Chapter 13

Land Drainage

D. E. Boyer

Abstract

Under certain nursery soil conditions, land-drainage improvements and surface-water control can enhance seedling quality and production and provide greater operational flexibility. Good drainage minimizes soil compaction, allows maintenance of proper soil chemical and biological conditions, reduces surface runoff and erosion, decreases nutrient losses, and diminishes occurrence of soil pathogens. However, water management can be complex because sources of water include surface water from adjacent lands, paved areas, and wheel tracks; subsurface flows; and seasonal or perennial water tables. Good drainage-system design and installation rely on careful and complete analysis using all available resources, including aerial photography, topographic maps, field-by-field observations, and expert technical assistance.

13.1 Introduction

Due to the typical location of conifer nurseries and the nature of their operations, adequate surface and subsurface water drainage is a common concern (OSU Nursery Survey; see chapter 1, this volume). The percentage of land within the nursery that can receive, store, and transmit water for plant growth is usually out of balance with those areas causing rapid runoff or ponding such as roads, wheel tracks, and buildings. This frequently results in surface erosion, sediment production, and wet spots. Surface erosion and sediment production are often subtle expressions that are easily overlooked or accepted as part of the cost of doing business. However, wet spots impair trafficability and productivity because machinery can become mired down and operations disrupted, or seedling growth can be retarded.

Nursery soil-management techniques should take into account the source, quality, quantity, and timing of all waters added to the site. The natural or altered physical properties of the soil and its ability to utilize those waters are of equal importance. Because water quality is seldom a major problem in the Northwest, this discussion will be confined to other factors.

In this chapter, the impacts of poor land drainage and surface-water control are discussed and some typical drainage problems presented so that nursery managers may better combat the conditions they are likely to encounter and understand the management implications of land-drainage improvements.

13.2 Drainage Impacts

The physical properties of soils largely dictate their internal drainage characteristics. Two important properties—infiltration rate (the ability of a soil to absorb water) and percolation rate (downward movement of water through a soil)—can be affected by soil-forming processes and may be altered through heavy use (see chapter 6, this volume).

Under typical irrigation and cultivation practices, the most significant changes in physical properties take place in the wheel tracks between seedbeds and at the base of cultivation depths within seedbeds. When percolation rates are slow or become reduced, especially within seedbeds, the surface soil layer tends to stay moist for longer than normal periods. This condition affects biological and chemical properties within the seedbed; furthermore, the excess water can move laterally into the wheel-track zone, causing a loss of bearing strength necessary to support machinery. But maintenance or improvement of existing physical characteristics, along with careful surface-water management, can protect or enhance productive-ity and operations.

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.

13.2.1 Detriments

- **Greater soil compaction:** When subjected to continuous cultivation or frequent machinery traffic at optimum moisture contents, even the most resistant soils can become densified to the extent that internal drainage rates are diminished. Densified layers can form at the soil surface, where machinery wheels contact soil, and extend downward, or they can form at the base of the tillage operating plane. For example, rototilling at optimum moisture levels but repetitious depths can create a densified layer, commonly referred to as a "traffic pan" or "plow sole," at that depth: this layer can extend downward nearly twice that depth. Under such conditions, soil water contents can reach a saturation level above the densified layer whereby most of the pore space is filled with water and soil air is excluded.

- **Impaired chemical and biological conditions:** Detrimental effects of saturated soils are: (1) low pH levels and excess soluble manganese, which can become toxic to plants: (2) retardation of organic matter decomposition and mineralization of organically bound nutrients: (3) release of organic sulfur as toxic hydrogen sulfide; (4) denitrification, which converts nitrates to volatile forms of nitrogen (N) that are lost from the soil: and (5) promotion of pathogens [4].

- **Increased runoff and erosion:** When infiltration rates are reduced, the opportunity for surface runoff increases dramatically. Erosion may not be significant within the wheel-track zone, where this condition would be expected to occur, but runoff waters can either inundate adjacent areas or provide the energy to cause erosion on downslope areas. In seedbeds where percolation rates are diminished, soils become increasingly wetter, lose their resistance to detachability, and increase their susceptibility to transport.

13.2.2 Benefits

- **Enhanced operational efficiency:** Well-drained soil profiles can permit considerable flexibility in tractor access. Installing a shallow drainage system with closely spaced pipelines, along with soil-management practices such as subsoiling, can increase downward water movement. For example, one nursery manager reported that after the installation of his drainage system, he could enter his fields within 24 hours after a heavy rain-as opposed to a week previously [pers. commun., 3]. This particular system was installed 36 inches deep, on a 20-ft spacing, in sandy, flood-plain soils whose water table was associated with a rise in streamflow levels.

- **Warmer soil temperatures:** Properly drained soils warm earlier in the spring, permitting earlier sowing. Wet soils warm more slowly because water requires 4 to 5 times more heat to raise a unit weight 1 ° than is needed for the same weight of mineral soil. Plant growth and all chemical reactions are slowed approximately 25% for each 10°F that temperature drops [2]. Lyon et al. [6] reported that inadequately drained surface soil may be from 5 to 15°F cooler than contiguous areas relieved of excess water.

- **More uniform soil moisture:** Proper drainage allows soil moisture to be distributed more evenly over the entire field, eliminating wet spots. This permits earlier, more predictable, and more efficient tilling [2]. Northwest soils are inherently variable in their water-transmission characteristics. Layered soils with different textures and structure can temporarily restrict water movement. However, drainage installations with closely spaced pipelines favor the disruption of these layers and increase downward water movement. The net result is a soil profile uniform in moisture content.

- **Decreased soil-N losses:** Saturated soils create anaerobic (lacking oxygen) conditions which favor denitrification. Although some N is lost through the drainage systems themselves, most of those losses are not nearly as significant as the ones attributed to the combined effects of denitrification and lack of oxygen in wet soils.

- **Fewer soil pathogens:** Some diseases are particularly enhanced by excessive soil moisture or an irregular water supply-for example, Pythium and other damping-off fungi [8]. Well-drained soils tend to favor a balanced mixture of biotic populations, rather than to promote a few species.

- **Reduced surface erosion:** The loss of topsoil and the effect of that loss on productivity are difficult to assess. At present, the U.S.D.A. Soil Conservation Service has proposed soil-erosion tolerance levels for agricultural lands which allow from 3 to 5 tons/acre/year of topsoil to be lost. Considering the value of conifer nursery land and the fraction of an inch that it takes to produce 5 tons of topsoil, that level of loss may be more than the nursery manager is willing to accept. Erosion can be reduced on a well-drained soil by increasing the soil's capacity to hold water, thereby reducing runoff.

13.3 Common Drainage Problems and their Remedies

The solution to an excess water problem usually defies a "cookbook" approach. Most solutions are site specific. In addition to the technical aspects of drainage design and installation, there are often political or legal considerations, especially where the contributing lands and the receiving lands are not under one ownership.

Various problems and their possible solutions are offered here as examples. Although each problem requires a different investigation and design approach, all have this in common: the source of the excess water must be located and the feasibility of diverting or relieving it determined.

13.3.1 Surface water

The main objective in handling surface waters is to move them off the nursery site as quickly as possible without impairing the water quality of any receiving streams.

13.3.1.1 From adjacent lands

Nurseries located immediately downslope from steep uplands often experience surface-water runoff, as do lands subjected to some cultural practice such as grazing. Runoff may be from confined water flows, such as small creeks or drainageways, or from unconfined flows, such as slope wash or seepage.

This condition usually calls for a diversion system or physical structures to carry water through or around nursery beds. In one instance, surface water originating from an upslope watershed was confined to a channel that discharged water, at peak flow, onto the nursery: at low flows, it disappeared into the channel and emerged downslope as seepage. The recommended solution was to capture and contain the water in a concrete ditch, diverting it to an off-site discharge point. This corrective measure was expensive but appeared to be the most efficient and effective [1].

13.3.1.2 From paved areas, wheel tracks, and buildings

These sources of runoff, which also may be from confined or unconfined flows, probably account for most of the drainage problems within Northwest nurseries. As such, they offer the greatest opportunity for imaginative solutions.

Water collected on roads or in "permanent" wheel tracks has to be discharged somewhere but, unfortunately, often ends up in nursery beds or pools on roads (Fig. 1). In some situations, roads can be constructed so that they slope toward the center line, collecting and transporting the water off site. If the volumes of water are significant, a sediment pond also may be needed before the water is discharged into a stream. In some nurseries, surface erosion accompanies excess water accumulations. Remedies might include grassed waterways or temporary dams made of plastic-tied straw bales. Sandbagging has also been used at the end of seedling beds but can interfere with traffic movement; the bags should be small enough so they can be moved out of the way when necessary. In one nursery, water from seedling beds discharged onto perimeter roads and caused wet spots. It was recommended that the perimeter roads have constructed rock dips in the travel way to allow passage of water while maintaining a running surface for vehicles [1].

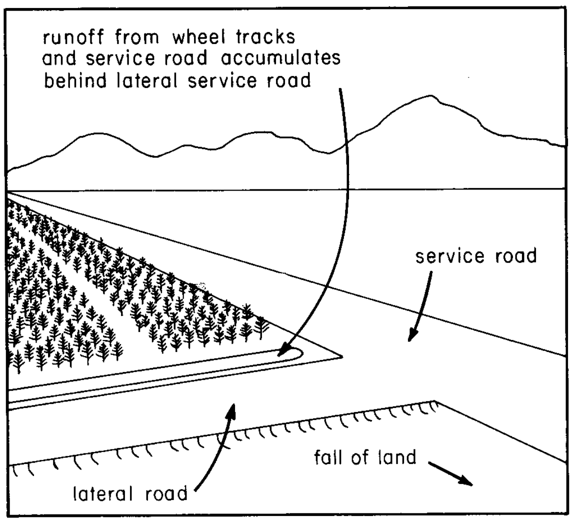

Figure 1. Surface-water collection against a service road.

13.3.2 Topographic depressions

Because land-forming processes seldom produce perfectly shaped landscapes, depressions are a common occurrence. Included in this category are man-made depressions, or catchments.

Although extensive land leveling is generally not recommended due to its negative impacts on soil nutrients, it is often advantageous to grade and smooth land to achieve uniform water application and eliminate the possibilities of surface-water accumulation. Occasionally, however, extensive leveling may be necessary; when the nursery manager is faced with this situation, the topsoil should be removed, stockpiled, and reapplied. Even though this is an expensive practice, it will pay in the long run.

Smoothing is simply the elimination of minor ridges and depressions in the field without altering the general topography. Smoothing usually requires 2 years to complete: land is graded and smoothed the first year and then graded and smoothed again the second year, after the soil has settled. The quality of the smoothing is best viewed immediately after a storm [2]. If puddles persist, the smoothing is not adequate and should be redone, provided that irregularities in topography—and not compaction-are the culprit. At any rate, any existing depressions should be investigated to see if soil is draining adequately: if it is not, a subsurface drainage system may also be required.

13.3.3 Subsurface water from adjacent lands

Some of the landforms large enough to support a nursery are also known for having unpredictable subsurface water flows; alluvial-colluvial fans and toeslopes are the most common landforms encountered (Fig. 2). Subsurface flows include seepage from ditches, reservoirs, and high-gradient streams. Usually, these water-table conditions are localized and have a gradient or hydraulic head behind the water flow.

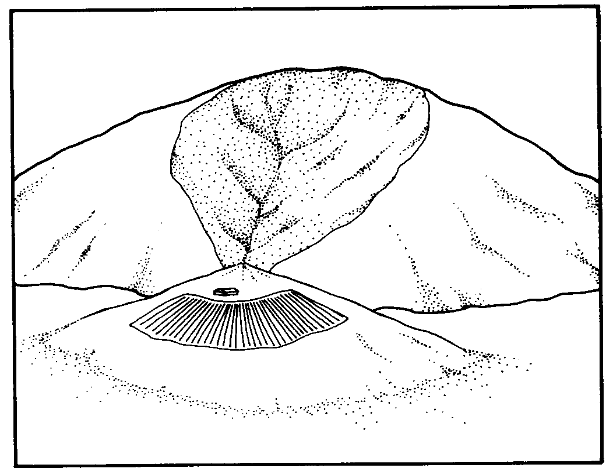

Figure 2. Nursery located on an alluvial-colluvial fan at the base of a watershed.

The normal intent of subsurface drainage is to lower the groundwater level in the soil or to prevent waterlogging from seepage. Two principal types of systems are used: open and closed. Open systems consist of one or more ditches that border or transect the land being drained; they are continuous and have a disposal system that carries the water to a natural drainageway. Closed systems, for the most part, consist of interconnected pipelines located below the water-table level, where they can collect and transport water to an open drainageway [4]. Heavy-textured soils, composed of expanding clays, can only be drained by open systems. However, because most Northwest nurseries are not located on clayey soils, this discussion will concentrate on closed systems (OSU Nursery Survey). Further, the maintenance problems associated with open ditches (e.g., weeds and rodents) are so numerous that such systems are usually discouraged.

There are two main types of closed systems: interception and relief. Interception systems are common for handling subsurface water from adjacent lands but are usually confined to small land areas. They may consist of a simple line of pipes located at the seepage source or the lower edge of an off-site slope, or they may have complex grids. Interception drains are similar in effect to surface drainage systems in that they remove water before it enters the soil. In contrast, relief systems drain already saturated soils. They may consist of a single pipeline or a complex grid, depending upon the size of the affected area, and can be installed in isolated depressions or soft spots that might be remedied by land smoothing. Whether for interception or relief systems, complex grids may have parallel, gridiron, or herringbone patterns (Fig. 3). The lay of the land, direction of subsurface water flow, and irregularities of subsoil characteristics dictate the layout to be used.

Drainage spacing and depth are functions of soil characteristics, chiefly percolation, and the type of drainage problem encountered. Pipeline size is a function of inflow rate and should also be determined on site.

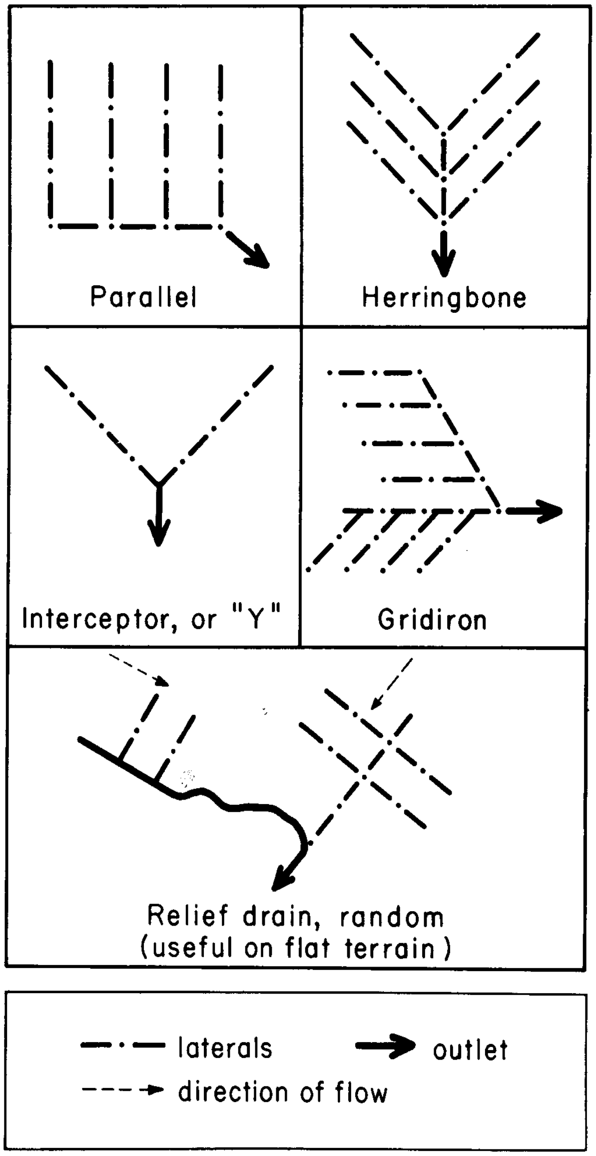

Figure 3. Typical drainage patterns (adapted from [4]).

13.3.4 Seasonal or perennial water table within the plant influence zone

The plant influence zone is usually considered to be the upper 5 feet of soil. In the Northwest, wetting of this top 5 feet is not uncommon because of abundant rainfall and irrigation. Seasonal or perennial water tables within the plant influence zone are most prevalent on flat-lying terrain adjacent to a body of water, such as is found in valley-fill positions (Fig. 4). The water flow is of a low gradient and usually fluctuates in response to changes in streamflow or lake level.

Intercepting water that moves in response to changes in streamflow or large expanses of water-table intrusion are considerably more complicated than other drainage problems because the required drainage system must have a discharge outlet lower than the system itself. On flat-lying terrain, this is often difficult to achieve. In one case, the elevation for an outlet was not suitable, and a sump basin with a pump was recommended. For these conditions, an open ditch also may be an alternative.

13.3.5 Impeded or slow water movement within the soil profile

This particular condition is common to "perched" water tables but may also affect soils that are naturally or artificially compacted (Fig. 5). Where downward drainage is blocked by an impermeable layer, a perched water table may form. If a perched water table exists, a complex grid with closely spaced pipelines may be the best drainage solution. If the soil conditions are not as severe as in the perched water-table situation but seasonal saturation occurs, there are new advances in drainage design that offer "controlled" water levels. Pipelines may be installed according to a variety of patterns (see Fig. 3) at shallow depths, depending on the crops to be grown and the cultural practices to be used. These shallow-depth drainage systems with closely spaced pipelines offer some potential in nursery fields where the timing of operations is critical. Furthermore, an elaborate field investigation seldom is needed for designing such systems, although several factors, such as slope available to the drainage lines, total acreage to be drained, and desired water-removal rates, need to be determined. Water-removal rates (i.e., drainage coefficients) of 1/2, 3/8, and 1/4 inch in 24 hours-the basis for agricultural lands-would be sufficient for nurseries. For example, for a 40-acre field on a 2 ft/1,000 ft slope, the 1/4 inch/24-hour rate would require an 8-inch main drain line, and the 1/2 inch/24-hour rate a 10-inch main drain line.

Drainage of seasonally saturated soils may be expensive but can provide benefits that include early sowing and flexibility in late-season entry. Successful systems have been installed in nurseries and filbert orchards on deep, moderately well-drained Willamette Valley soils that did not truly have perched water tables.

In any drainage-system installation, it is important to recognize that the soil around the pipeline must be saturated before water will flow into the pipeline. If soil saturation occurs for only brief periods, deep ripping may be a better solution than a drainage system.

13.4 Identifying Drainage Problems

If a drainage problem is suspected, a field investigation should be initiated to determine which one or combination of possible soil-water or environmental conditions is causing the difficulty (see 13.3). To gain an overview of the entire situation, both small- and large-scale aerial photographs should be obtained. In addition, topographic maps with the most usable

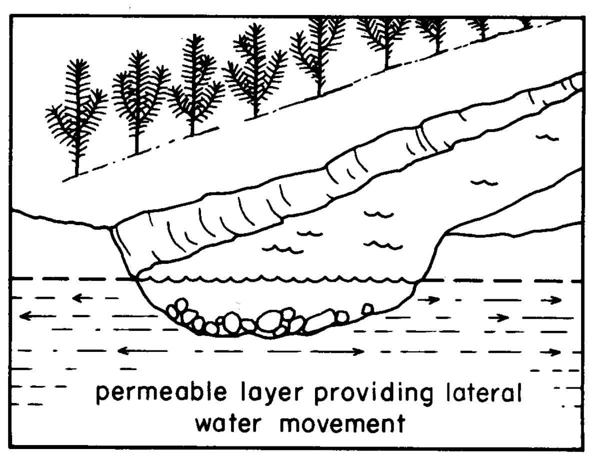

Figure 4. Streamflow within a valley creates lateral flow of subsurface water through permeable strata during high runoff periods.

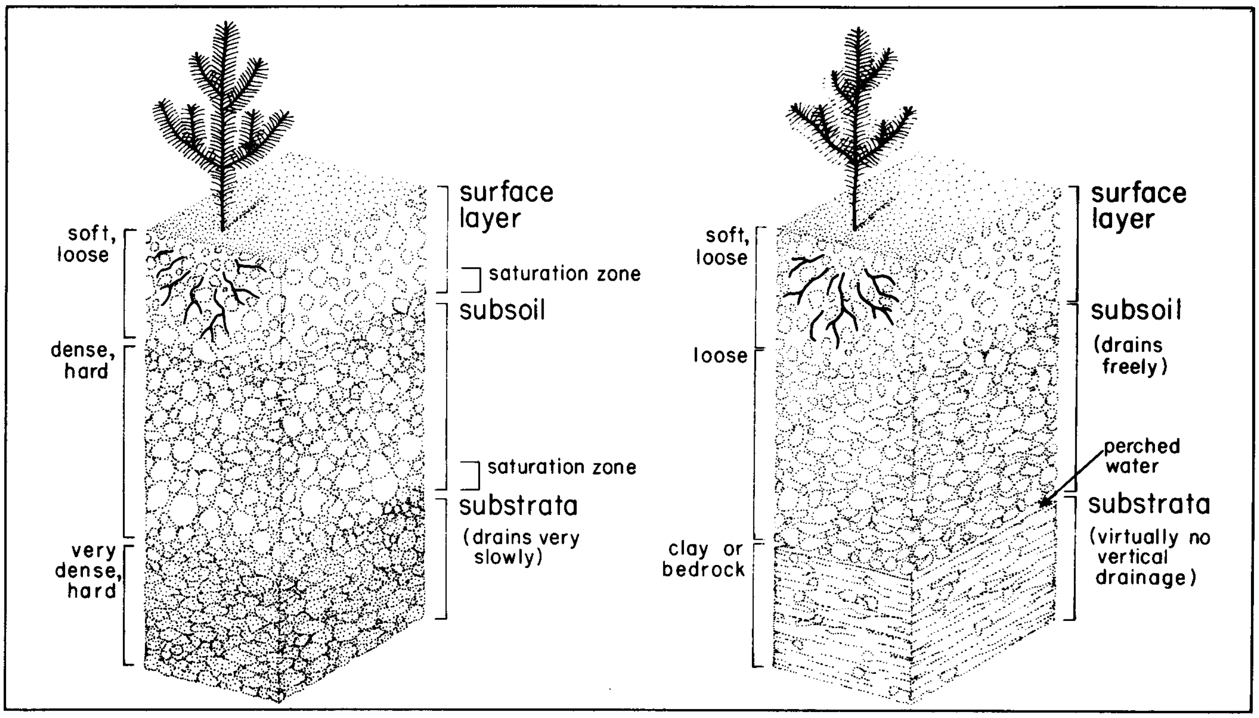

Figure 5. Physical properties of two typical Northwest soil profiles and their effects on water movement.

scale available are a valuable supplemental source of information in heavily wooded areas such as those west of the Cascade Mountains.

13.4.1 Off-site effects

Occasionally, problems at a particular site can be related to distant, off-site conditions, especially in mountainous terrain. Utilizing small-scale (1:60,000 or 70,000), high-altitude, aerial photography, the nursery manager can speculate on the contributions of runoff waters from lands adjacent to the nursery site (see 13.3.1.1). Stereoscopic viewing at this scale can aid in identification of possible sources of excess water. For example, in one nursery, it was determined that runoff from roads located upslope and 3/4 mile from the affected fields was collected and discharged through permeable subsoil layers and surfaced midway downslope—in the nursery. This source of runoff could have easily been overlooked had the manager studied on-site conditions only. Similarly, the transmission of waters from distant or upslope watersheds into alluvial-colluvial fans or toeslopes (see Fig. 2) lacking well-defined channels can be a hidden source of drainage problems. Water will follow old, obscure channels and emerge as seepage [1].

Managers of nurseries located in valley-fill positions can also profit from studying aerial photos, which reveal changes in stream gradients, streamflow configuration, and old meanders. If the stream gradient is nearly level above or adjacent to the nursery site, subsurface flow into the nursery can be anticipated; but if the stream gradient slopes away from the nursery, the opportunity for subsurface flow is not as great. Streamflow configuration can indicate possible water movement from upstream or sidestream channels. Sinuous or meandering streams frequently have higher water-table levels within the adjacent lands than do "straight" streams. Old meander channels are often hard to detect on the ground but are usually observed in tonal differences as well as topographic depressions on aerial photographs.

13.4.2 On-site areas

Topographic maps, in combination with large-scale (1:15,840) aerial photography, are useful for identifying depressions where water is likely to collect. A closer examination may also be needed to determine how well a depression drains (see 13.4.3). Depending on the size of the nursery, it could be a worthwhile investment to have a topographic map constructed on a 100-ft grid. A well-prepared topographic map can also be used for other purposes, such as field and irrigation-system layout or traffic patterns.

Service-road and wheel-track runoff, as well as excess water from buildings and parking lots, should be inventoried to identify the disposition of all surface waters on the site. Obviously, the best time to evaluate this would be during a storm. However, sediment accumulations can be observed several days after a storm, provided that sediments are not cultivated or disturbed. Observations by field workers are also an important source of information.

13.4.3 Subsoil investigations

Subsoil and substrata conditions are evaluated by traversing the land and boring holes in the soil. Borings can be made randomly or according to an established grid spacing. Large-scale aerial photographs may be the basis for selecting where the random borings should be made according to changes in topography or tonal expressions on the photos. If borings expose saturated soil conditions or free water within the top 5 feet, then a problem exists. Depending on their texture, good nursery soils should be capable of draining from a saturated condition to field capacity within a couple of days. Abrupt changes in soil texture and structure—which can be natural or induced by traffic-often indicate pronounced reduction in soil-water movement (see chapter 6, this volume).

Examining subsoil colors can be revealing. Blues and grays predominate in saturated soils in which insufficient oxygen causes soil minerals to be chemically reduced. Seasonally saturated soils usually show alternating streaks of oxidized and reduced materials, principally yellows to rusty reds. These are normally referred to as "mottled" colors and may extend upward into the surface layers.

Careful examination of the changes in texture and structure and of color differences can help managers approximate the elevation of a water-table level or fluctuation. To plot these, record the water level (as depth below ground line) when soil borings are made. Then take a second reading 24 hours later to see if the water table is stabilized or rising. A rise in levels could indicate a substantial hydraulic head behind the flow, as opposed to a static "pool." A hydraulic head might be alleviated by an interception system, whereas a static pool might be remedied by a relief system.

13.4.4 Determining the source or direction of flow

By preparing a ground-surface topographic map and overlaying this with a water contour map constructed in the same manner, a nursery manager can pinpoint the source of water or its direction of flow. This technique, particularly useful on sloping lands, requires that the field be staked on a 100-ft grid. Elevations at each grid point are determined and plotted; borings are then made at each grid point, and the elevations of the stabilized water table are determined. Both land and water-table contours are plotted in different colors. The result provides the information necessary for designing the point of interception, depth, and spacing of drain lines (Fig. 6). If the borings are carefully made and logged, such characteristics as dense subsoil layers, gravel lenses, or aquifers and bedrock can be noted. This information can also be plotted in cross section, which would be useful to the drainage-system designer and installer.

13.5 Subsurface Drainage Installation

Because most nurseries produce 2+0 seedlings on 1/3 of the nursery site, it may take several years to complete a drainage installation. Careful planning is essential so that nursery operations are not disrupted.

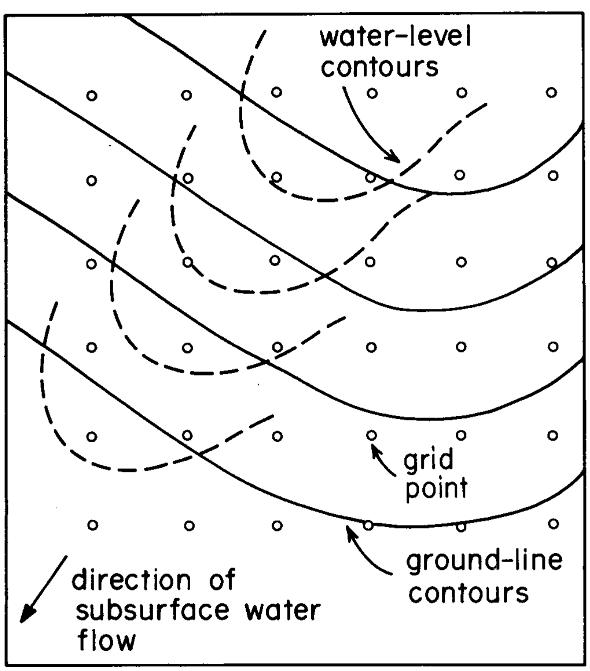

Figure 6. Surface and water-table contours plotted on a 100-ft grid.

13.5.1 Pipelines

Clay pipelines are still popular in some areas and work well as long as settling is not a problem. A clay or concrete pipeline may function satisfactorily for a century or more if properly planned, adequately constructed, and carefully maintained. Both clay and concrete are acceptable except in instances of strongly acid soils because the acids can dissolve the concrete or bonding.

A more recent innovation is plastic pipeline, or tubing. Tubing is corrugated for strength and perforated for infiltration efficiency. It can be quickly and accurately installed, especially by laser-guided machines—a single operator can easily lay over 4 miles of tubing daily with an alignment accuracy of within 1/8 inch. The problem of misalignment, so common with clay or concrete pipe, is eliminated because the tubing is continuous. Although laser-guided laying equipment is expensive, installation is rapid, particularly in large fields, and the final costs are competitive when compared with those of conventional trenching equipment.

Strength and durability of the selected pipeline are major considerations. Loads created by backfilling and, in some cases, surface loading must be considered. The U.S.D.A. Soil Conservation Service requires a minimum of 35 psi crush strength before fracture. The crushing resistance of plastic tubing is directly related to the cross-sectional design at the corrugations, and stretching adversely affects this structural integrity. Latest specifications by the Soil Conservation Service and American Society for Testing and Materials allow minimum installation stretch of 5% on plastic tubing [5].

13.5.2 Excavators

Regardless of the system and the purpose, two methods of excavator installation are popular: "plows" and trenchers. The plow is a long shank, much like a subsoiler tooth, attached to the rear of a crawler tractor. Tubing is fed automatically behind the shank, causing very little surface disturbance and minimal soil settling. The trencher, an excavator on a continuous belt, leaves a trench that requires backfilling. As with the plow, tubing is fed into the trench automatically; after installation, however, the trench may settle, creating traffic problems for a year or two. Most drainage contractors in the Northwest are equipped with laser-guided systems on both plows and trenchers.

Backhoes also are sometimes used in excavator installations. Though convenient for small jobs, they are slower and less accurate in laying a grade and, therefore, usually more costly.

13.5.3 Filters

Most nursery soils in the Northwest need filters—either gravel envelopes or nylon fabric-to reduce pipeline siltation. Sandy clays, clay loams, loams, sandy clay loams, loamy sands, and sands require removal or blockage of particles that would otherwise deposit in the drain line and cause plugging; silt loams and silts require sand and gravel filters (nylon fabric is unacceptable). Clays, silty clays, and silty clay loams, however, do not need filters [7].

Minimum trench width for a conventional filter envelope of graded sand and gravel usually is the width of the pipe (outside diameter) plus 8 inches. Plastic tubing wrapped with bonded nylon fabric, however, requires only the trench width necessary for the size of the tubing used (Fig. 7).

13.5.4 Outlet protection

Drainage outlets must be designed to prevent entry by small animals. A grill or flap gate is good insurance. Where plastic tubing is used and where the outlet discharges into a ditch that is frequently burned or cleaned, a short section of metal pipe should be installed at the outlet to protect the tubing.

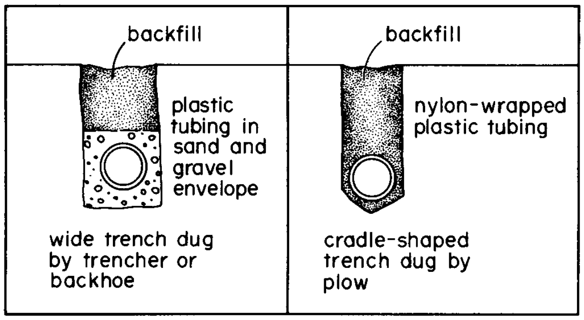

Figure 7. Typical filter systems (adapted from [5]). Note that nylon-wrapped plastic tubing allows a much narrower trench than tubing or pipe within a gravel and sand envelope.

13.6 Drainage Systems and Nursery Operations

13.6.1 Recycling drainage waters

The question often arises as to whether discharge waters should be collected and returned through the irrigation system. This practice sometimes is acceptable, but caution should be exercised. The water should be thoroughly analyzed to ensure that salt buildup does not create new problems for the nursery manager. Unfortunately, water quality is unknown until after a drainage system is installed.

Provisions could be made, however, to capture and recycle the water, if so desired. Salt concentrations can be diluted with normal irrigation water, or drainage water can be chemically desalinized. At this time, there is no known practical method of extracting pesticides from water. Therefore, recycling of water should not be relied upon until potential problems are identified and measures taken to correct them.

13.6.2 Ripping or subsoiling

A drainage system intended to intercept or relieve a water-table problem is usually installed at a depth of 3 to 5 feet. A system to correct temporary saturation conditions can be installed at 2 to 4 feet. However, installing a drainage system at these shallow depths could interfere with deep ripping or subsoiling. Moreover, if a nursery is suffering from a zone of densified or compacted soil, the shallow drainage system alone may provide only temporary relief.

The ideal soil-management program would consist of deep (24 to 30 inches) ripping to alleviate the compacted layers; then installation of drain lines at a depth (24 to 36 inches) more responsive to water movement; and, finally, shallow (12 to 16 inches) subsoiling when the land is lying fallow or is planted in cover crops. Development of a new compacted layer must be avoided if the shallow drainage system is to survive and function properly. A program to monitor compaction development could be initiated to alert the manager if the compacted zone approaches the subsoiler's capacity to perform. A shovel or probe would serve as the monitoring device.

13.6.3 Recommended management approach

Because a nursery may experience drainage difficulties for numerous reasons, the nursery manager must be able to recognize the severity and extent of any problem when planning and budgeting for its remedy. Managers are urged to analyze drainage problems using all available resources, initially with an overview approach, then with field-by-field observations.

Fortunately, free assistance is often available. Soil scientists and agricultural engineers from the U.S.D.A. Cooperative Extension Service. U.S.D.A. Soil Conservation Service, and U.S.D.A. Forest Service can provide investigative data and design criteria. Many Northwest drainage contractors are well qualified or employ agricultural engineers who are willing and capable of designing and installing a system that will perform as expected.

Nursery management is a complicated form of farming. So many factors are involved-from cone collection to outplanting. But nursery soils that are well drained can eliminate some of the negative or troublesome aspects of conifer production.

References

1. Boyer, D. 1977. Wind River Nursery land treatment plan. U.S.D.A. Forest Serv., Portland, Oregon. 44 p.
2. Donahue, R. L., R. W. Miller, and J. C. Shickluna. 1977. Soils, an introduction to soils and plant growth. 4th ed. Prentice-Hall Inc., Englewood Cliffs, New jersey. 626 p.
3. Gonzales, O. 1982. Personal communication, U.S.D.A. Forest Serv., Grants Pass, Oregon.
4. Hausenbuiller, R. L. 1978. Soil science, principles and practices. 2nd ed. Wm. C. Brown Publishers, Dubuque, Iowa. 611 p.
5. Jeffords, O. 1978. Drainage handbook. Advanced Drainage Systems Inc., Columbus, Ohio. 47 p.
6. Lyon, T. L., H. O. Buckman, and N. C. Brady. 1952. The nature and properties of soils. 5th ed. The MacMillan Co., New York. 591 p.
7. U.S.D.A. Soil Conservation Service. 1976. Washington, D.C. Advisory Memo ENG. WA-6.
8. Walker, J. C. 1950. Plant pathology. 1st ed. McGraw-Hill Book Co., Inc., New York. 699 p.