Chapter 6
Physical Properties of Forest-Nursery Soils: Relation to Seedling Growth

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Abstract

The physical properties desirable in forest-nursery soils are those that provide the optimum environment for root growth and function. Because these properties are difficult to alter, they should be used to determine which sites are chosen for forest nurseries. Solid grains, about half the soil volume, provide the framework for stable soil pores and an anchor for plant roots. The large pores, about half the pore space, allow for necessary gas exchange; the small pores store water for plant use. Soil cultivation and drainage change the relative proportions of solids and pores. Tillage can improve soil tilth, but excess tillage usually results in undesirable changes in the soil. Soil organic matter content is important to tilth as well as to stability of structure. Soil compaction, including crusting, represents a special problem, which can be both caused and ameliorated by tillage. Increased soil resistance to compaction and adequate organic matter maintenance should be major objectives in nursery soil management for Northwest forest nurseries.

6.1 Introduction

The vigor of a shoot depends upon the health of the root. But though the shoot is always in sight, the root is not. The root must proliferate in the soil to supply the shoot with the necessary water, oxygen, nutrients, and structural support. Any hindrance to root growth restricts root functions and thus influences shoot growth. Yet such hindrances may not be obvious until the soil is examined to see how the root has developed.

Our objective in managing nursery soils is to manipulate them to provide an optimum physical environment for root growth. In this chapter, physical properties of soils are examined to this end **from a root's perspective.** What are the root's requirements? What are the impediments in the soil to meeting those requirements? How can soil management remove or alleviate those impediments to improve the physical environment, so roots-and shoots-can thrive?

Specific nursery practices for applying the principles are not thoroughly discussed here. This is due in part to my lack of familiarity with all nursery soil problems and the management options available to cope with them, but also in part to a conviction that forest-nursery managers are best able to design practices to apply the principles.

6.2 Physical Environment for Root Growth

The physical characteristics desired in nursery soil are:

- Optimal proportions of air and water in soil pores after natural drainage
- Rapid drainage of excess water from soil
- Adequate infiltration rate for rainfall or irrigation water
- High resistance to compaction
- Low shear strength for easy harvest of seedlings
- Low adhesion of soil to seedling roots
- Absence of frost heaving, erosion, and soil splash onto seedlings

These characteristics are optimized in loamy sands or sandy loams whose silt plus clay contents are 10 to 25% and whose organic matter contents can adequately stabilize soil structure to maintain pore size and continuity.

Adequate "root room," a concept that has been used to evaluate the root's environment [6], requires adequate depth of freely draining soil. Root proliferation also requires low soil resistance to root growth. Compacted layers, poor drainage, and root pruning decrease root room. Seedbed density also affects root room, as do various management practices to change shoot:root ratios. The mass of roots is approximately half the mass of shoots, although this ratio can vary from 0.3 to 0.8, depending upon management factors [10]. A good root environment, with adequate aeration and low resistance to root penetration, favors high root mass.

Root growth depends upon movement, or fluxes, of materials in the soil. Fluxes of water as it redistributes in the soil, of oxygen as it diffuses to the root and of carbon dioxide and other gases as they diffuse away from the root, and of nutrients as they either diffuse or flow to the root are all necessary

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for root function. In addition, the root itself moves as it extends into the soil, and any resistance that it meets influences its function. Root hairs, mycorrhizae, and enhanced biological activity in the rhizosphere all involve fluxes. Most root growth occurs in early spring and again in autumn, when shoot growth is not great, although it can also occur during summer, depending upon species and weather [10].

Soil physical characteristics are important in nursery-site selection because they are hard to change. Soil fertility, for example, can be changed quite readily by adding fertilizer and lime, but it is usually impractical to mix in enough off-site soil to change soil texture or depth. The easiest way to modify physical characteristics is to add organic matter from mulches such as sawdust or cover crops (see chapters 9 and 10, this volume). It is no wonder, then, that in considering soil physical factors for site selection, Northwest nursery managers listed good soil workability and drainage as the dominant desirable characteristics (OSU Nursery Survey; see chapter 1, this volume) (Table 1).

Table 1. Important soil factors considered by Northwest nurseries in selecting sites (OSU Nursery Survey).

	% of time	
Soil factor	Considered	Listed 1st or 2nd in importance
Workability and drainage	67	38
Texture	57	28
Depth	43	19
Fertility	33	14

6.3 Soil Structure

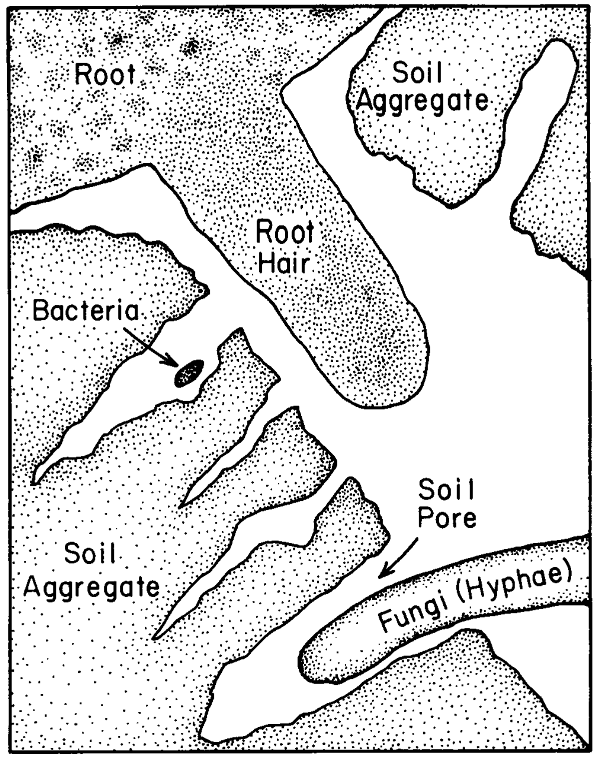
Soil structure refers to the size, shape, and arrangement of soil grains and pores. The relative sizes of the different physical and biological components are shown in Figure 1. The solid portion of a soil is composed of soil grains, or particles, of different sizes (Table 2). Different proportions of these sizes produce the texture classes (e.g., sandy loam, silt loam, etc.). The pore space of a soil—that portion between the grains or grain aggregates—is occupied by air and water. Porosity (volume of pores divided by total soil volume) of soils in desirable physical condition is around 0.5.

Table 2. Grain-size fractions.

Name	Size, mm
Clay	< 0.002
Silt	0.002 - 0.05
Very fine sand	0.05 - 0.1
Fine sand	0.1 - 0.25
Medium sand	0.25 - 0.5
Coarse sand	0.5 - 1.0
Very coarse sand	1.0 - 2.0
Gravel	> 2.0

Aeration, which occurs only in pores not filled with water, consists both of oxygen diffusing through soil to the root and of carbon dioxide and gases such as ethylene diffusing from the root to the soil surface. Diffusion rates are 1,000 times slower in water than in air; therefore, water-filled pores do not contribute to aeration. In a well-drained soil, most diffusion occurs in transmission pores larger than 0.05 mm (Table 3). For good aeration, a minimum of 20% of the pores should be filled with air [4]; when only about 10% are, diffusion of gases falls to zero. The pores constituting this 10% porosity are isolated by water; their continuity is limited, and diffusion cannot readily occur.

Optimum bulk density (mass of dry soil divided by soil volume) varies with grain size and nature of the soil. A clay or



AVERAGE SIZES, μm	
Soil Bacteria	2.0 x 0.05
Fungi (Hyphae)	5
Root Hair	10
Root	200
Soil Pores	
Empty at wilting	0.1
Empty at field capacity	15
Soil Aggregate	5,000

Figure 1. Architecture of the soil, showing relative sizes of biological and physical components (adapted from [12]). Root hairs can penetrate only the largest soil pores holding water available to plants; even bacteria cannot penetrate the smaller pores.

clay loam should have a bulk density of 1.0 to 1.1 g/cm^3 because a large part of its porosity is in the very small residual pores (Table 3). Soils developed on volcanic parent materials have optimum bulk densities of 0.9 to 1.1 g/cm^3. Some very sandy soils can provide an adequate root environment at a bulk density of 1.45 g/cm^3 because the pores are mostly storage and transmission pores.

Table 3. Pore-size classifications in soils (adapted from [5]).

Classification	Size, μm (mm)	Function
Fissures	500-5,000 (0.5-5)	Allow rapid drainage
Transmission pores	50-500 (0.05-0.5)	Allow flow of water, diffusion of gases
Storage pores	0.05-50	Hold water available to plants
Residual pores	0.005-0.05	Hold water not available to plants

An ideal sandy loam soil, then, from a root's perspective, could have a bulk density of 1.3 g/cm^3, an air-filled porosity of 20%, and a water content of 23% at field capacity (see 6.4). On a volume basis, this soil would have 50% solids, 30% water, and 20% air.

6.4 Soil Water

Water infiltrates the soil at the surface and redistributes below. The force of gravity pulls water down. Soil water potential (Y soil) (the negative pressure that must be applied to prevent pure water from moving into soil) pulls water into drier soil and decreases as soil water content decreases. In dry soils, soil water potential is much smaller than the force of gravity. A small amount of added water will, therefore, be distributed in the surface layers of dry soil. Soil water potential depends upon pore size and is lowest in the smallest pores; thus, water will be sucked first into these. The force of gravity can remove water from larger (> 0.05 mm) pores; thus, drainage will empty those.

The water retention curve (Fig. 2) relates soil water potential with water content. Varying water potentials can be applied to a soil sample in the laboratory, the resulting water content measured, and a water retention curve produced. The shape of the curve for a particular soil gives information on the amount of water released to plants at different potentials. Plant roots will first absorb the water held at the highest potential in the largest pores (see chapter 12, this volume).

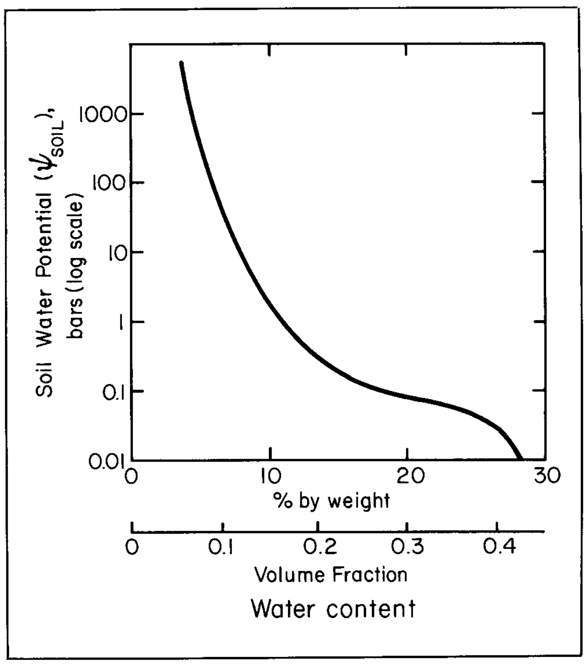


Figure 2. Water retention curve for a typical sandy loam with bulk density of 1.5 g/cm^3;.

Water content may be expressed by weight or volume. Water content by weight, usually a percentage, is the mass of water divided by the mass of oven-dry soil. Water content by volume is the volume of water divided by total soil volume and can be calculated as water content by weight multiplied by bulk density. This volumetric water content is a useful number because it is directly related to centimeters (inches) of water in a soil. A value of 0.10 means 0.10 cm of water per centimeter of soil, or 10 cm of water per meter of soil (1.2 inches of water per foot of soil).

A saturated soil without growing roots will drain to field capacity (water content of a soil saturated by rainfall or irrigation and then allowed to drain for 24 to 48 hours). The water remaining in the soil at field capacity, held at lower soil water potentials, will drain only very slowly. Any water added in irrigation beyond that required to increase the water content to field capacity is wasted. Excess water will drain away before an appreciable part of it can be used by plants, leaching fertilizer and preventing good aeration (see chapter 13, this volume, for more detailed discussion of land drainage).

Clearly, water control is a very important part of managing soils for intensive use such as forest nurseries. Nursery managers should know the field capacity of their soils, which can be readily measured: (1) after the soil is saturated by irrigation or rainfall, a small area is covered with a plastic sheet to prevent evaporation; (2) after 48 hours, soil samples are taken at 6- and 12-inch depths, and water content is determined.

The total "available water" stored in the soil is defined as the difference between field capacity and wilting percentage (water content at which a plant wilts and will recover turgor only if more water is added). Figure 3 shows the water retention curve from Figure 2 replotted on the basis of available water instead of water content. For this soil, half of the available water is released between — 0.1- and — 0.3-bar soil water potential and less than a quarter is left at — 1 bar.

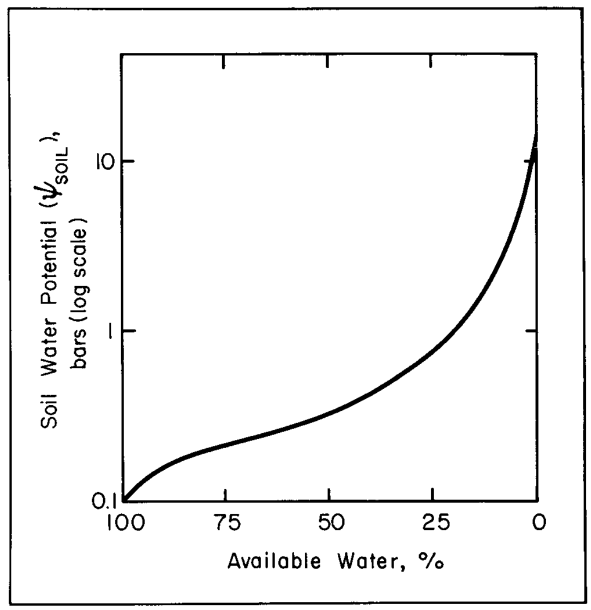


Figure 3. Water retention curve for typical sandy loam (Fig. 2) replotted on the basis of available water.

Growth is not constant over the water-content range from field capacity to wilting percentage (Fig. 4). Atmospheric conditions, which determine atmospheric demand and the amount of water transpired, shape the growth vs. available water curve. In many situations, growth is measurably reduced once about half of the available water has been used. For maximum growth, the soil should be irrigated when it has dried to that point.

It is often assumed that the effects of water stress are temporary, restricted to the period of actual stress, and that maximum growth resumes once plants are irrigated. However, water stress has longer term effects. These may be due to changes in roots on drying which make roots less able to absorb water. New root growth must then occur before maximum shoot growth can.

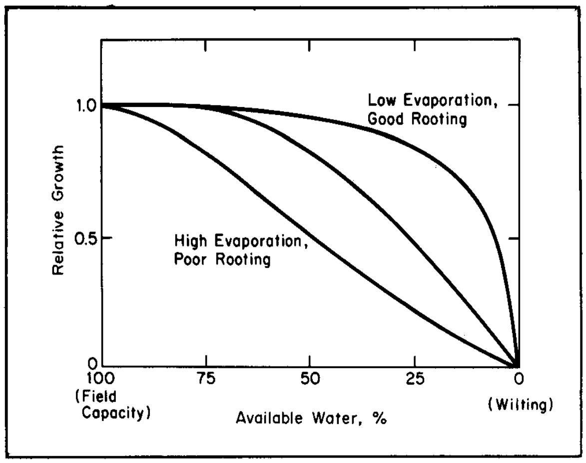


Figure 4. Generalized relation between plant growth and available soil water.

6.5 Soil Temperature

The temperature of the soil, as well as that of the soil relative to the air, affects root growth and function. The root zone has a gradient in soil temperature within which temperatures change diurnally and with depth. Both low and high soil temperatures can be a problem in forest nurseries.

Soil temperature can be controlled through change in either water content of the soil or absorbing and evaporating properties of the soil surface. The amount of heat required to raise the temperature of a volume of water is twice as high as that required for an equal volume of soil. Drainage to decrease water content will increase soil temperature. Mulches can control soil temperature by decreasing or increasing absorption of insolation and by reducing evaporation (see chapter 12).

6.6 Tilth and Tillage

Soil tilth is hard to define but easy to recognize from feel and from kicking the soil with your toe. Tilth is the physical condition of a soil related to ease of tillage, suitability as a seedbed, and impedance to seedling emergence and root growth. A soil in good tilth has aggregates that are rounded and porous, in a range of sizes, that crush easily in the hand. From the standpoint of the plant root or the germinating seed, tilth is the system of pores of different sizes that supply the roots' needs. That system of pores—and its stability—is the concern of tilth and tillage.

Tillage can be used to increase the volume of transmission pores and of the larger (> 10 µm) storage pores (Table 3), though it does not influence the smaller storage pores and residual pores. These small pores are determined by physical and chemical interaction between soil grains, such as swelling and shrinking, and by intergrain movement caused by biological activity in the soil. in sum, tillage directly affects the larger pores and indirectly affects the smaller pores by changing the environment for biological and physical-chemical action.

6.6.1 Seedbed preparation

The main physical effect of plowing is a loosening of the soil. How long this increase in porosity lasts depends upon the stability of soil structure (Fig. 5). A soil with stable structure will retain a high porosity for many months; this is typical of soils that have been in grass sod. Other soils will revert to their original porosity within weeks; this undesirable condition is characteristic of soils low in organic matter or those under continuous cultivation.

Tillage operations that prepare a fine seedbed from a plowed soil decrease porosity by making smaller aggregates that can fit more closely together, eliminating the larger pores and fissures. The close fit is assumed to be required to assure that the seed contacts the soil adequately to imbibe moisture for germination. However, the decreased porosity created in a fine seedbed is not optimum for later plant growth. Therefore, soil in seedbed preparation should be manipulated only to the degree of fineness needed for adequate seed germination. It may be better to accept a lower germination percentage to ensure a favorable environment for subsequent growth.

Many studies have been carried out to determine optimum size of aggregates for seed germination and plant growth. The results depend upon the watering regime—with fine aggregates, aeration is limiting; with coarse aggregates, water is limiting. Generally, growth is optimum for aggregates of 0.5 to 2 mm. This observation indicates that rototillers create aggregates that are too small.

Some tillage operations are used for weed control (see chapter 18, this volume). Where weed-control alternatives are available, the benefits and hazards of the extra tillage need to be evaluated.

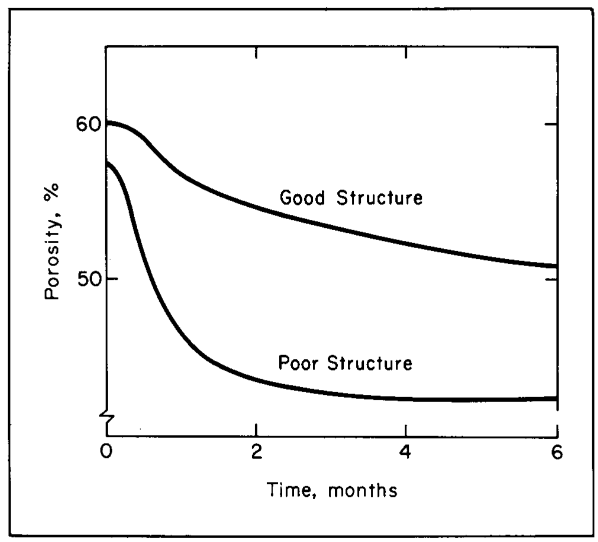


Figure 5. Total porosity of soil after plowing.

6.6.2 Organic matter

Organic matter is the energy source for biological activity in the soil. Molecules produced during decomposition stabilize soil aggregates, thus maintaining good soil structure. This process, like others previously described, is dynamic: because decomposition is continuous, a supply of fresh organic matter is always needed for stable soil structure (see chapter 9, this volume).

In most agricultural crops, the root and some of the shoot are left in the soil as a source of fresh organic matter. The root can be 40% of the weight of the shoot. In a forest nursery, however, root and shoot are both removed. Therefore, organic matter must be either brought in from somewhere else and added to the soil or grown on site as a green manure crop (see chapter 10, this volume). A green manure crop grown alternately with nursery seedling crops helps to maintain organic matter, and its prolific roots stabilize soil structure.

6.6.3 Response to tillage: soil workability

Soil workability depends primarily upon soil cohesion, the forces holding soil grains and aggregates together, and soil adhesion, the forces holding soil to tillage implements. Both of these properties vary with water content. Figure 6 shows this variation for sand and clay, which manifest the extremes in cohesion and adhesion. Clays develop the highest cohesive and adhesive forces because of the small grain size and large surface area. In contrast, sands develop cohesion or adhesion only through water films—when the soil is saturated or dry, these properties are not displayed. Agricultural soils fall between the extremes of sand and clays.

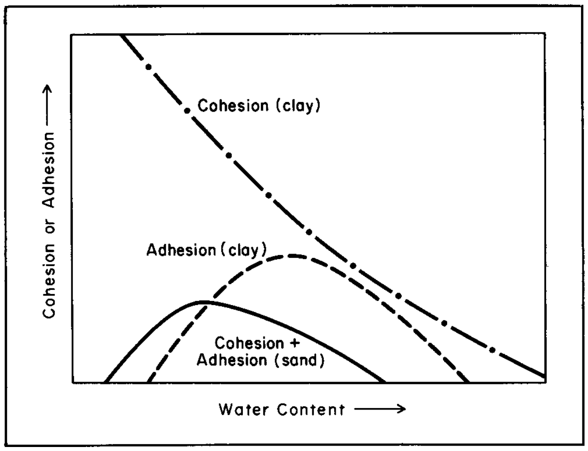


Figure 6. Cohesion and adhesion of clay and sand as a function of water content.

Achieving tilth requires breaking down large aggregates against the force of cohesion. The energy needed increases as soil becomes drier. However, good tilth cannot be achieved at high moisture contents because the broken aggregates will not remain as separate units. Tillage is, therefore, most effective at intermediate water contents, the correct water content depending upon texture and kind of clay, and is best determined by experience with a particular soil.

The main practical way to alter soil workability is by adding organic matter. Organic matter increases cohesion of, sandy soils and decreases cohesion of clays; in either case, the result is better tilth, or range of pore sizes, for optimum root growth. Organic matter also decreases adhesion of most soils.

6.7 Soil Compaction

Soil compaction is the rearrangement of soil aggregates into a position of higher bulk density, hence lower porosity, as a load is applied to the soil (Fig. 7). Because rearrangement is easiest into large pores, most of the loss of porosity is in the large pores where water flow and gas exchange occur. Rearrangement also increases soil strength and resistance to root penetration. As a result, a small amount of compaction can have a large influence on root growth.

Soils differ in inherent compactability due to grain-size composition and organic matter content. Soils having predominantly one grain size are not easily compacted. However, when a range of sizes is present, small grains can be moved into pores between larger grains, increasing compaction. Organic matter stabilizes aggregates, increases their strength, and decreases compaction.

Aggregates can be rearranged to a higher bulk density from both applied pressure and shear. A tractor tire without slip would apply only pressure to a soil; however, if slip is present, which is the usual case, both pressure and shear are applied. A tractor tire or track produces equal pressure lines that form bulb shapes below it (Fig. 8), but maximum pressure drops off

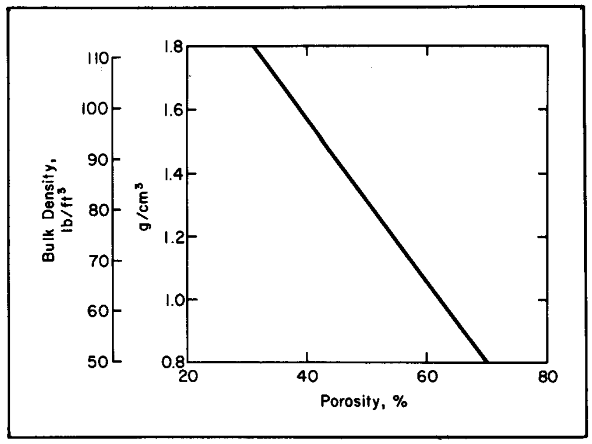


Figure 7. Calculated relationship between porosity and bulk density.

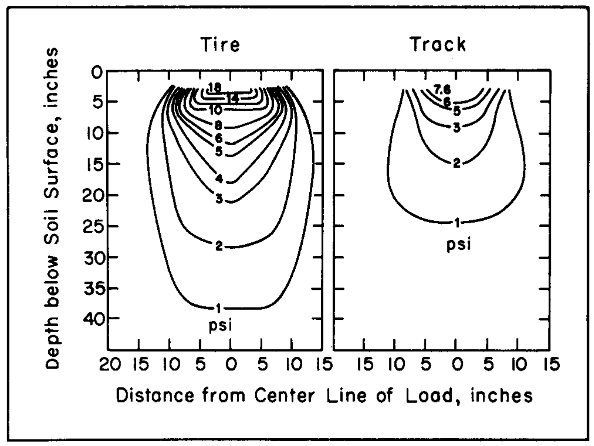


Figure 8. Mean normal stress (psi) under a wheel with a 13-38 tire and a 12-inch track (adapted from [8]).

quickly with depth and with lateral distance from the tire or track. Because track pressures are lower than tire pressures, vehicles with tracks may be preferred to minimize compaction.

The main soil variable determining compaction is water content. Increasing water content to a certain point makes the soil easier to compact; for example, the loose sandy loam soil in Figure 9 is more compactable at 11 % water content than at 6%. Above an optimum water content, compaction decreases and soil puddling increases. Over the range of water contents below field capacity, where soils are usually tilled, compaction increases with increasing water content.

6.7.1 Recognizing soil compaction

Compacted layers in soils become apparent when they interfere with water movement or root growth. Various methods are available to measure severity and depth of compaction.

Soil penetrometers measure the force required to push a probe through a soil, giving a quantitative comparison among different fields in the nursery and from year to year. This is a relative measure, however, because no probe pushed rapidly into soil can adequately reproduce the process by which a root grows. Penetrometer readings show whether compacted layers are present and where they occur. Because soil resistance to the penetrometer probe increases with decreasing water content, a comparison of readings is valid only if water content is the same.

Mechanical resistance and poor aeration, the two main factors limiting growth in compacted soils, often work together and are hard to separate. Compaction increases mechanical resistance by increasing soil strength and decreases the volume of large pores in which gas exchange occurs. For example, root growth of maize seedlings (Fig. 10) is shown as a function of these variables; applied pressure formed the mechanical resistance, and different oxygen concentrations simulated aeration. In Figure 11, root elongation of pea seedlings is shown as a function of bulk density and water content of a soil. The mechanical resistance due to these two variables was measured as penetrometer resistance. If only mechanical resistance was present, root elongation would have followed the line segments labeled "b." Decreased root elongation shown by the line segments "a" resulted from decreased aeration in the wetter soil samples.

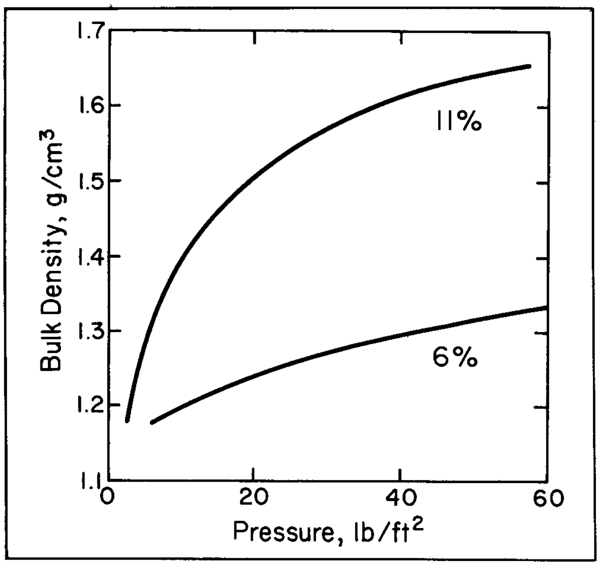


Figure 9. Compaction of a sandy loam soil at two different water contents (adapted from [3]).

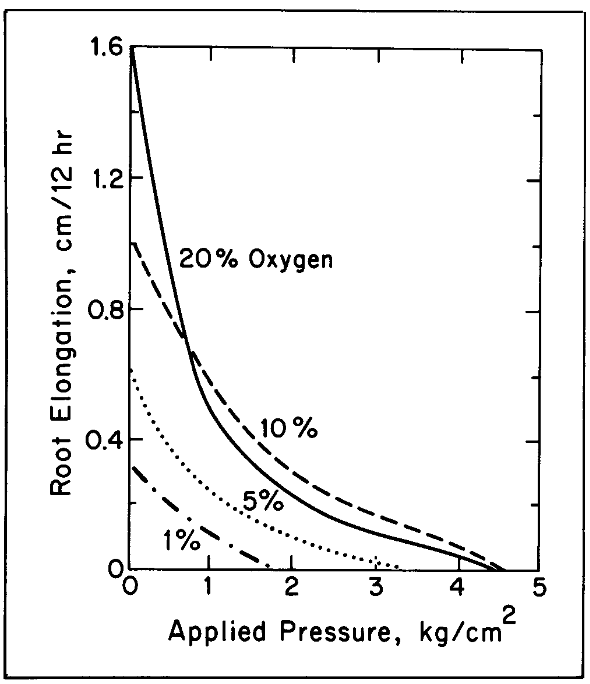


Figure 10. Effect of interaction of aeration and mechanical resistance on growth of maize roots (adapted from [2]).

Many measurements and observations have shown that roots can exert large forces to grow; for example, roots can crack pavement. However, growth rates under those conditions are very slow and are inadequate to support active shoot growth. Figures 10 and 11 show that root growth decreases very quickly as soil resistance increases.

Bulk density can be readily measured, but its measurement requires some care. Soil can be cored at different depths and then dried, and its bulk density calculated by dividing its oven-dry weight by the volume of the core. Bulk density also can be measured nondestructively. Nuclear density probes, largely research tools, can be placed on or into soil for this purpose. However, this equipment is expensive, and special safety precautions must be taken with its radioactive source. Air permeameters also are used in research work to evaluate compacted layers which restrict air movement.

Bulk density values for sandy loam soils normally fall in the range of 1.3 to 1.5 g/cm^3. High (above 6%) organic matter contents result in lower bulk density. Soils with high contents of halloysite clay, amorphous clay minerals, or pumice grains have low bulk densities, around 1.0 g/cm^3; these soils also usually have good drainage, good workability when wet, and lower susceptibility to compaction.

6.7.2 Minimizing soil compaction

On the basis of the compaction process described above, the options for minimizing soil compaction fall into four groups:

(1) Decrease the amount of pressure applied to soil and the number of times it is applied. Use tractors and equipment with low ground pressure (see Fig. 8); use equipment as few times as possible; and dedicate certain soil areas for tractor wheels.

(2) Increase the resistance of the soil to compaction by adding organic matter to increase soil aggregate stability and by draining soils to decrease water content.

(3) Till the soil at lower water contents, where it is more resistant to compaction.

(4) Use tillage equipment that has the least compacting influence. Avoid creating tillage pans; till to different depths at different times; do not use vibrating tools.

6.7.3 Improving compacted zones

Though avoiding compaction is most desirable in principle, it is often not possible in practice. Seedbed preparation requires certain tillage operations, and seedlings often must be lifted when the soil is wet. Compacted soil zones do occur—and amelioration is necessary.

Reversing compaction requires moving soil aggregates into an arrangement of greater porosity and then stabilizing that new arrangement in some way. The most common practice for overcoming compacted subsoils is ripping. Ripping shanks, at 40- to 80-cm (15- to 30-in.) spacing, are pulled through the soil 40 to 80 cm (15 to 30 in.) deep. A second pass at right angles to the first is common.

Although most nursery managers claim good results with ripping, soil scientists have theoretical reasons for believing that changes in the soil due to ripping may be only transitory. If the same forces, whether natural or due to soil manipulation such as tillage, continue to act on the soil, then soil particles would again settle into the original bulk density. To prevent this, the soil would have to be modified in some way. Many measurements of porosity and rooting have failed to detect differences between ripped and unripped fields [unpubl. data, 11].

What are the requirements for effective ripping? To increase porosity, the soil volume must be increased (Fig. 12). If ripping does not increase height of soil at the surface, which is a function of design, angle, and depth of the implement used, it cannot increase soil porosity. There is a critical depth for each type and shape of ripping tine [9].

If the soil is dry, ripping will shatter it, producing the desired effect. If the soil is wet, aggregates can readily flow back into a structure with the original porosity. However, even under ideal conditions of loosening and shattering, ripping may produce small soil clods, loosely arranged, which have large pore spaces between them but low porosity within. Ripping cannot change the internal porosity of 1- to 5-mm clods. Though the ripped soil has some large fissures, which aid aeration, root penetration, and water drainage, root hairs cannot easily extract water and nutrients from clods. The increased drainage due to large fissures probably accounts for much of the benefit obtained from ripping.

The effects of ripping can probably best be evaluated visually. Expose a soil face to below the depth of the ripping tine. The amount of shattering and lifting and any compaction from the shaft or tine can then be observed (Fig. 12).

6.7.4 Soil crusting

Soil crusts are thin layers at the surface that are either rigid enough to decrease seedling emergence and damage stems of growing plants, or impermeable enough to decrease infiltration of water into soil or gas exchange between soil pores and the atmosphere. The crusts, commonly 1 to 5 mm thick, result from movement and bonding of soil grains into a new, more dense arrangement due to falling water drops from either rainfall or irrigation. Crusting is most common in soils with a high content of fine sand or coarse silt. Stable aggregates are difficult to maintain in these soils, and special management practices often are necessary to overcome effects of crusts.

Some soils contain plate-shaped grains such as unweathered mica in their sand and silt fractions. If the aggregate stability of these soils is low, the grains will disperse on wetting. These plate-shaped grains then settle out with a preferred orientation along their horizontal axis. On drying, clay grains will bond the adjacent plates. The effect is analogous to sheets of paper allowed to fall and then glued in spots. A hard and impermeable crust forms.

Another common mechanism for crust formation is for dispersed grains of fine sand and coarse silt to flow into pores between aggregates or large grains. The silt grains seal the pores in a thin layer of soil at the surface. When the soil dries, a hard and impervious crust forms.

Because crusts result from grain movement and rearrangement, wetting alone will not remove them although it decreases their strength. Light cultivation will obliterate the effect of crusts by bringing uncrusted soil to the surface: however, a crust will form at the next wetting.

Preventing crusts requires increasing aggregate strength to prevent dispersion of grains, protecting the surface from the energy of water striking it, and decreasing the bonding between grains on drying. Mulches protect the surface from direct impact of falling water drops. Organic matter commonly is added to increase aggregate stability and decrease bonding between soil grains on drying; decomposing organic molecules coat mineral grains and interfere with strong grain-to-grain bonds. Type of cultivation also influences aggregate stability: for example, rototillers destroy aggregates, thereby increasing the chance of crusting.

Various materials such as phosphoric acid and vermiculite have been added to soils as anticrusting agents: the effect is usually to decrease bonding. Chemicals can be added in a band above the seed; vermiculite can be covered with a thin

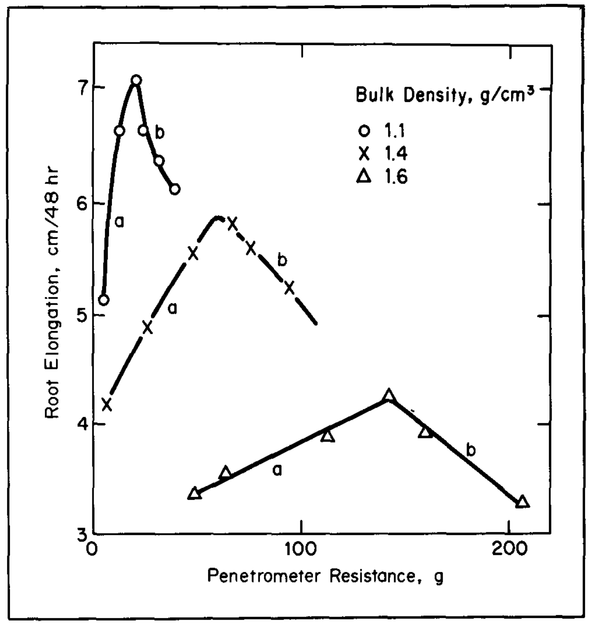


Figure 11. Effects of aeration (a) and mechanical resistance (b) on growth of pea roots (adapted from [1]).

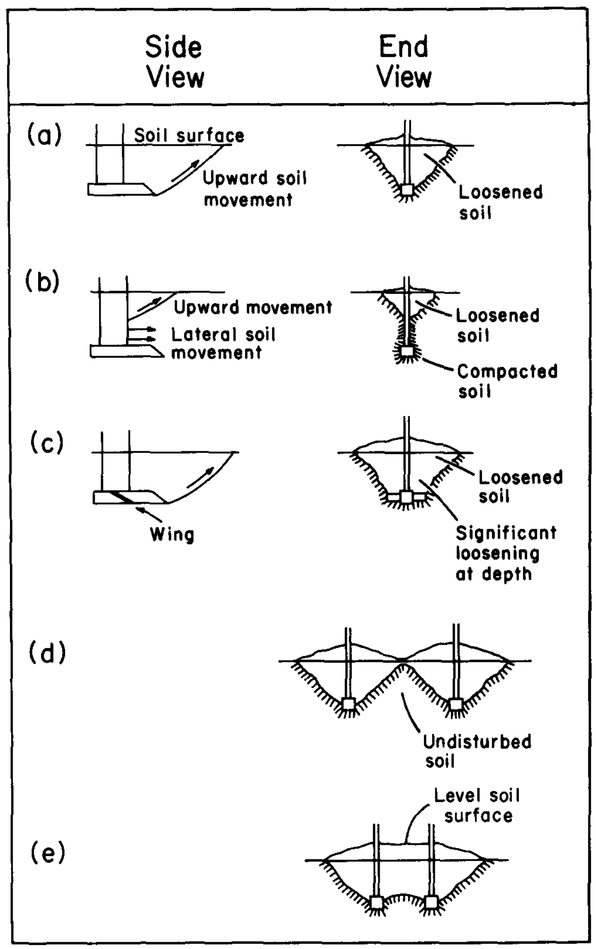


Figure 12. Effects of various subsoil tines: subsoiler (a) above critical depth and (b) below critical depth; (c) winged subsoiler above critical depth; soil disturbance (d) at wide tine spacing and (e) at narrow tine spacing (adapted from [9]).

layer of soil to prevent it from being blown away by wind or washed away by water. Hemphill [7] found vermiculite more effective than phosphoric acid (Table 4) in promoting emergence of vegetable seeds.

Table 4. Evaluation of anticrusting materials for vegetable crops (adapted from [7]).

	Number of seedlings emerged per meter of row at 14 days		
Treatment	Carrot	Lettuce	Onion
Control	4.7	4.7	5.2
Phosphoric acid	8.8	9.0	8.3
Vermiculite	15.7	27.3	17.3

6.8 Northwest Nurseries: Assessment of Soil Physical Properties

Of the soils identified in the OSU Nursery Survey (see chapter 1, this volume), 54% were sandy loams, 18% loamy sands, 12% loams, 8% silt loams, and 8% clay loams.

The sandy loams had 2 to 3% organic matter. Most managers prefer an organic matter content of at least 5% and are actively adding organic matter to their soils. Most tillage equipment can be used on sandy loam soils, which are relatively easy to till; tilth improves as organic matter is added. Good tilth in sandy loams depends predominantly on maintaining high levels of actively decomposing organic matter.

The loams to clay loams, which are finer grained, store more water and can be tilled effectively only over a narrow range of water contents. Seedbed preparation, which consists of breaking the soil into fine aggregates, is more difficult, as is separating soil from roots during lifting. However, these characteristics depend upon the type of clay. For example, the clay fraction of soils formed on volcanic materials has relatively low cohesion and adhesion.

Rototillers are used in almost all nurseries. Some managers realize that this equipment destroys soil structure by pulverizing the soil too much and leaving a compacted layer just below depth of working; nevertheless, rototilling is often the easiest way to get the fine seedbed desired for uniform germination of small seeds. Although rototillers are often singled out, any tillage operation has the potential to destroy soil structure and create tillage pans in the soil. Therefore, the best general management guide is to decrease the number of tillage operations to the minimum necessary for seedbed preparation.

Of the soil-related problems identified by nursery managers (Table 5), compaction and organic matter maintenance were the major concerns. Preventing compaction requires that soil not be worked when it is at a water content near field capacity. Because this is often unavoidable, compacted zones have to be ameliorated by ripping. The large emphasis on maintaining organic matter seems justified, based on its many benefits, although a few soils have inherently good physical properties at low organic matter levels. Certain amorphous or oxide clay minerals can impart good structure. For most soils, however, organic matter is essential to good soil structure.

Table 5. Soil-related problems in Northwest nurseries (OSU Nursery Survey).

	% of time	
Problem	Considered a problem	Listed 1st or 2nd in importance
Compaction	62	24
Organic matter maintenance	62	19
Poor drainage	43	19
Wind abrasion	34	19
Too much variation	29	14
Too "heavy"	29	14
Uneven topography	24	5

Poor drainage was identified as a problem, although most managers rated their soils as having good drainage. The poor drainage may result from unevenness in the fields, identified as a problem by a quarter of the managers. Inadequate drainage may be more of a problem than managers realize, however, because its effects are subtle. Decreased root growth, decreased efficiency in nutrient uptake, and plant changes due to decreased aeration will reduce seedling growth uniformly over an area; therefore, the amount of the decrease may not be apparent. Intensive management of soils usually requires artificial drainage.

Soil variation within a field makes it difficult to manage the field uniformly. Variation in physical properties is hard to correct; often, the variation occurs over such a small scale that different units cannot be separated as different fields. Land with excessive variation over a small area should be avoided for use as nursery sites.

Soil splash, often a first step in crust formation, has been identified as a problem in some nurseries. Soil splash will be controlled by the same preventative measures used to control crust formation.

Success in maintaining a good physical environment for growth of seedlings depends upon a wise choice of site and wise manipulation of the soil. The objective of this manipulation is to maintain a stable soil structure with a sufficient volume of pores of different sizes to allow for the important fluxes of air, water, and nutrients and for water storage. The soil must resist compaction, puddling, and crusting to maintain this pore assemblage. No "magic" substance can be added to soil to achieve a stable structure—this is truly a management concern. Maintenance of organic matter, adequate subsurface drainage, use of soil-building crops in a rotation, and judicious tillage are all parts of a successful soil-management program.

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