6

Evaluation and Modification of Soils

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With respect to soil requirements, walnuts are probably the most exacting of California orchard crops. They do best on fertile, deep well-drained, nonstratified loamy soils. Under ideal soil conditions, roots can be found to depths of 10 feet or more. Any soil condition, physical or chemical, that limits the rooting system or affects the health of the roots, directly influences the walnut tree's size and vigor.

In California, walnuts are grown commercially in many of the 58 counties. Most of the orchards are concentrated in the Sacramento and San Joaquin valleys, but substantial plantings are located in some of the Sierra Nevada and Coast Range foothill counties. Because of their wide distribution throughout the state, walnuts are grown on a wide variety of soils. These include upland soils developed from various rock types in the foothills of the Coast Range (fig. 6.1) and Sierra Nevada; valley soils formed on floodplains, alluvial fans, and fan terraces in the Central Valley (fig. 6.2) and in intermountain valleys; and soils formed on stabilized sand dunes, such as those near Delhi and Atwater, in the San Joaquin Valley. Many of these soils are well suited for walnuts, whereas others are marginal because of some limiting soil features or conditions.

This chapter addresses the desirable and undesirable physical aspects of soils selected and used to grow walnuts. Management needs related to soil fertility for walnuts are discussed in chapter 23. Limitations and management needs for growing walnuts in salt-affected soils are discussed in chapter 7.

SOIL EVALUATION

In evaluating the physical suitability of a parcel of land for growing walnuts, you need to know: (1) the kinds of soils on the property, (2) their characteristics, and (3) the effects or limitations the soil characteristics may have on potential walnut growth and production. A readily available source of soils information is the soil survey report of the area or county

Figure 6.1 Walnut orchards on volcanic upland soils in Lake County.

Figure 6.2 Walnut on floodplain soils along the Feather River. Note loss of trees in poorly drained low areas.

where the property is located. These reports are available through the county Farm Advisor's office; district and state offices of the Soil Conservation Service, U.S. Department of Agriculture; the Department of Land, Air and Water Resources, University of California, Davis; and local public libraries. By locating the parcel of land on the soil map, you can determine the dominant kinds of soils, their distribution, and acreage. For each kind of soil delineated on the map, there is in the report a detailed description of that soil map unit that describes its characteristics and other conditions, some of which may limit its use for walnuts and other crops.

The pattern of soils on any landscape is complex. Soil survey reports cannot depict every detail because of the limitation imposed by map scale. Quality control in the National Cooperative Soil Survey of the United States currently has a goal of 85 percent accuracy for delineations of identified soil map units in standard soil surveys of agricultural areas (order 2 surveys). Older soil surveys, some on smaller scale maps, often fall below this level. Other kinds of soils included, by necessity, in a soil map unit may be similar or dissimilar to the dominant identified soil. To meet present criteria, the included soils should be listed in the unit description and their estimated proportions given. The dominant identified soil within any delineation of a soil map unit may vary somewhat in its properties. This variability, however, should be within a defined range for the identified soil. In like manner, the properties of included subordinate soils can be expected to vary somewhat.

Before intensive land use it is always wise to check the kinds of soils mapped on a parcel of land. Do this by digging a number of safely designed backhoe pits to a depth of 5 to 6 feet and by judiciously scattering hand-augered inspection sites dug to a similar depth. By doing so, you will improve your understanding of the major soil differences, if any, shown by the soil map. In addition, you can determine the actual location and extent of any soils not shown by the soil map. Examination of the soil profiles in the backhoe pits and augered sites will help identify potential restrictive layers (claypans, hardpans, siltstone layers, or bedrock contacts), stratification in alluvium, waterlogging, salt problems, and other conditions. This knowledge can be very helpful in correcting potential problems before planting and in selecting rootstocks and varieties tolerant of the site conditions.

The most common physical soil properties or conditions that affect root development and limit growth of walnut trees relate to soil texture; soil depth to restrictive horizons, or layers; infiltration and percolation; aeration; water tables and waterlogging; flooding; and erosion.

SOIL TEXTURE

The term *soil texture*, and the class names commonly used to describe texture, refer to various proportions of the three primary particle sizes of mineral material that compose the fine earth fraction of soil. The three particles sizes are sand, silt, and clay. The term *fine earth fraction* refers to all mineral particles that have a general diameter of 2.000 millimeters or less. Sand particles range in diameter from 2.000 to 0.05 millimeters; silt particles range from 0.05 to 0.002 millimeters; and clay particles are 0.002 millimeters or less in diameter. Soil texture names may be modified if there are significant volumes of coarse fragments of rock present. Examples of modified names are *gravelly loam, cobbly loam*, and *stony loam*.

The growth and rooting patterns of walnut trees vary considerably with differences in soil texture. Stud-

Figure 6.3 This stratified floodplain soil with an abrupt interface boundary between a fine sandy loam surface soil and white sand subsoil that limits root development and water movement. Note the wet zone immediately above the sand layer.

ies of rooting systems of a number of walnut orchards growing on a variety of soil textures in Stanislaus County indicate that walnut trees root deeper and grow more vigorously on nonstratified medium and moderate fine-textured loamy soils than on fine-textured clayey, or coarse-textured sandy soils. The permeability of loamy soils (sandy loams, loams, silt loams, clay loams, and silty clay loams) is moderately rapid to moderately slow. In loamy soils soil moisture is highly available and adequate aeration favors optimum development of roots and tree growth.

The permeability of fine-textured clayey soils (silty clays, sandy clays, and clays) is slow to very slow, and due to low porosity aeration is limited. Because of the small size of the pores in clayey soils, water is held more tightly and drains less rapidly than in loamy or sandy soils. This decreases the air space in the soil and reduces the diffusion of oxygen (O_2) to the roots. When the soil dries enough to permit sufficient O_2 to reach the roots, it is then time to irrigate again. Rooting depth is shallower in clayey soils because aeration is poorer and O_2 becomes less available with depth.

Sandy soils (sands and loamy sands) drain rapidly and are well aerated. They are, however, droughty and contain limited nutrients. The relatively large pores in coarse-textured soils retain only a small amount of available soil moisture. If frequent irrigations do not compensate for moisture deficiencies, tree growth is stunted and yields are reduced. Because much of the rainfall and irrigation water percolates through sandy soils, nutrients are readily leached from the soil. Fertility management is needed to maintain an adequate level of available plant nutrients and to avoid possible groundwater contamination. Splitting the required amount of fertilizer into several frequent applications would be helpful.

Many recent (subject to seasonal flood deposition) and young (older than recent and normally not subject to flooding) alluvial fan and floodplain soils have stratified subsoil layers of different textures or are underlain by sandy substrata. If the stratified layers are highly contrasting—for example, if a fine sandy loam is abruptly underlain by a sand substratum (fig. 6.3)—and if the head of water in the soil above the substratum is insufficient to break the capillary fringe between the two layers, a temporary perched water table (or zone of saturation) may develop in the horizon *above* the sand. A perched water table that persists for any length of time will damage roots in the waterlogged zone. In root studies of walnut trees in loamy soils underlain by sandy materials in Stanislaus County, the late Farm Advisor Norman W. Ross found that the number of roots decreased sharply in the sandy substratum. The reduction was caused by limited available soil moisture and the low nutrient status of the sand.

Soil Depth

In most soils plants root effectively to a depth where a restrictive horizon or a substratum limits water movement, aeration, and root development. With valley soils, the impeding subsoil horizon is usually a dense claypan horizon or an indurated hardpan as well as textural stratification, discussed previously. In foothill soils, the rooting depth normally corresponds to the depth of soil to bedrock.

Figure 6.4 This compacted subsoil tillage pan in Columbia soil restricts root development. Note the horizontal concentration of roots.

The most productive walnut orchards in California are found on deep, well-drained, loamy soils on recent alluvial fans and floodplains. Representative examples of these ideal walnut soils are the Columbia, Grangeville, Hanford, Vernalis, Vina, and Yolo series in the Sacramento and San Joaquin valleys. Rooting is normally deep because these soils have no naturally compact subsoil layers to limit root development. However, over time, many of these ideal soils have developed compacted plowpans or traction pans from improper use of farm machinery. These compacted layers form close to the soil surface and can restrict depth of root development (fig. 6.4) and water movement.

Over thousands of years, soils develop dense subsoil horizons, such as claypans (fig. 6.5) or hardpans (fig. 6.6), that impede or restrict movement of water and air, and root growth. Claypans are tight, compact clay-textured horizons, in contrast to hardpans, which are naturally cemented rocklike layers. Some soils contain both horizons. The San Joaquin series, for example, contains a claypan above a hardpan.

The porosity of claypans is very low. Some roots will grow into a claypan, but the low porosity and small size of the pores limit adequate aeration for maximum root growth. Percolating water from winter rains and irrigations can build up above the claypan horizon to form a temporary perched water table. If waterlogging persists, root damage can occur.

A hardpan is a much more restrictive barrier than a claypan. It is a naturally rocklike layer that stops root development and is essentially impervious to water. Thus, the depth to the hardpan layer determines the trees' rooting depth. When percolating rain or irrigation waters reach the hardpan, a perched water table develops. Damage to the rooting system depends on the timing and persistence of the perched water table. Some valley soils, such as the Dinuba and Gridley series, have a siltstone substratum, a geologic substratum that acts much like a weakly cemented hardpan horizon. The depth to this restrictive layer is variable within short distances, and in many places it is discontinuous. The substratum varies in thickness and hardness.

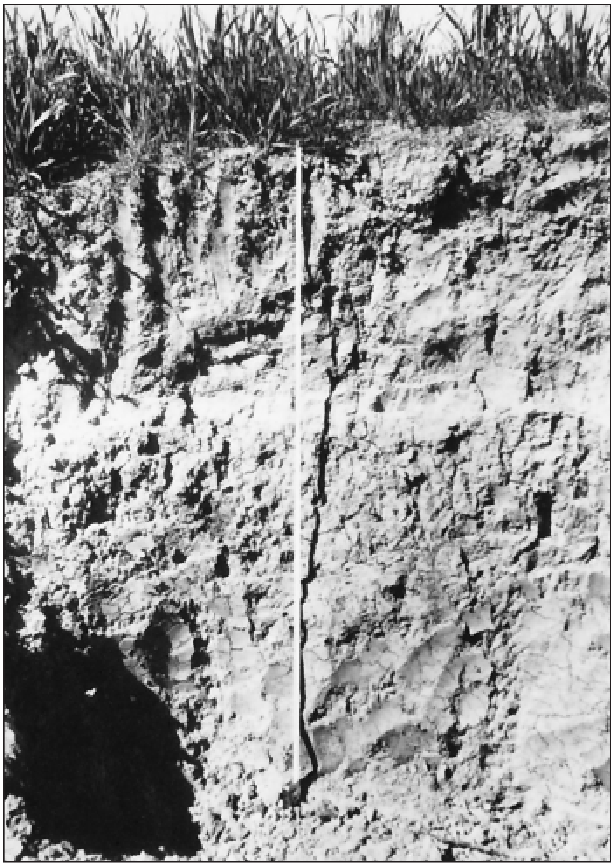

Figure 6.5 This dense clay subsoil horizon in the San Ysidro series is typical of claypan soils in California. This claypan layer at about 23 inches restricts root development and deep percolation of rain and irrigation waters.

Figure 6.6 This impervious hardpan layer in the Yokohl soils at a depth of about 2 feet limits root development and water movement. This rocklike layer can be broken up with deep ripping.

Infiltration and Percolation

The term *infiltration* refers to the entry of water into the soil at its surface. Cultural practices can affect the soil surface physically or chemically so that rates of water entry are markedly lowered because of crusting, sodic dispersion, or loss of organic matter. The term *percolation* refers to the continued downward movement of water through the soil profile. The term *water penetration* is often used to include both infiltration and percolation, usually to some soil depth. Still another term, *permeability*, is used to describe the relative ease with which water moves through the soil. A soil is called rapidly, moderately, or slowly permeable, depending on the rate of percolation through the soil profile. Table 6.1 shows the soil permeability classes used by the Soil Conservation Service. They are defined in terms of inches of water passing through the various textures in 1 hour.

In any soil, water moves through tubular pores previously formed by roots or soil-dwelling organisms and through spaces between soil particles or within masses of soil. Because soil particles attract water, films of water build up around them. When the soil is saturated, water moves through pores, progressively wetting particle after particle and building films around them as water continues to be applied at the surface. Although also referred to as pores, the spaces between particles should not be thought of as continuous tubes. Rather, they form an irregular network of interconnected spaces of various sizes and shapes. Water moves more rapidly through large pores than through small ones. In any soil there is a range of pore sizes that is referred to as its pore size distribution. A soil with a high percentage of large pores is rapidly permeable; a soil with mostly fine pores will have much slower permeability.

The soil texture and structure together affect pore size distribution. A soil containing mostly large particles has a high percentage of large pores; a soil containing mostly small particles has many small pores but may also contain a fair percentage of large pores because of the favorable effects of soil structure.

Soil structure is the aggregation of primary soil particles (sand, silt, and clay) into larger clusters or bodies called "peds" (fig. 6.7). The aggregates or peds are held together—sometimes weakly, sometimes rather strongly—by organic material, clay, and, occasionally, other binding materials. Various kinds of soil peds are classed as granular (rounded or subrounded masses), blocky (angular or subangular, nearly cubic masses), platy, prismatic, and columnar, depending upon their natural form. Prismatic and columnar peds are similar, vertically elongated, angular aggregates. Prismatic peds have flat tops; columnar peds have rounded tops. If no aggregates are present, the soil is described as single grain (incoherent, such as sand), or massive (coherent, but without structural form). Massive soils are sometimes porous, but often they are dense and provide a poor root medium. A medium-textured soil, such as a loam, with strong granular structure may have almost as many large pores between its granules as does a

Table 6.1 Soil texture classes and related permeability classes.

Texture	Textural class	Permeability class*	Permeability rate (in/hr)
Gravel Coarse sand	Very coarse	Very rapid	More than 20.00
Sand Loamy sand	Coarse	Rapid	6.00–20.00
Sandy loam Fine sandy loam	Moderately coarse	Moderately rapid	2.00–6.00
Very fine sandy loam Loam Silt loam Silt	Medium	Moderate	0.60–2.00
Clay loam Sandy clay loam Silty clay loam	Moderately fine	Moderately slow	0.20–0.60
Sandy clay Silty clay	Fine	Slow	0.06–0.20
Clay		Very slow	Less than 0.06

*The permeability classes shown above in relation to texture classes are only a general guide. Differences in bulk density may alter the cited rates.

sandy soil with weak or no structure. In addition, it will contain many fine pores within the granular peds; therefore it is an excellent root medium.

Soil Aeration

Air and water share the pore space in a soil. Between irrigations, water occupies the smaller pores while air fills the larger pores. During an irrigation, percolating water displaces part of the air occupying the pores. A soil with a favorable proportion of larger pores allows water to percolate readily while still providing sufficient space for the air roots need continuously. However, water entering a soil with a large proportion of small pores penetrates slowly and occupies a higher percentage of the total pore space. When less than 10 percent of the soil volume consists of air-filled pores, plant roots are susceptible to oxygen starvation. An uncompacted loam soil with a bulk density of 1.45 grams per cubic centimeter (g/cc) will have a total pore space of about 45 percent of the soil volume. Such a soil will be able to maintain greater than 10 percent air-filled pores at field capacity moisture content. The same soil compacted to a bulk density of 1.72 g/cc will have a total pore space of only about 35 percent. Since compaction has eliminated mainly the larger pores, the air space during and after irrigation will likely be less than 10 percent of the soil volume. If roots cannot get enough air, the plant may die even though it has ample water.

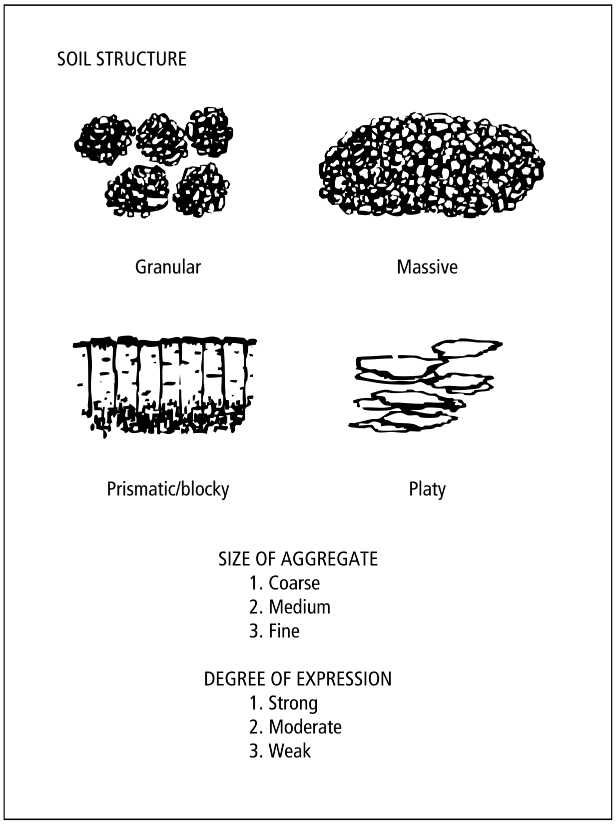

Figure 6.7 Examples of soil aggregates or peds. The kind, size, and strength of a ped varies with texture, organic matter content, depth, management, and mode of soil formation.

Water Tables and Waterlogging

Before planting walnuts, growers often fail to assess adequately the potential hazards or limitations of a high water table. In characterizing the hydrologic features of soils, two types of water tables are recognized: (1) a permanent, or stable, water table and (2) an intermittent, or fluctuating, high water table. Either type may be a long-standing, natural feature of the landscape or a recent feature human activity has imposed on naturally well-drained soils.

Where water tables of either type are natural features of the landscape, a characteristic soil color can usually serve as a clue to their presence within the bodies of soils. Soils with permanent water tables are commonly darker in the upper part of their profiles and have a higher content of organic matter than neighboring, better drained soils. In addition—and this is important—subsurface or subsoil horizons at and below the position of the water table have low-chroma colors: blue, green, or light gray. The colors reflect low oxygenation or, in other words, reducing conditions that act on iron minerals in the soil. The presence of an intermittent water table is indicated by horizons with reddish or yellowish mottles within a matrix of contrasting brownish or grayish soil. This reflects periodic reducing and oxidizing conditions as the water table rises and lowers, bringing about a mobilization and segregation of iron oxides. The surface soil colors may or may not be significantly darker and their content of organic matter may or may not be significantly higher than in nearby, better drained soils.

Root Disease. In soils with a permanent high water table, the depth of the tree's rooting system is limited to the depth of soil above the water table. Roots will not grow into the water table zone because of lack of aeration (oxygen). Thus, the water table level determines the depth of the soil reservoir that the tree's rooting system can tap for nutrients and moisture.

In the case of an intermittent or fluctuating high water table, time of occurrence and duration of waterlogging are as important as height of the water table itself. If the high water table occurs during dormancy and then drops below the rooting depth for the remainder of the year, injury to the rooting system will be minimal. Should the water table rise into the rooting zone after the tree breaks dormancy, chances for damage or injury to the roots are much greater. The extent of injury depends on the duration of waterlogging, amount of oxygen dissolved in the water, and soil temperature. Root damage increases with increasing duration of waterlogging and increasing soil temperatures. Flowing high water tables have greater aeration (exchange of oxygen) and are therefore less injurious than stagnant water tables.

Intermittent high water tables during winter and spring are usually related to high stream flows or river stages from storm runoff or, in late spring or early summer, mountain snowmelt. Summertime high water tables are most commonly associated with seepage from unlined irrigation canals, drainage ditches (fig. 6.8), or from neighboring crops, such as rice, that require large amounts of surface water.

When soils are excessively wet due to high water tables, slow percolation, overirrigation, or flooding, diseases may develop in walnut roots. Sometimes it is not easy to determine whether poor aeration or root disease bears primary responsibility for poor health or death of the trees. For a more complete description of problems specific to walnut roots, see chapters 27 and 28.

Figure 6.8 High water tables associated with seepage from drainage ditches and adjacent fields may result in stunted trees, as illustrated.

Figure 6.9 Debris left by floodwaters must be removed before normal cultural practices can continue.

Figure 6.10 Sand and silt deposits left in an orchard by floodwaters often require releveling or removal of the sediments.

Flooding

Some of California's most productive walnut orchards are located on floodplains along the major creeks and rivers of the Coast Range and the Central Valley. Most streams have been leveed to prevent flooding of adjacent lands. Lands that lie within the levees are generally subject to periodic flooding during winter and early spring. In years of heavy runoff, the lands may be flooded several times during the wet season; in dry years, they may not be flooded at all. The flood damage an orchard sustains due to inundation depends upon the trees' stage of growth and the duration of the flooding.

Flooding results in debris, deposition, and scour. Uprooted trees and trash floating in floodwaters can be carried into orchards when the streams overflow their banks. Much of this debris may be left behind when the floodwaters recede, requiring expensive cleanup (fig. 6.9). Trees often suffer physical damage (scarred trunks, broken limbs, or uprooting) when large debris bumps or piles up against them.

Figure 6.11 Severe scour in a young walnut orchard. Some trees have been uprooted and the roots of others have been exposed.

Floodwaters contain suspended sands, silts, and clays. When the velocity of the floodwaters decreases, as they flow through the orchard, sediments are left behind (fig. 6.10). The depth of material deposited may vary from a fraction of an inch to several feet.

Scour is the opposite of deposition. Soil materials can be eroded away as fast-flowing floodwaters pass over the land. If scouring is deep, tree roots may be exposed or, in extreme cases, a tree may be uprooted (fig. 6.11). Releveling is necessary to cover exposed roots and carry on normal orchard operations.

An additional hazard of farming floodplain lands along such major streams as the Sacramento and Feather rivers is stream bank erosion (fig. 6.12). Channels of such mature streams are constantly changing their courses. Consequently, land is being eroded along one stretch of the river and being redeposited at another point. Depending upon the location of your property, you can lose land or gain it.

To assess the potential flooding hazards of a parcel of California land not protected by levees, check with the U.S. Army Corps of Engineers or the California Department of Water Resources. These agencies have historical records of flooding and river-stage readings for most major streams. Such data, correlated with the location and elevation of the property in question, can

Figure 6.12 Many walnut orchards along major streams suffer high tree losses due to stream bank erosion.

give a realistic idea of the frequency, depth, and duration of probable flooding.

Upland erosion. Most California walnut orchards are planted on nearly level to very gently sloping lands; as a result, erosion is not a serious problem. Exceptions are to be found in the foothill districts of the Coast Range and the Sierra Nevada. Walnuts in these areas have been planted on gently undulating to hilly slopes. The degree of erosion is generally related to the steepness and length of slope; the steeper and longer the slope, the greater the amount of site erosion. Other factors influencing erosion are rainfall intensity and duration, nature of the soils, type of ground cover, and management practices.

Sheet erosion and gully erosion reduce the nutrient level of soils by removing the more fertile upper-soil horizons. If erosion is severe, roots are often exposed and deep gullies develop that interfere with normal cultural practices. To correct these conditions, land planing, or smoothing, may be necessary. Sheet and gully erosion can be minimized by converting to noncultivation. If tillage is necessary, the land should be cultivated across the slope. In new orchards, contour planting and terracing can minimize erosion losses.

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SITE PREPARATION AND CORRECTION OF PHYSICAL SOIL PROBLEMS

Establishing a walnut orchard is an expensive undertaking; before the trees are planted, do everything possible to ensure the orchard's long life and productivity. Soil preparation operations that are simple before planting become difficult or impossible after the orchard is established. The first part of this section will discuss the various soil operations you should consider doing before planting. The second part will deal with soil problems that may arise after establishment of the orchard.

Preparing the Orchard Site

Soil uniformity. More often than not, soil from one part of a field differs in texture, depth, or kind from that in another part. The variations can result in nonuniform irrigation, since they influence the infiltration rate and amount of water stored for use. Differences in available water-holding capacity suggest the need for different irrigation schedules. The irrigation system should be planned, as much as possible within other constraints, to allow irrigation of similar soils in blocks based on their ability to absorb and store water for use by trees. For example, figure 6.13A shows a field with a mixture of surface textures, from loamy sand on one side to clay loam on the other. Figure 6.13B shows how it might be blocked to group relatively uniform textures. Figure 6.14 shows a similar situation, except that soil depth above a restricting layer also varies. Soil boundaries seldom follow straight lines or turn at right angles; uniform blocks can only be approximated. Irrigation frequency and quantity between blocks can be varied accordingly to compensate for soil differences.

Soil variability is one factor to consider in choosing an irrigation system (see chapter 8). Uniform, medium-textured soils can be irrigated efficiently by either surface or sprinkler methods, but sprinklers can place a more uniform application on nonuniform or coarse-textured soils. Even with sprinklers, some flexibility in application rate and frequency is necessary to compensate for soil variations.

The depth of shallow soils often can be increased by deep ripping or slip-plowing, thereby increasing the uniformity of fields with a mixture of deep and shallow soils. (Ripping and slip-plowing are discussed in greater detail later in this chapter.)

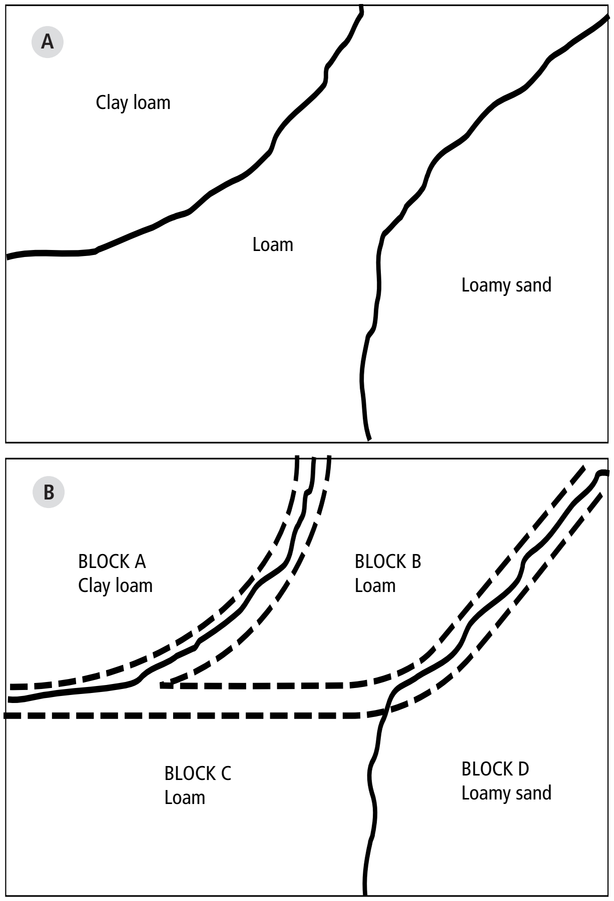

Figure 6.13 (A) Consider an orchard with three distinct soil types. (B) Irrigation blocks are laid out so soil with uniform texture is within one block. This allows irrigation based on the ability of each soil to absorb and store water. Dotted lines indicate avenues.

Creating a uniform texture across a field is more difficult. If land leveling will be done anyway, it may provide an opportunity to mix coarse and fine soil materials. However, to prevent layering, these materials must be broken up and mixed by deep plowing. Deep plowing can also be used to mix contrasting topsoils and subsoils, if subsoils are within reach of the plow. Deep ripping alone does very little mixing of soil layers.

Leveling and grading. Land that is to be irrigated by surface flooding or furrow methods must be graded to a uniform slope. The final grade generally varies from 0.03 to 0.30 feet per 100 feet. Length of run can then be adjusted, depending on the infiltration rate of soil and the head of water available.

In clearing and leveling new land for orchards or releveling older fields, brush and tree debris or surface sod layers may be covered by fill material. If drainage conditions are slow, these buried organic layers may develop zones of reduction in the soil that turn bluish because of lack of oxygen (fig. 6.15). With periodic or continuous waterlogging, anaerobic soil microorganisms transform the organic materials into methane gas and other toxic materials that may damage root systems and can cause death of newly planted orchard trees. Burn the cleared brush and trees or, before leveling, thoroughly incorporate a former sod layer by deep discing or plowing. This minimizes formation of the toxic compounds.

Soil structure breakdown is inevitable during land-leveling operations. Even when dry, compaction results in both cut and fill areas, but it is particularly evident on the heavily traveled "haul roads" across the field. Ripping to loosen cut and fill areas is standard practice, and in many cases it serves also to deepen the soil profile where heavy cuts have reduced the available depth of the potential root zone.

Paddle-type scrapers compact the cut areas less than do push-loading scrapers, but they tend to powder the soil to a flour-like state that does not settle properly when deposited in fill areas. In major leveling jobs, the main cuts and fills should be made one year and the final grading the following year, after an annu-

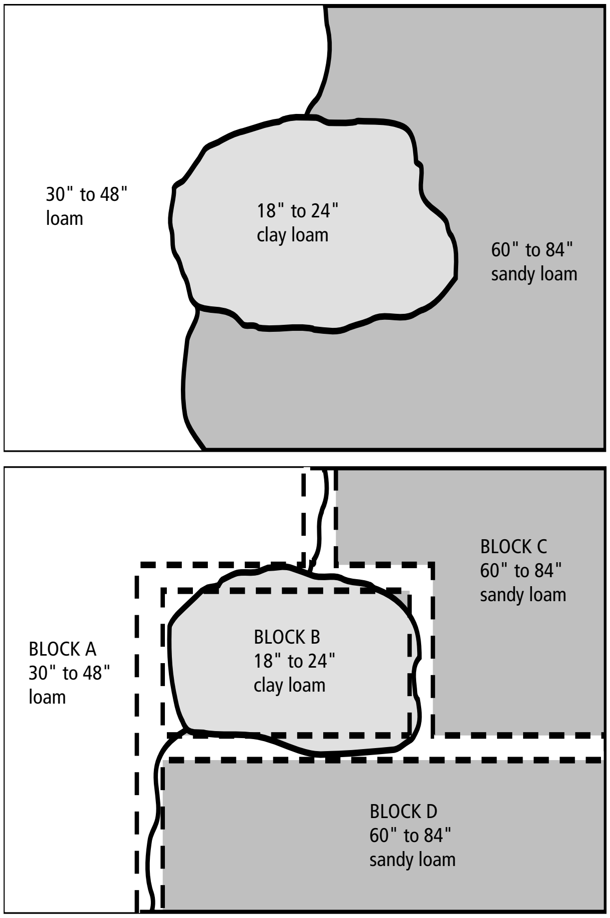

Figure 6.14 Orchard blocks are laid out according to soil depth and texture, with the goal of maximum uniformity within individual blocks. Dotted lines indicate avenues.

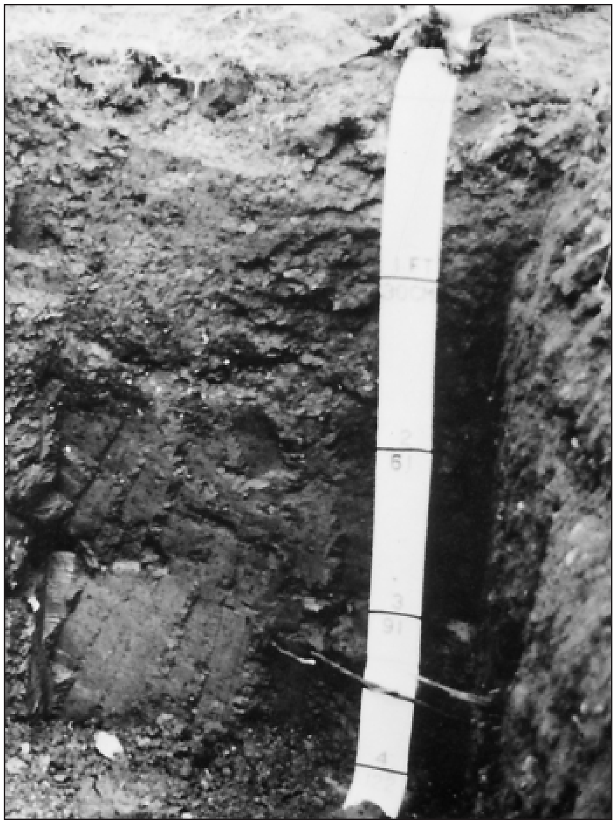

Figure 6.15 Buried organic layers often develop into bluish zones of reduction (because of the lack of oxygen). This is especially likely where waterlogging occurs. Anaerobic decomposition of buried organic matter may produce methane gas and other organic compounds toxic to tree roots.

al crop has been grown. Where orchards will be planted, engineers recommend growing annual crops for 2 years before planting trees, so the final grade will be stable. Crop responses over the leveled area also provide a visual indication of possible differences in fertility or moisture management needs. These needs may result from dissimilar soil materials exposed in cut areas as opposed to materials deposited in fill areas.

Contour checks are often constructed across the natural slopes of alluvial fans, but even that system can work more effectively if some grading is done. Leveling is not essential for sprinkler or drip irrigation, but some smoothing is often desirable to minimize runoff or ponding in low spots.

In upland areas of foothill districts, lands with suitable soils for walnuts commonly have undulating to hilly surface relief. Land leveling is usually impractical. To improve irrigation management and to minimize loss of soil and nutrients through erosion, contour planting of trees and terracing are advisable.

Deep tillage. The subject of deep tillage will be divided into two parts: (1) deep ripping and slip-plowing, 3 to 6 or more feet deep, to break up natural restricting layers in the subsoil (such as hardpans, claypans, and stratified layering), and (2) intermediate to shallow ripping, 1½ to 3 feet deep, to loosen farming-induced soil compaction. Many soils on recent alluvial fans and floodplains are deep and relatively uniform in texture throughout the profile. These soils do not need deep ripping or slip-plowing. Other soils, on the recent floodplains along major rivers, are stratified. That is, they have layers with abrupt changes in texture beneath the surface (fig. 6.16). Though not restrictive to roots in a physical way, the layers upset the uniform flow of water and cause zones of poor aeration. The soil would be improved if the soil profile were completely mixed, but equipment to do that may not be available and the operation can be expensive. Trenching in the tree row has solved the problem in extreme cases of stratification (fig. 6.17). (Caution: Intercept-

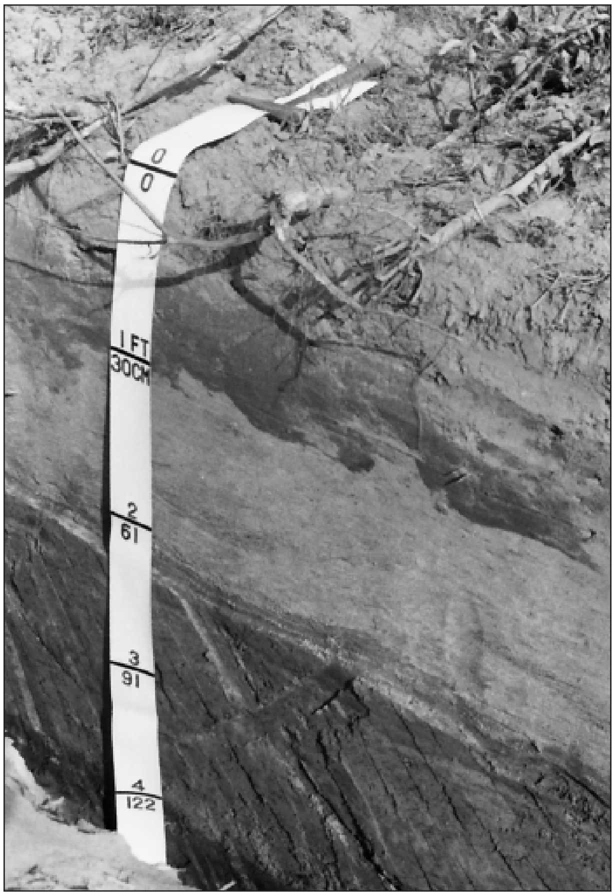

Figure 6.16 An extreme case of stratification with abrupt boundaries between the first foot of sandy loam, the second foot of white sand, and the underlying silty clay loam. Soil density was not a problem here, but roots of young trees would not grow across the boundary into the coarser white sand. Compare this root growth with that 2 years later (fig. 6.17) in the same orchard, after trees had been replanted in a uniform soil profile created by a trenching machine.

Figure 6.17 Two-year-old trees grow well in this very stratified soil because a portion of it was mixed by a trenching machine. Notice the roots growing in the uniform soil at center, but not in the white sand layer. Trees originally planted in this orchard, without the soil-mixing treatment, grew very poorly.

ing deep sandy layers may aggravate seepage problems close to the levees of major rivers. It is wise to consult with the local Soil Conservation Service or land-grading engineers before attempting deep tillage in such areas.) Slip-plowing in the tree rows before planting results in less uniform mixing but does break up the continuity of stratified layers. (A slip plow with a 15-inch wide "slip" is shown in fig. 6.18.) Ripping would provide less benefit in the tree rows of orchards with layered soils, but it might still be useful to break up fine layering.

Soils with impermeable hardpans (fig. 6.6) are poor locations for any orchard unless the hardpan is shallow enough and thin enough that deep ripping can break completely through it and into permeable soil material below. Where the hardpan is shallow but thick, or rests on a massive, compact substratum, double-shank cross-ripping, closely spaced, can effectively deepen the rooting volume of the soil. However, drainage may still be somewhat impeded. During the growing season adjust irrigation practices to provide adequate moisture but avoid lengthy periods of saturation in the rooting zone. Heavy-duty augers or backhoes may be able to dig through the hardpan to judge its thickness. Seismic equipment is also available for this purpose.

For deep ripping to be effective, two things must be accomplished: (1) A channel must be created to drain perched water, and (2) the volume of soil available for root growth must be increased. For most effective fracturing, spacing between ripper channels should be equal to or less than the depth of ripping. Slip plows are increasingly being used in hardpan soils. Their power requirements are greater than those for ripping, but slip-plowing results in a greater volume of loosened and mixed soil. A combination of closely spaced cross-ripping followed by slip-plowing in the tree rows provides good opportunities for drainage and increased root growth.

Figure 6.18 With the shank shown, this slip plow can operate almost 5 feet deep. The slip plate is 15 inches wide.

Claypan soils are those in which a clay layer severely reduces water percolation, aeration, and root growth in the subsoil (fig. 6.19). The clay layer is most restrictive in its upper 6 to 12 inches and usually grades into clay loam, loam, or sandy loam at lower depths. The more that can be done to break up and mix the clay layer with the rest of the soil profile, the better for the eventual root growth of orchard trees (fig. 6.20). In experiments with almonds on a claypan soil, 5-foot-deep ripping in the tree rows, with two ripper channels between rows, resulted in a significant improvement

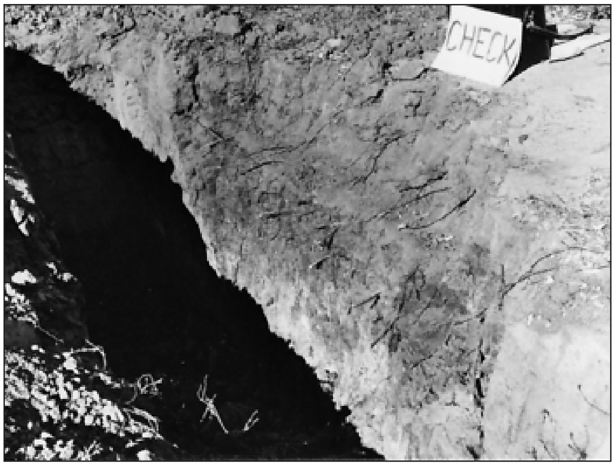

Figure 6.19 A sandy loam surface layer abruptly changes to blocky clay subsoil at a depth of 15 inches. Tree roots have been able to grow into cracks in the upper 8 inches of the clay layer, but below that the soil is too dense for root growth. Even these roots will be drowned if excessive late spring rainfall or overirrigation occurs. Compare these roots with those in figure 6.20, in which deep moldboard plowing extended the root zone.

Figure 6.20 The claypan soil shown in figure 6.19 after being ripped and plowed by a deep moldboard plow. Notice that roots make use of all the soil to 3 feet deep. At that depth the soil still appears crumbly and loose 3 years after the plowing was done.

over the unripped control (fig. 6.21). Slip-plowing increased the average root depth and yield; deep ripping at 4-foot intervals followed by moldboard plowing 3 feet deep produced the deepest root zone, largest trunk circumference, and highest yield (fig. 6.20 and table 6.2). Walnuts would be expected to respond in a similar manner.

A backhoe pit for each tree, dug through restricting subsoil layers, is an alternative to deep ripping or slip-plowing (fig. 6.22). Compared to deep ripping or slip-plowing, backhoeing offers these advantages: (1) it can dig much deeper, if necessary, to get through deep layers; (2) it mixes soil layers better; (3) it is more adaptable and economical for small acreages; and (4) fumigants may be applied in the pits. The disadvantages of backhoeing are: (1) the “pot effect,” which sometimes restricts root growth to the volume of the backhoe pit; and (2) cost, particularly for large pits in medium- or fine-textured soils.

Table 6.2 Trunk circumferences, number of roots, and yields of almonds in relation to deep-tillage treatments.

Treatment	Trunk circumference* (cm)	Number of roots,† 1-ft wide column, 3 ft deep	Yield† of almond meats per acre (lb)
Check	37.5	78	1,009
Ripper	42.2	94	1,120
Slip-plow	42.3	118	1,185
Moldboard plow	43.3	175	1,433

*4th leaf.
†8th leaf.

Drainage. If a high water table exists in part or all of a potential orchard, the first decision is whether to plant at all. If the choice is to proceed, have a drainage specialist diagnose the problem and plan a drainage system, if the problem is manageable and cost effective.

Shallow observation wells 10 to 15 feet deep may be needed to verify the presence of a water table. If possible, these wells should be established several years before planting to determine the source and direction of subsurface groundwater flow and to monitor the frequency, height, and duration of waterlogging. Once the source of water has been determined, remedial steps, such as lining defective canals, installing drainage tile, or digging an interceptor ditch, can be taken to correct or minimize the problem.

Fumigation. If fumigation is necessary to control soil-borne pests, the soil must be well ripped before applying the fumigant. Rip and cross-rip the soil at least 3 feet deep, using a shank spacing no greater than the ripping depth. Consult the local Farm Advisor or pest control advisor for recommendations. (For a detailed discussion of nematode control, see chapter 27.)

Correcting Problems in Established Orchards

Nothing that happens in the soil is simple. The delicate balance of water and air that makes healthy root growth and nutrient absorption possible can easily be upset. Some of the more important problems are flooding and soil compaction.

Flooding. Flood damage can be minimized by maintaining a barrier of natural vegetation along the edge

Figure 6.21 Trees planted during an unusually wet spring grew normally where 5-foot-deep ripping had been done (left row). In unripped plots (right row) trees were drowned by water standing on top of the shallow claypan.

of an adjacent stream channel. The barrier will act as a sieve to prevent large debris from being carried into the orchard. It also reduces the velocity of the overflow, thereby reducing the amount of soil scour or deposition of sands and silts. Unfortunately, some recently developed floodplain lands in the Sacramento and San Joaquin valleys have been cleared and leveled to the riverbank. As a result, some of these lands have undergone severe scouring and deposition during flood periods.

Scouring or deposition in an orchard often requires releveling or, in extreme cases, removal of the flood sediments from the orchard. Use of heavy equipment, such as carryalls, to remove the sediments may result in scarred tree trunks and broken limbs. If the sediments are not removed from around the base of the trees, crown rot and other diseases may develop.

Soil compaction. Although many root growth problems can be attributed to an improper water-air balance in the soil, sometimes roots are not physically able to enter small soil pores or to push soil particles aside. This is particularly evident in some of the very sandy soils of the San Joaquin Valley where cultivation has formed dense tillage (plow) pans of interlocking and compacted sand and finer particles. These soils normally have high percolation rates for water, and roots penetrate them readily. But where tillage pans have formed, permeability to water is greatly reduced and roots will not readily grow unless the soils are physically loosened. Root and water impedance in compacted horizons of medium- and moderately fine-textured soils is also a problem.

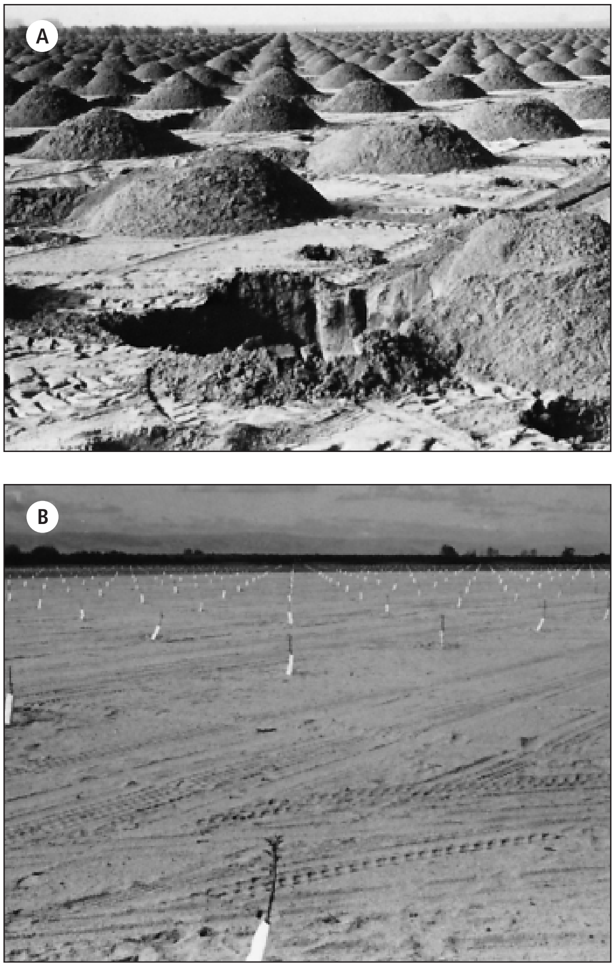

Figure 6.22 Refilled backhoe pits (A) have been found to stimulate growth of young trees, particularly in sandy and stratified soils (B). These pictures were taken 2 months apart.

- Because some soils are more susceptible to compaction than others and some growers are less careful managers than others, problems due to soil compaction vary greatly. Implements working the soil and wheel traffic bearing down on it cause compaction by breaking down soil structure. Some compaction is unavoidable, but effective management can help minimize it. Consider the following suggestions when developing your management plan.

- Moist soils compact more readily than dry soils, so perform operations other than cultivation on as dry a soil as practical.

- Planted or native cover crops can extract moisture from soils in the winter and spring and make the ground firmer for spraying. They also contribute to soil organic matter, and their roots develop tubular pores that improve water and air movement in the soil.

- Permanent sod may improve water infiltration in some soils, but the effect may be only temporary. Returning to surface tillage occasionally may be necessary in situations where water infiltration is reduced over time. If soils are cultivated, soil moisture should be moderate—moist enough to work easily, but not so wet that it puddles or slicks.

- A shovel cultivator may be used as an alternative to a disc plow. Sometimes a cultivator can break soil crusts without pulverizing them as much as a disc plow would.

- Dry soil must not be overworked.

- Standardize wheel spacing for all machinery operations so all machines run in the same wheel tracks.

The effects of ripping on soil compaction and water penetration have not yet been precisely determined. It is clear, however, that a single shank pulled through the middle between tree rows will not accomplish much. Single or widely spaced shanks do little to loosen soil in the lower half of the penetration depth (fig. 6.23). A 20-inch spacing of several shanks (fig. 6.24) creates enough overlap in the ripping pattern to loosen significantly more compacted subsoil.

If soil management practices listed previously are insufficient to reduce compaction to an acceptable level, ripping might help. The best device is a multiple-shank subsoiler that will penetrate 16 to 24 inches, depending on depth of compacted soil, with shanks spaced about 20 inches apart. Make one or more passes to loosen at least half the space between tree rows. There is always a tradeoff between correcting a compacted soil and pruning some tree roots, so it is wise to rip only every other middle in a given year. Root galls may form on Paradox roots where they are broken, but whether this is a more serious consequence than the compacted soil is unknown. Ripping at right angles to the predominant orchard traffic pattern will result in recompaction of less soil than ripping parallel with the traffic. Rip only in the fall and when the soil is relatively dry.

Figure 6.23 Ripper shanks spaced 30 inches apart produce channels without any overlap and therefore leave much compacted soil unloosened. Depth of ripping is 16 inches.

Figure 6.24 When shank spacing is reduced to 20 inches, much more soil is loosened. Normally, the lower one-third of the shank makes almost straight-walled channels which fan out toward the less confined soil surface.