of July and August, the probabilities of an irrigation need of more than 2.5 inches (65.3 mm) are 34 and 25%, respectively.

Once the water requirements of a nursery have been computed, the amount of water to be applied per acre (or per hectare) can be rapidly determined. Table 3 gives the volumes of water necessary to satisfy monthly water requirements ranging from light (0.2 5 inches, or 6.3 5 mm) to heavy (2.5 inches, or 63.5 mm).

**Table 2. Percentage probability of monthly irrigation-water requirements at the Thunder Bay Forest Station, computed by the Thornthwaite method.**

| Water requirements (basis 1947-1978), | | Probability of monthly water requirements, % | | | | | |
|---|---|---|---|---|---|---|---|
| in. | mm | May | June | July | Aug. | Sept. | Oct. |
| <0.1 | <2.5 | 59 | 31 | 19 | 28 | 68 | 63 |
| 0.1-0.5 | 2.5-12.7 | 19 | 31 | 6 | 15 | 10 | 25 |
| 0.6-1.0 | 12.8-25.4 | 10 | 3 | 12 | 19 | 6 | 6 |
| 1.1-1.5 | 25.5-38.1 | 3 | 10 | 19 | 0 | 10 | 3 |
| 1.6-2.0 | 38.2-50.8 | 3 | 10 | 10 | 10 | 0 | 3 |
| 2.1-2.5 | 50.9-65.3 | 3 | 3 | 0 | 3 | 0 | 0 |
| >2.5 | >65.3 | 3 | 12 | 34 | 25 | 6 | 0 |

**Table 3. Volume of water per unit area needed for various monthly Irrigation-water requirements.**

| Water requirement, | | Volume of water | | | |
|---|---|---|---|---|---|
| | | Per acre, | | Per hectare, | |
| in. | mm | $ft^3$ | U.S. gal | $m^3$ | L (x $10^3$) |
| 0.25 | 6.35 | 908 | 6.789 | 635 | 635 |
| 0.50 | 12.70 | 1,815 | 13.578 | 1,270 | 1,270 |
| 1.00 | 25.40 | 3,630 | 27,156 | 2,450 | 2,450 |
| 1.50 | 38.10 | 5,445 | 40,734 | 3,810 | 3,810 |
| 2.00 | 50.80 | 7,260 | 54,312 | 5,080 | 5,080 |
| 2.50 | 63.50 | 9,075 | 67,318 | 6.350 | 6,350 |

## 11.3.2 Water quality

Water quality is defined in terms of the elemental composition and concentration of salts dissolved in the irrigation water [1,7,8]. As the ratio of precipitation to potential evapotranspiration varies seasonally in arid and semi-arid climates, so do the salinity and resultant quality of irrigation water. Salinity is a common problem in poorly managed container nurseries when fertilizer salts are allowed to build up in the medium without adequate leaching, but is not usually a problem in bareroot nurseries except in the prairie regions of Canada and the United States. In these regions, where potential evapotranspiration exceeds precipitation, the quality of irrigation water may be more critical than that of the soil for growing healthy nursery crops [14].

Bareroot conifer crops are readily damaged by an excess of salts in the soil solution. The damage initially takes the form of brilliant reddening of needle tips; this is followed by progresssive browning of the foliage and may be accompanied by resin bleeding from the roots. Salts injure bareroot stock in four ways: (1) by increasing the osmotic pressure of the soil solution, causing stress and drought; (2) by decreasing soil permeability owing to loss of soil structure and aggregation caused by the deflocculation of soil colloids (particularly in clays); (3) by direct ion toxicity from sodium, chloride, borate, and other ions; and (4) by change in nutrient availability owing to changes in pH and associated solubility and to antagonisms between ions.

The best method of evaluating water quality is to determine: (1) conductivity in micromhos/centimeter of total salts, (2) pH, and (3) concentrations of the specific ions sodium ($Na^+$), potassium ($K^+$), calcium ($Ca^{++}$), magnesium ($Mg^{++}$), carbonate ($CO_3^-$), bicarbonate ($HCO_3^-$), sulfate ($SO_4^{--}$), chloride ($Cl^-$), nitrate ($NO_3^-$), and boron (B), measured in milliequivalents/liter (meq/L) [14].

### 11.3.2.1 Osmotic stress

The following values are often used to assess the effects of salts on growth [14]:

| Salt hazard | Conductivity, micromhos/cm |
|---|---|
| Low | < 250 |
| Medium | 250-750 |
| High | 751-2,250 |
| Very high | > 2,250 |

### 11.3.2.2 Reduced soil permeability

The effects of salts on soil permeability are generally determined from two indexes, the Adjusted Sodium Adsorption

Ratio (ASAR) and the Residual Sodium Carbonate (RSC). ASAR is the relative proportion of deleterious ions (i.e., $Na^+$, $CO_3^{--}$, and $HCO_3^-$) to beneficial ions (i.e., $Ca^{++}$ and $Mg^{++}$). Although sodium ions are usually the principal offenders, carbonate ions are included in the ASAR because they can dissolve beneficial calcium and magnesium ions [1]. RSC reflects the harmful effects of salts in deflocculating clays and dissolving soil organic matter. RSC values are computed by subtracting the sum of the carbonate and bicarbonate ions from the sum of the calcium and magnesium ions. The following index values are often used to judge the effects of salt on soil permeability:

| Type of value | Effect on soil permeability | | |
|---|---|---|---|
| | Good | Marginal | Poor |
| ASAR | < 6.00 | 6.00-9.00 | > 9.00 |
| RSC | < 1.25 | 1.25-2.50 | > 2.50 |

### 11.3.2.3 Direct ion toxicity

$Na^+$, $Cl^-$, and B ions injure plant tissues directly. $Na^+$ and $Cl^-$ can be absorbed through the foliage, causing plasmolysis (osmotic dehydration of cell protoplasm) and tissue death. The following values are given by Ayers [1] and Landis [14]:

| Absorption site and ion | Effect of ion toxicity, meq/L | | |
|---|---|---|---|
| | Good | Marginal | Poor |
| **Foliage** | | | |
| Sodium | < 3.0 | > 3.0 | ….. |
| Chloride | < 3.0 | > 3.0 | ….. |
| **Root** | | | |
| Sodium (ASAR) | < 3.0 | 3.0-9.0 | > 9.0 |
| Chloride | <4.0 | 4.0-10.0 | > 10.0 |
| Borate | < 0.5 | 0.5-2.0 | > 2.0 |

### 11.3.2.4 Changes in nutrient availability

Changes in nutrient availability can only be defined by determining the effects of salts and of pH changes caused by salts on foliar levels of absorbed nutrients. Prime examples are absorption of phosphate ions ($PO_4^{---}$) when pH is high or when $Ca^{++}$ or $Mg^{++}$ ions are in excess, or of ferrous ($Fe^{++}$) or ferric ($Fe^{+++}$) ions when $CO_3^{--}$ or $HCO_3^-$ ions are in excess (i.e., "lime-induced chlorosis").

## 11.3.3 Water quantity

A dependable, abundant source of water adequate to meet all water-management needs is an indispensable component of any nursery or prospective nursery site (see chapter 2, this volume). Yield of a proposed source must be determined before a nursery site is approved, This source must be able to meet the demand for all water requirements regardless of the aridity of the season, the severity of the irrigation need, and the need for water for other purposes.

Water sources for bareroot nurseries are usually streams, rivers, or wells on or near the nursery property. In the Northwest, where many bareroot nurseries have to depend on wells for water, managers must be sure that the amount of water needed in the driest seasons can be supplied either directly or from storage in cisterns or reservoirs. The details of well construction specifically for use in irrigation programs can be found in Israelsen and Hansen [13]. For many bareroot nurseries, a supply stream can be dammed and a storage reservoir created. Such reservoirs are designed both to provide adequate water supplies in periods of peak water requirements and to buffer fluctuations in downstream flow [13, 16, 17, 29].

# 11.4 Irrigation Systems

As in the past, most agricultural water is still applied by the ditch with flood, border, or furrow methods [4, 16, 23, 29, 30]. With the development of efficient mechanical pumps and turbines in the 19th century, sprinkler irrigation systems came into common use for agriculture in the developed countries and are now almost universally used in nursery practice. In this chapter, the ditch with flood, border, or furrow methods will only be briefly described; sprinkler irrigation systems, which are more important in nursery practice, will be discussed in detail (see 11.4.2 and, especially, 11.5).

## 11.4.1 Ditch with flood, border, or furrow systems

These systems run water onto the surface of the land from a nearby irrigation ditch. As a result, they can only be employed on relatively flat terrain. None of these systems are particularly satisfactory for most of the water-management objectives listed in this chapter's introduction (see 11.1): transporting and infiltrating fertilizers; leaching excessive salt concentrations; protecting the crop from atmospheric drought, soil heating, freezing, or frost heaving; promoting the germination of weed seed and regulating the growth of cover crops on fallow land; restricting the losses of fertilizer and biocides; and limiting the amount of water to the optimum needed for crop production.

### 11.4.1.1 Flood irrigation

Flood irrigation systems can only be operated on land with very gentle topography because large areas must be uniformly supplied with water from irrigation ditches. Fields are typically subdivided by dikes or border ridges into strips or basins 300 to 1,200 ft (91 to 365 m) wide. The water is usually transported from a supply canal to secondary ditches that parallel the strips or basins. By opening gaps or setting up short siphons at 30- to 60-ft (9- to 18-m) intervals along the secondary ditches, the strips are flooded each time irrigation is required. As soon as the water covers the entire strip and has remained long enough for infiltration, irrigation is complete. The openings in the secondary ditches are then closed or the siphon tubes removed to shut off the water.

### 11.4.1.2 Border irrigation

Border (or strip) irrigation is similar in many respects to flood irrigation except that each strip, 300 to 1,200 ft (91 to 365 m) wide, is subdivided into substrips 30 to 60 ft (9 to 18 m) wide. Water is then allowed to enter each substrip in successsion until the main strip is completely irrigated. Border irrigation has the advantage of limiting the area under irrigation at any one time, providing superior depth control and permitting more uniform, less wasteful applications even when the ground is gently sloping.

### 11.4.1.3 Furrow Irrigation

Furrow (or corrugation) irrigation differs from both the flood and border systems because it is limited to row crops. The water is run into furrows which are made either by cultivating the rows for the crop or by digging special shallow ditches called rills between the crop rows. The furrows or rills are run down a gradual slope. However, use of furrow irrigation must be restricted to suitable soils (usually loams): water in pervious soils (i.e., sands and sandy loams) may sink beneath the irrigation furrows or rills before it is absorbed by the crop lands and that in impervious soils (i.e., clays) may be so slowly absorbed that it never reaches the crop's root system.

## 11.4.2 Sprinkler systems

Sprinkler irrigation is completely different from the ditch methods described in 11.4.1 in that mechanical turbines or pumps are used to pressurize a pipeline system that delivers water at a specific head pressure to sprinklers spaced so that their spray simulates rainfall. Sprinkler irrigation is almost always used on bareroot nurseries because, unlike the ditch methods, it satisfies all the purposes of water management listed in this chapter's introduction (see 11.1).

Sprinkler systems have considerable advantage over all other irrigation systems because they can be calibrated for use on almost any soil type, can deliver the exact amount of water needed for any water-management purpose, and can be used on uneven or gently rolling terrain. Their main disadvantage is that their water distribution is readily affected by winds over 7 mph (11 kph); other disadvantages are their high initial capital cost and higher maintenance costs and power requirements than other systems. A minor disadvantage of sprinkler systems with overland supply pipes is that the branch lines feeding the laterals block access to one end of each nursery compartment; to overcome this problem, some nurseries have installed fully permanent systems with subterranean branch and even lateral lines.

Two principal types of sprinkler systems—oscillating nozzle line and rotating sprinkler-are used in bareroot nurseries. Although nozzle line systems were favored in the 1950s at some locations, rotating sprinkler systems are used almost exclusively in modern forest-tree nurseries because of cost advantages, simplicity of installation and maintenance, and superior rates of application.

### 11.4.2.1 Oscillating nozzle line

Oscillating nozzle line systems consist of galvanized steel pipelines, tapped and fitted at regular intervals with aligned nozzles, spaced at uniform intervals in a parallel pattern across each compartment to be irrigated. Each nozzle line is attached at the header supply line to a water-powered motor which causes it to oscillate in rowlock-shaped supports so that water is sprayed upwards through a 120 to 165° arc. Oscillating nozzle lines produce a uniform overlapping spray pattern that covers their length and sweep.

Because nozzle lines must be supported on semipermanent posts set above the height of mechanical equipment, these irrigation systems tend to lack mobility and versatility. They also tend to be more expensive to install and maintain than rotating sprinkler systems. Water motors are complex, subject to breakdown, and costly to buy, repair, and maintain. In addition, application rates generally are low; maximum is 1/4 inch (0.64 cm) of water/hour, or, with special nozzles, 1/3 inch (0.85 cm) of water/hour. Furthermore, because the nozzles in the lines have small orifices, nozzle clogging may be a serious maintenance problem unless the irrigation water is either very clean or filtered. Thus, although many older nurseries have oscillating nozzle line systems, new nurseries rarely install them.

### 11.4.2.2 Rotating sprinkler

Rotating sprinkler irrigation systems generally consist of portable aluminum pipes joined by couplings fitted with risers (just high enough to clear the crop) and rotating sprinkler heads [19-22]. In some nursery installations, the main, branch, lateral feeder, and lateral lines are permanently buried beneath the ground to permit superior machine access. Usually, several lateral pipelines fitted with sprinkler heads at 30-ft intervals are spaced at 30, 40, 50, or 60 ft (9.14, 12.19, 15.24, or 18.29 m) across each compartment, so that the water radiating from the sprinkler heads is sprayed in a circular overlapping pattern. The distances between sprinkler heads in lateral lines should be approximately 40 to 60% of the area covered by their circular spray patterns (see chapter 5, this volume). It is essential to select sprinkler heads with orifices that can achieve this objective at available head pressure. Because rotating sprinklers are made that can operate from 3 psi (21 kPa), with a discharge of as little as 1 U.S. gallon (3.78 liters)/minute, to 100 psi (690 kPa), with a discharge of 110 U.S. gallons (416 liters)/minute, almost any rate of application or arrangement of sprinklers is possible. Thus, rotating sprinklers have many advantages over oscillating nozzle lines-including considerably lower cost. One problem of rotating sprinklers is the difficulty in obtaining a uniform irrigation pattern because the spray is circular; however, this can be overcome by designing sprinkler-head layouts with effective overlapping spray patterns.

In most modem bareroot nurseries, rotating sprinkler systems with lateral lines in place throughout the water-management period are universally preferred. Such systems are essential where water may be required at any time to implement any of the objectives listed in this chapter's introduction (see 11.1).

# 11.5 Rotating Sprinkler System Design

The designs of all sprinkler irrigation systems are similar in principle yet infinitely variable in layout and degree of mobility. In this section, sprinkler-system components, types, and design factors are discussed.

## 11.5.1 System components

The following components are common features of all sprinkler systems:

- **Pumps or turbines** located at the water source, supplying and pressurizing the distribution pipelines (Fig. 2). These may be static or mobile and are usually either diesel or electric. Because the pumps are often located at the lowest point in the system, a check valve usually must be installed to prevent uncontrollable back pressures when pumps stop or are shut down.
- **Main line or lines** connecting the pumps to the branch supply lines. These are the largest diameter supply lines and are fitted with pressure-regulating valves (PRVs) just before they connect with the branch lines (Fig. 3). PRVs ensure an acceptably uniform head pressure in the branch lines regardless of variation in pump pressure.
- **Branch and connector lines** linking the main lines to compartment header lines. The branch lines are usually smaller in diameter than the main lines and are often arranged in loops extended from the PRV at the end or ends of a main line or lines. Looping branch lines ensure a reasonably uniform pressure at any point on the line.
- **Compartment header lines** connecting the branch lines to the lateral supply lines. These are usually considerably smaller in diameter than the branch lines because they are only required to supply water to the individual compartments.
- **Lateral lines** delivering the irrigation water from the compartment header lines to the sprinkler heads. These are the smallest diameter pipelines in the irrigation system and may even be stepped down to a smaller diameter at half their length. The laterals are fitted with sprinkler heads at regular intervals and are laid out in parallel lines across each nursery compartment so that uniform amounts of irrigation water may be applied to the soil or crop.

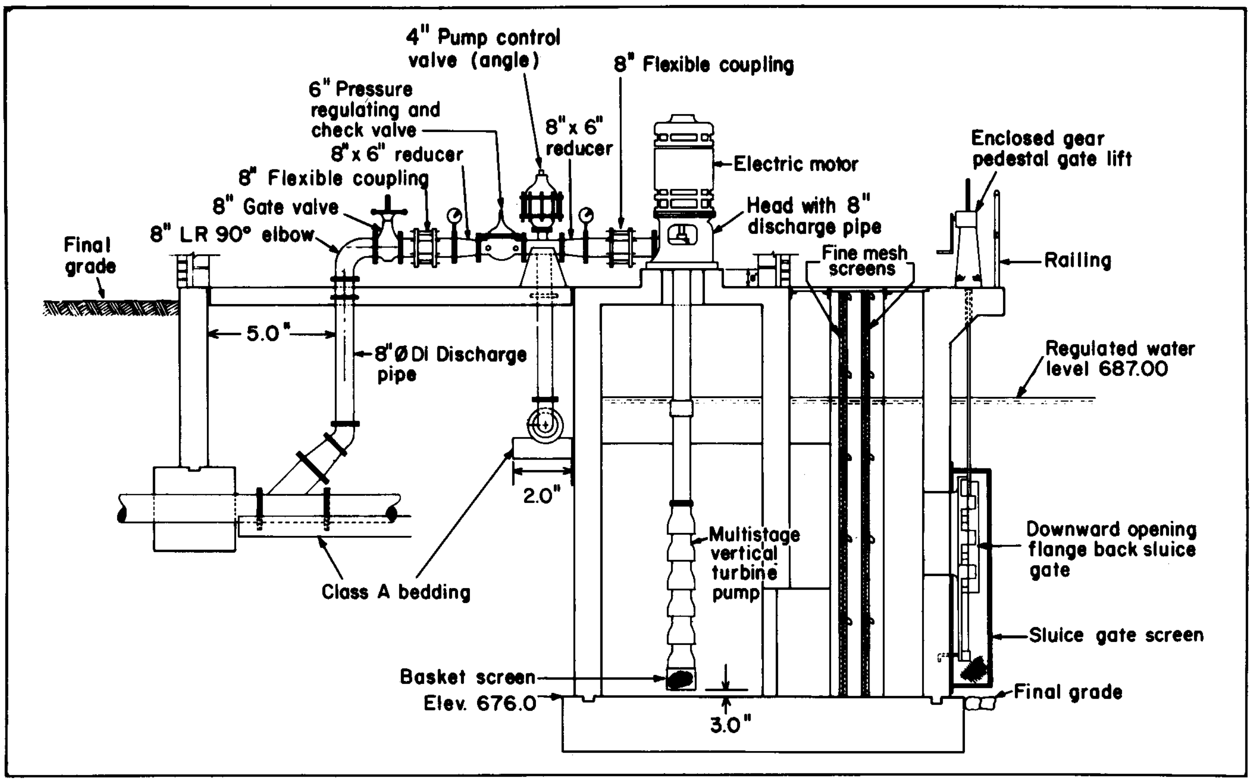



**Figure 2. Profile of a modern bareroot-nursery pumping station.**

## 11.5.2 System types

The types of rotating sprinkler systems used on bareroot nurseries are: (1) fully permanent, (2) solid set, (3) semi-permanent, (4) fully portable with manually moved laterals, and (5) fully portable with mechanically moved laterals. Solid set and semipermanent systems are most commonly chosen (Table 4). Both these systems have semipermanent laterals that remain in position on the nursery compartments throughout the entire water-management period but are removed at the end of the period to permit cultivation and for overwintering. Fully permanent systems have been installed in recent years at some nurseries (e.g., the Ontario Ministry of Natural Resources Dryden Tree Nursery), but they are not common because of the additional cost of burying and then servicing the lateral lines. The comparative advantages of fully permanent, solid set, and semipermanent sprinkler systems will stimulate argument among nursery managers for years to come because all these systems work well. Their advantages and disadvantages may be summarized as follows:

### Fully Permanent

- **Advantages**

  —Vehicular and machinery access is optimal because the branch, compartment header, and lateral lines are buried.

  —Lateral lines stay in the design pattern all the time, and risers and sprinklers threaded into them remain vertical, ensuring a uniform irrigation pattern.

- **Disadvantages**

  —Permanent risers fitted with sprinkler heads prevent complete soil cultivation or ripping close to or across the buried lateral lines. Hand or chemical weed control near the risers is usually necessary.

  —Machinery damage to the risers is not uncommon because most nursery machines must work near them. Repair of ruptured lateral lines or damaged risers is slower and more expensive because excavation is required.

  —Lateral and other pipelines not installed below frost level must be drained and blown out with compressed air before winter.

### Solid Set

- **Advantages**

  —Vehicular and machinery access is fair because the main and branch lines are buried.

  —Lateral and compartment header lines can be removed at the end of the irrigation season and at the end of each crop rotation, clearing the compartment for complete cultivation and ripping.

- **Disadvantages**

  —Compartment header lines feeding the laterals block vehicular and machinery access to one end of each compartment.

  —Sprinkler risers (and heads) tilt unless staked or guyed, disrupting the uniformity of the irrigation pattern.

### Semipermanent

- **Advantages**

  —None over those listed for solid set.

- **Disadvantages**

  —All those of solid set. In addition to compartment header and lateral lines, main and branch lines block ready access to many parts of the nursery. To overcome this problem at road intersections, main and branch lines may have to be set in underpasses or bridged.

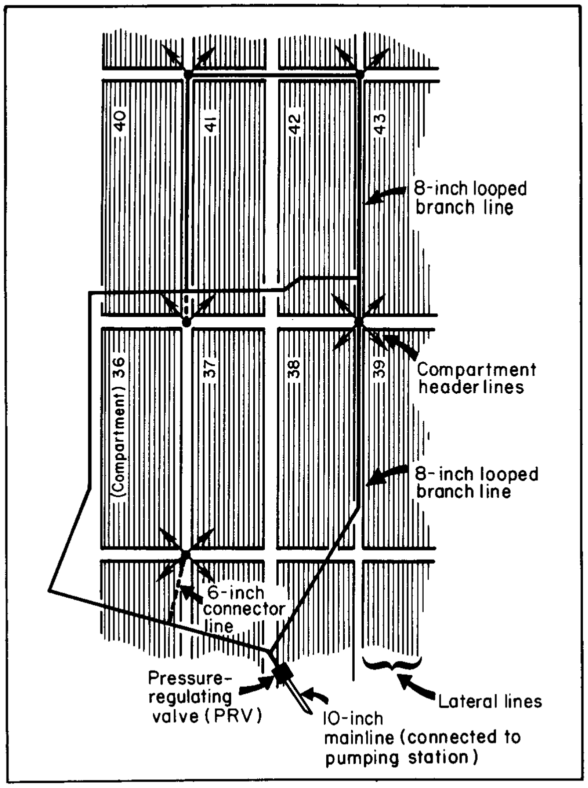



**Figure 3. Portion of a nursery sprinkler-system layout.**

Fully portable systems with manually moved laterals are sometimes used on undercapitalized bareroot nurseries. However, such systems are inadequate to supply irrigation to meet all the requirements of a fully developed water-management program and should be upgraded to a semipermanent or solid set system as soon as funding permits. Fully portable systems with mechanically moved laterals are rarely found on bareroot nurseries for similar reasons.

## 11.5.3 Design factors

Sprinkler-system design for a bareroot nursery depends on the following components: (1) water resource, (2) soil depth and type, (3) irrigation need, (4) pressure head, (5) relative land elevation, (6) system friction loss, (7) sprinkler layout, and (8) local wind characteristics.

### 11.5.3.1 Water resource

Because an adequate water supply is an important constraint in establishing a bareroot nursery, the water resource should always be of sufficient quality and quantity to meet nursery water requirements (see 11.3.2 and 11.3.3). Because many bareroot nurseries are established adjacent to watercourses or wells with delivery rates that are lower than the rates of use during irrigation periods, water storages such as dams and cisterns often must be built to create a reservoir of water. For a nursery obtaining its water from a stream, impoundment minimizes fluctuations in streamflow which may affect others during periods of heavy water use. Water storage also allows water to warm before it is applied to the crop or soil.

### 11.5.3.2 Soil type and depth

Bareroot nursery stock is generally grown in soils plowed at least 7 inches (18 cm) deep. Because seedling roots are almost always confined to the plow layer, water should be applied to keep this layer optimally moist-that is, in an optimum range of soil water potential (between -0.1 and at most -0.75 bar [6]). To maintain the plow layer in the optimal range, soil-moisture retention curves-the percentage of total soil-moisture content by weight [%TSMC (wt)] plotted over soil moisture tension (SMT)—must be derived for the range of soil types on each nursery (see 11.5.3.3 and also chapters 6 and 12, this volume).

Principal factors affecting water relations of cultivated bareroot-nursery soils are texture and organic matter content (see chapters 6 and 9, this volume). Light soils (sands and sandy loams) have a lower water-holding capacity than medium soils (loamy sands and loams); heavy soils (clay loams and clays) have the highest water-holding capacity. Ideally, bareroot nurseries should be located on light soils so that seedlings may be harvested with minimal root loss; thus, organic matter is usually added to improve soil water-holding and cation-exchange capacities.

Data presented in Table 5, drawn from a typical irrigation handbook [10], suggest that "available moisture" is the soil water between field capacity (-0.1 bar SMT) and wilting coefficient (-15.0 bars SMT). Although soil water in this range is technically "available," growth of seedling crops in sandy soils is severely limited at SMTs greater than -0.75 bar [6]. Table 5 clearly shows that the light soils preferred for bareroot nurseries hold the least water yet have the highest percentage of available water and, conversely, that heavy soils hold the most water yet have the least available. Thus, the soils most desirable for bareroot nurseries are also those that tend to need regular irrigation and a well-planned program of water management.

**Table 4. Comparison of five basic types of rotating sprinkler systems.**

| | Type of sprinkler system | | | | |
|---|---|---|---|---|---|
| System component | Fully permanent | Solid set | Semipermanent | Fully portable, manually moved laterals | Fully portable, mechanically moved laterals |
| Water source | Single | Single | Single | Single or several | Single or several |
| Pumping plant | Static | Static | Static or semimobile | Mobile | Mobile |
| Main lines | Static buried | Static buried or surface | Static buried or surface | Portable surface | Portable surface |
| Branch lines (Loops) | Static buried | Static buried or surface | Static buried or surface | Portable surface | Portable surface |
| Lateral lines | Static buried | Static surface | Portable surface | Portable surface | Mechanically moved, surface |
| Use at bareroot nurseries | Rarely | Commonly | Commonly | Rarely | Very rarely |

**Table 5. General water relations of various soil types In inches of water/foot of soil (ln./ft)[1] and percent total soil-moisture content (%) (adapted from [10]).**

| Soil type | Moisture-holding capacity | | | | Available moisture | |
|---|---|---|---|---|---|---|
| | At field capacity, | | At wilting coefficient, | | (field capacity - wilting coefficient), | |
| | in./ft | % | in./ft | % | in./ft | % |
| **Light** (sands to loamy sands) | 1.25 | 100 | 0.25 | 20 | 1.00 | 80 |
| **Medium** (loamy sands to loams) | 2.25 | 100 | 0.56 | 25 | 1.69 | 75 |
| **Heavy** (clay loams to clays) | 3.67 | 100 | 1.28 | 35 | 2.39 | 65 |

[1]To convert in./ft to cm/m, multiply by 8.3332.

### 11.5.3.3 Irrigation need

Soil texture and depth, depth of root development, and soil moisture content govern the amount of water to be applied at any irrigation. To irrigate a nursery crop scientifically, nursery staff need the following information to compute the amount of water to be applied [6]:

- The **average depth of the plow layer** in centimeters (or inches)-conventionally, this has been 18 cm (7 in.). During germination or for 1+0 crops, it may be desirable to reduce the soil depth to that exploited by the seedling roots.

- The **bulk density (BD),** or dry weight of the soil per unit volume in grams per cubic centimeter. The BD of most bareroot nursery soils averages 1.3 g/cm$^3$, ranging from 0.9 g/cm$^3$ in sands to 1.6 g/cm$^3$ in clay loams.

- The **soil-moisture retention curve —%**TSMC(wt)/SMT—with exact values for %TSMC(wt) at field capacity (-0.1 bar) and at the upper limit of dryness (normally between -0.5 and -0.75 bar [6]).

From this information, the amount of irrigation required to maintain the soil within the optimum moisture range for growth may be calculated:

(1) Compute %TSMC by volume [%TSMC(vol)] at field capacity before irrigation:

%TSMC(vol) = %TSMC(wt) x BD/l

where l = the density of water at 20°C.

This computation is essential for scientific application of water: the volume of water (in centimeters) held in the soil before irrigation and that which must be applied by irrigation must be determined to return the soil to an optimally moist condition at field capacity.

(2) Compute, in centimeters:

(a) The amount of water in the soil at field capacity, W(fc):

$$W(fc) = \frac{\%TSMC(vol)\text{ at field capacity x soil depth}}{100}$$

(b) The amount of water in the soil before irrigation, W(bi):

$$W(bi) = \frac{\%TSMC(vol)\text{ before irrigation x soil depth}}{100}$$

(c) The amount of irrigation water to be applied, W(i):
W(i) = W(fc) – W(bi)

(3) Compute the volume of irrigation water to be applied per unit area:

(a) In liters/hectare (L/ha):

$$L/ha = \frac{W(i)\text{ in cm x }10^6}{10.0}$$

(b) In U.S. gallons/acre (gal./ac):

$$gal./ac = \frac{W(i)\text{ in cm x }10^6}{10 \text{ x } 3.7853 \text{ x } 2.471}$$

$$= W(i)\text{ in cm x }10{,}691$$

where 1 U.S. gallon = 3.7853 liters and
1 hectare = 2.471 acres.

In practice, it is necessary to know both the amount of water to be applied and the rate of infiltration of the soil between field capacity and the upper limit of dryness (i.e., between -0.1 and -0.75 bar [6]). The irrigation system can then be designed so that the rate of application is slightly lower than the rate of infiltration capacity of the soil, to avoid flooding [2]. If the sprinkler system is not designed in this way, the scientific application of irrigation water becomes a more complex and expensive procedure because water will have to be applied several times to return the soil to field capacity and to avoid flooding. in practice, it is always best to determine the infiltration rate and capacity of the soil in the range to be maintained by irrigation before the sprinkler system is designed. General relationships between soil moisture-holding capacities and infiltration rates of various soil types are given in Table 6 [11].

**Table 6. Generalized relationship between soil moisture-holding capacity and approximate Infiltration rate in various soil types (adapted from [11]).**[1]

| Soil type | Moisture-holding capacity | Infiltration rate/hour |
|---|---|---|
| | ~ ~ ~ ~ ~ ~ ~ in. (cm) | ~ ~ ~ ~ ~ ~ ~ |
| **Light** (sands to loamy sands | 0.75 (1.9) | 1.5 (3.8) |
| **Medium** (loamy sands to loams) | 1.30 (3.3) | 0.75 (1.9) |
| **Heavy** (clay loams to clays) | 2.15 (5.5) | 0.5 (1.3) |

[1]For a 7-inch (18-cm) plow layer.

### 11.5.3.4 Pressure head

The pressure head required to operate a sprinkler system is usually the sum of the following:

- **Sprinkler head pressure (SHP),** the pressure required to operate the sprinkler heads with an appropriate overlap.
- **Frictional loss pressure (FLP),** the pressure drop caused by frictional losses in the main, branch, compartment header, and lateral lines between the pumps and the highest sprinkler head in the system.
- **Lift pressure (LP),** the pressure required to lift irrigation water from its source to the highest sprinkler head in the system.

Pressure head (PH) may thus be calculated:

PH = SHP + FLP + LP

If the water source is above rather than below the sprinkler system, so that head pressure is added to the system, LP should be subtracted, rather than added, in the above equation.

### 11.5.3.5 Relative land elevation

For an effective water-management program, it is best that slope vary less than 5% within any one nursery compartment or block of compartments operating from a single or looped branch line, To ensure that the amount of water prescribed is uniformly applied, the nursery should be designed so that blocks of compartments are located on level land and are served and circumscribed by looped branch lines fed by main lines fitted with PRVs (see Fig. 3). Thus, a bareroot nursery may be located on sloping ground provided that the areas to be irrigated from any looped branch line are level or are terraced to less than 5 % slope.

Because the water source is usually located below the compartments in bareroot nurseries, blocks of compartments may be established at one or more levels above the pumping station provided that each block is fitted with a separate PRV. The PRVs will then reduce head pressure to the optimum for irrigation at each level.

### 11.5.3.6 System friction loss

Friction losses occur in the main, branch, compartment header, and lateral lines of all sprinkler systems. Losses in the main, branch, and compartment header lines should not exceed 10 psi (70 kPa), or the cost of operating the pumps will rapidly rise above that of fitting larger supply pipelines [11]. Losses in the lateral lines should be kept below 20% of the operating pressure to ensure uniform water application. A 20% pressure variation in the lateral lines causes approximately a 10% variation in discharge from the sprinkler heads from the point at which each lateral tees onto the compartment header line to its distal end. Because variations in discharge from the sprinkler heads are virtually impossible to eliminate, most sprinkler systems attempt to keep the variation in sprinkler-head discharge to within 10%.

Friction losses vary with the type of pipe used and the pressure (or rate of flow) applied to the line. They are least in plastic pipes and progressively increase in cement asbestos, aluminum, and steel pipe, especially aging and corroded steel pipe. Friction losses have been estimated for the above types of pipe and may readily be determined by reference to North Plains [16] or Gray [11].

### 11.5.3.7 Sprinkler layout

Because the fully permanent, solid set, or semipermanent sprinkler systems used at bareroot nurseries are costly, it is wise to design the best sprinkler layout for the crops to be grown before calculating pipeline diameters or considering pumping requirements. Each layout must be tailored to the soil, wind, and crop conditions at each nursery. Generally, the design process begins with selection of the type and spacing of sprinkler heads that will be optimum for the infiltration rate of the soil to be irrigated. The amount of water to be applied to the whole compartment per unit time is then calculated so that the size of the lateral, compartment header, branch, and main lines may be determined.

For example, Figures 4a-a show recently designed sprinkler layouts for seedbed and transplant compartments at the Dryden and Thunder Bay Forest Stations [12, 24-26]. Figure 4a depicts a typical, fully permanent, square-spaced sprinkler layout, with all pipes buried, in a single compartment at Dryden; all compartments at Dryden, whether seedbed or transplant, are so equipped [2 5]. Triangular offset and square sprinkler-head layouts in the solid set system are compared for seedbed (Figs. 4b, c) and transplant (Figs. 4d, e) compartments at Thunder Bay; these layouts can be interchanged to accommodate specific crop types. All of these are used here to illustrate how sprinkler layouts may be designed.

Compartments at Dryden are 200 ft (60 m) wide and 450 ft (137 m) long and are serviced by four 3-inch (7.6-cm) polyvinyl chloride (PVC) lateral lines spaced 52 ft (15.8 m) apart. The two outer lateral lines are fitted with 11 #25 Rain Bird® impact sprinklers [21, 22], spaced 40 ft (12.2 m) apart, each delivering 4.03 U.S. gallons (15.3 liters) of water/minute at 50 psi (345 kPa) over a 20-ft (6.09-m) radius; nozzles are 3164 inch (3.6 mm). The two inner lateral lines are fitted with 11 #30 Rain Bird" impact sprinklers spaced 40 ft (12.2 m) apart, each delivering 6.84 U.S. gallons (25.9 liters)/minute at 50 psi (345 kPa) over a 48-ft (14.6-m) radius; nozzles are 5/32 by 3/32 inch (4.0 by 2.4 mm). Thus, the rate of application over the whole compartment averages 239.14 U.S. gallons (905.2 liters)/minute [(22 x 4.03) + (22 x 6.84)].

The rate/minute/unit area applied to a Dryden compartment (Fig. 4a) can be more usefully expressed:

(a) $\text{U.S. gallons/minute/acre} = \dfrac{43{,}560 \text{ ft}^2 \times 239.14 \text{ gal.}}{200 \text{ ft} \times 450 \text{ ft}} = 115.7$

(b) $\text{Liters/minute/hectare} = \dfrac{10{,}000 \text{ m}^2 \times 905.2 \text{ L}}{61 \text{ m} \times 137 \text{ m}} = 1{,}083.2$

where $43{,}560 \text{ ft}^2 = 1$ acre and $10{,}000 \text{ m}^2 = 1$ hectare.

(c) $\text{Inches/hour/acre} = \dfrac{43{,}560 \text{ ft}^2 \times 60 \text{ min} \times 239.14 \text{ gal.}}{200 \text{ ft} \times 450 \text{ ft} \times 27{,}154} = 0.256$

(d) Centimeters/hour/hectare =

$\dfrac{10{,}000 \text{ m}^2 \times 60 \text{ min} \times 905.2 \text{ L}}{61 \text{ m} \times 137 \text{ m} \times 100{,}000 = 0.65} = 0.256$

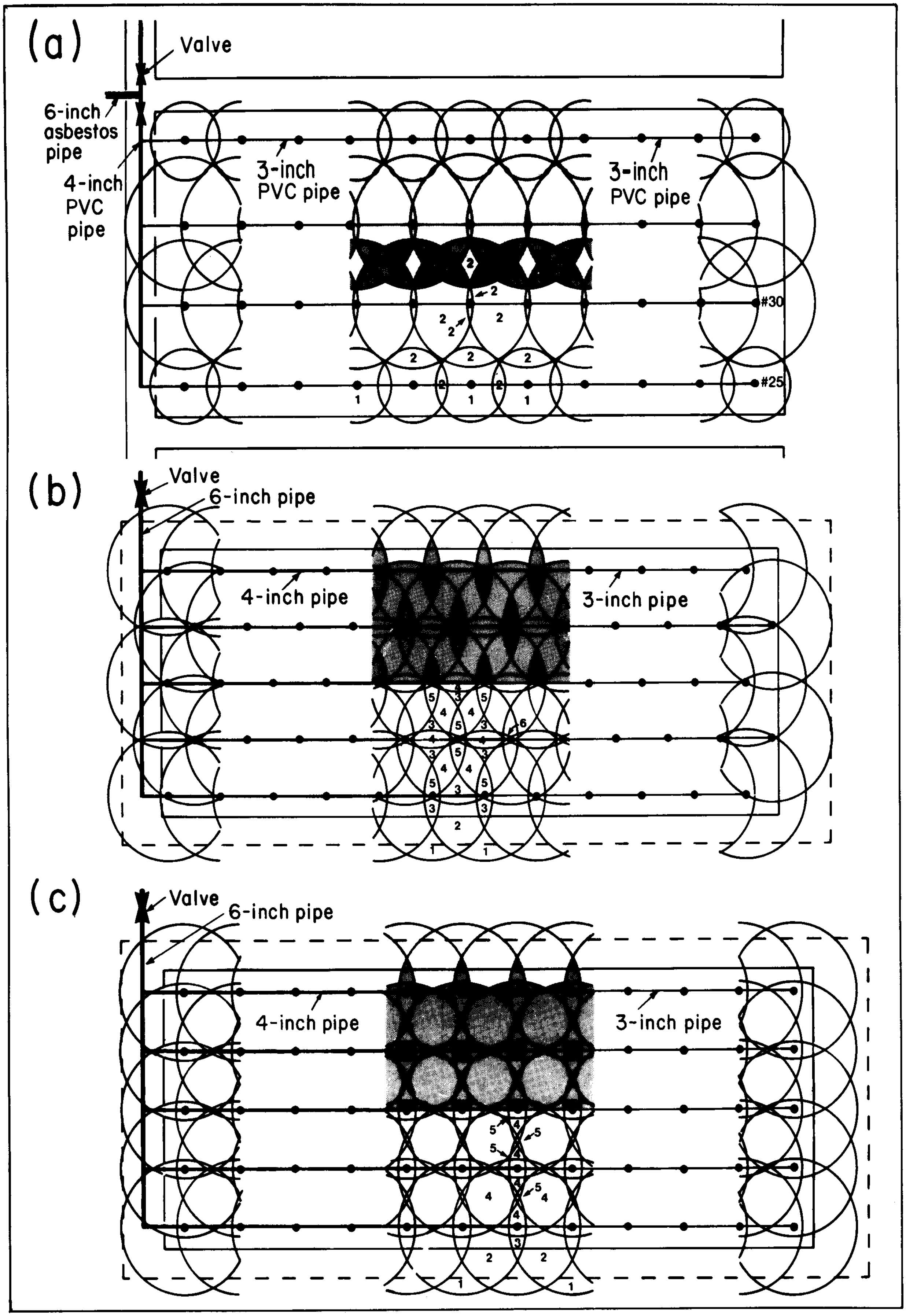
where 27,154 is the factor used to convert U.S. gallons/acre to inches, and 100,000 is the factor used to convert liters/hectare to centimeters.

The lateral header lines supplying the Dryden compartments are made of 4-inch (10.2-cm) PVC pipe. These are connected to 6-inch (15.2-cm) cement asbestos compartment header lines, which in turn are connected to 8-inch (20.3-cm) ductile iron looped main lines and a PRV. Finally, the PRV is connected to the 10-inch (25.4-cm) ductile iron main line and the pumps. Two electric 75-hp vertical turbines (see Fig. 2) able to deliver 1,700 U.S. gallons (6,435.0 liters)/minute are used, permitting approximately seven 2.0-acre (1.2-ha) compartments (1,700/239 gallons, or 6,435/905 liters) to be irrigated simultaneously.

The sprinklers in all the Dryden compartments are arranged as those shown in Figure 4a, regardless of whether the compartments are used for seedbeds or transplant beds. The distance between sprinklers is small enough to provide sufficient overlap, but the overlap clearly will be greater in the center of the compartment than at the edges; in practice, this tends to cause a wet strip in the center and, possibly, dry edges.

To irrigate seedbeds, Thunder Bay sets out five laterals spaced 40 ft (12.2 m) apart. Each lateral is equipped with 12 #30 Rain Bird® impact sprinklers [21, 22] at 30-ft (9.1-m) intervals, arranged in a triangular offset pattern (Fig. 4b). Each sprinkler delivers 10.9 U.S. gallons (41.25 liters)/minute at 55 psi (379 kPa) over a 48.5-ft (14.8-m) radius; nozzles are 3/16 by 1/8 inch (4.8 by 3.2 mm). Figure 4c shows a similar layout except that the sprinklers are arranged in a square pattern. Although it may be argued that triangular offset spacing provides more uniform irrigation than square spacing, comparing Figures 4b and 4c suggests this is not so.

To irrigate transplant beds, Thunder Bay sets out three laterals spaced 60 ft (18.2 m) apart. Each lateral is equipped with eight #70 Rain Bird® impact sprinklers at 70-ft (21.3-m) intervals, arranged in a triangular offset pattern (Fig. 4d). Each sprinkler delivers 13.7 U.S. gallons (51.85 liters)/minute at 55 psi (379 kPa) over a 60.5-ft (18.4-m) radius; nozzles are 7/32 by


(a)
Valve
6-inch asbestos pipe
4-inch PVC pipe
3-inch PVC pipe
3-inch PVC pipe
#30
#25
(b)
Valve
6-inch pipe
4-inch pipe
3-inch pipe
(c)
Valve
6-inch pipe
4-inch pipe
3-inch pipe

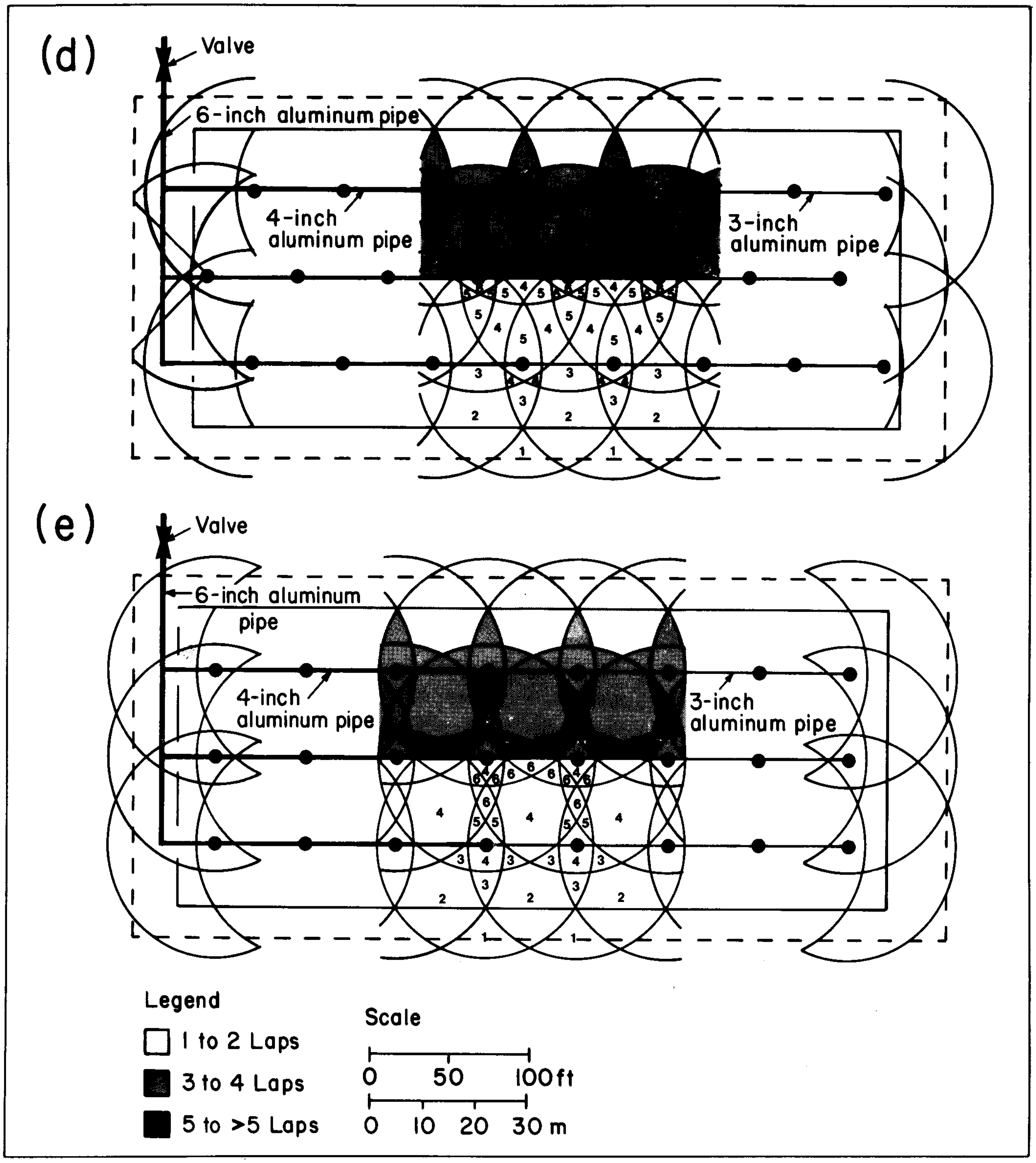



**Figure 4. Sprinkler irrigation layouts at the Dryden and Thunder Bay Forest Stations: (a) fully permanent, square-spaced system for seedbeds or transplant beds at Dryden: (b,c) solid set system for seedbeds at Thunder Bay for (b) triangular offset and (c) square patterns; (d e) solid set system for transplant beds at Thunder Bay for (d) triangular offset and (e) square patterns. See text for all system specifications.**

11/64 inch (5.6 by 4.4 mm). Figure 4e shows a similar layout except that the sprinklers are arranged in a square pattern. Again, comparing Figures 4d and 4e shows that differences in overlap and uniformity between triangular and square arrangements are minimal.

In addition to versatility in arrangement of lateral lines and sprinkler heads, solid set and semipermanent irrigation systems permit changes in riser height to accommodate crop growth. When the crop is young (e.g., 1+0 seedbeds), the risers can be set close to the ground surface to minimize wind effects; as the crop matures (e.g., 2+2), taller risers can be used.

### 11. 5.3.8 Local wind characteristics

Local wind conditions may affect sprinkler-system design. Tests of sprinkler heads and determination of their distribution curves have shown that the maximum distance between sprinklers under normal wind conditions-winds less than 6 mph (10 kph)-should riot be more than 60% of the diameter of the area covered by the sprinkler head. The following percentages are recommended for sprinkler heads:

| | Mean wind speed, mph | kph | Spacing, % of irrigated diameter |
|---|---|---|---|
| Nil | 0 | 0 | 65 |
| Up to | 6 | 10 | 69 |
| Up to | 8 | 13 | 50 |
| Above | 8 | 13 | ≤ 30 |

On nurseries that experience high winds, a large number of small sprinkler heads are preferable to a small number of large ones. For winds in excess of 8 mph (13 kph), the distance between sprinklers should be reduced to 20 ft (6.1 m) to ensure adequate overlap.

# 11.6 Conclusions and Recommendations

The facts presented in this chapter should make nursery staff more aware of the need to plan a proper water-management program and to match it with an irrigation system that can implement it.

If planning such a program indicates a need for a new or modified irrigation system, nursery managers should solicit the assistance of an irrigation engineer in designing or modifying the system. Comprehensive knowledge of the water requirements for irrigation and all other water-management purposes and a basic understanding of sprinkler-system design are essential for all nursery managers, especially if they are to cooperate with the consulting irrigation engineer.

The following steps are recommended for nursery managers planning a new irrigation system or renovating an inadequate one:

- Determine the nursery's water requirements for all water-management purposes by using tables or, better, by calculation with the Thornthwaite method. Be sure to use the water requirements of the driest years on record as the basis for determining the maximum amount of water that may be needed.
- Determine the maximum quantity of water that will be needed for all water-management purposes on the nursery, even in the driest years.
- Determine the quality of the water supply to be sure that it meets the standards for acceptable crop growth; be sure to check quality of stored or impounded water, especially in the driest season.
- Determine the infiltration rate of water into the nursery soil over the optimal soil-moisture range for growing seedling crops.
- Select the type of sprinkler system most suited to the individual nursery; a fully permanent, solid set, or semi-permanent rotating sprinkler system is recommended.
- Select sprinkler heads and design sprinkler layouts that will be optimal for supplying irrigation water to each compartment at rates slightly lower than the infiltration rate. Be sure that the sprinkler-head layouts and riser heights are (1) matched to crop types, (2) can operate satisfactorily in the winds that prevail on the nursery, and (3) are optimal for water-management purposes *in addition* to irrigation.
- Determine how many compartments are to be irrigated at one time and design the pipelines and pumping system needed to supply them. Be sure to allow for future nursery expansion—it almost always occurs.
- Consult and cooperate with an irrigation engineer in planning the best bareroot-nursery irrigation system your budget will permit.

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