CHAPTER THIRTY-TWO

Soil Compaction

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Although most people think of soil as a solid material, it actually consists of a mixture of solid particles and the pores that exist between them. Biologically speaking, the porosity of a soil is just as important as its solid particles because the pores conduct the water necessary for plant growth and the air necessary for root and microbial respiration.

Soil compaction symptoms appear:
All ages
Any time thoughout rotation

Soil compaction can be defined as the decrease in pore space—most importantly, a decrease in the size of the pores—through either natural or cultural means. Although the soil in the entire plow layer will become compacted to some degree, the adverse effects of compaction can often be traced to specific compacted layers, or "pans," which usually develop at certain depths in the soil. Even though soil pans often form below the normal rooting zone, they restrict soil drainage, which in turn adversely affects the soil layers above.

The physical effects of compaction include an increase in bulk density and soil strengths and a decrease in drainage (permeability), water-holding capacity, and air movement within the soil. These physical effects cause a degradation in the biological and chemical properties of the affected soils. Restricted exchange of air and water reduces seedling root growth and encourages pathogenic organisms at the expense of favorable microorganisms such as mycorrhizae. After extended periods of compaction, the conditions in poorly aerated soils can reduce mineral nutrient uptake. Alone or in combination, these compaction-induced changes in soil properties can impair the growth of forest tree seedlings.

Figure 32-1. Soil compaction can result in poor root development. In this seedling, fine roots have failed to develop.

Figure 32-2. Roots killed by soil compaction. A soil pan that obstructs drainage causes an anaerobic environment, making root survival impossible. Dead roots are dark gray or black.

Occurrence: species and season

All seedling species and stock types are susceptible, and because soil compaction affects root function and growth, seedlings of all ages are affected. Some species are more tolerant of poorly drained soils than others. Three-needle pines and cedars are most tolerant, seven-needle pines are less tolerant, and Douglas-fir and true firs are most susceptible. The occurrence of compaction injury and the degree of damage depend more on soil characteristics and nursery

Figure 32-3. Diseased roots also indicate soil-compaction problems. Phytophthora root rot is often found in areas where drainage is poor because soil is compacted.

cultural practices than on species of seedling.

Symptoms

Compaction can be diagnosed by observing seedling symptoms and by testing the soil. Because compaction primarily affects the root system, many of the initial symptoms are hidden underground. Problems with reduced seedling vigor and growth rate soon develop, however, and many of the visible shoot symptoms can be attributed to earlier root problems. Specific symptoms of compaction are poor root development, particularly of the fine roots; dead and diseased roots; and chlorotic and stunted seedlings.

Poor root development. Compaction increases soil strengths, making it more difficult for seedling roots to penetrate compacted soil. Seedlings grown in compacted soils generally have poorly developed or distorted root systems. They often lack fine roots (Figure 32-1) and their root volumes are generally smaller than those of seedlings from surrounding uncompacted areas.

Dead and diseased roots. Roots that die as a result of compaction are dark gray or black in color and are often found at a uniform depth in the soil. This zonal pattern is caused by a soil pan that prevents drainage, resulting in a continuously saturated, anaerobic environment in which survival of roots is impossible. Diseased roots often indicate a soil compaction problem (Figure 32-2). Such root pathogens as *Pythium* and *Phytophthora* flourish under the saturated soil conditions created by compaction (Figure 32-3).

Chlorotic and stunted seedlings. Seedlings grown in compacted soils often become chlorotic and stunted in their first growing season (Figure 32-4). In extreme cases the new needles on the terminal may appear burned. Compaction symptoms generally occur in regular patterns across the seedbeds. These patterns can sometimes be correlated to the ways in which nursery equipment has been used—the direction of plowing or ripping, for example.

There are many ways to assess compaction in nursery beds, some of which require special equipment and training. The following techniques are the most practical for the nursery manager:

Shovel penetration—In this quick test, a shovel is used to determine whether compaction is present. If the weight of a person standing on a shovel in a moistened seedbed is not enough to make the shovel pass easily through the soil profile, compaction is likely. The main factors affecting shovel penetration are the moisture content of a given soil and the amount of pressure applied to the shovel. Any measurement of the soil strength should be done when the soil is uniformly moist (the drier the soil, the harder it is to penetrate) and when its moisture content is known, so that comparative measurements can be taken. Establish a standard sampling time by taking measurements 1 to 2 days after a deep irrigation. This should assure a similar soil moisture content for each test.

Figure 32-4. Poor 1+0 seedling growth due to soil compaction. Tall seedlings are growing in uncompacted soil. Stunted seedlings were sown in soil that was inadequately cultivated.

Cone penetrometer—The shovel test is quick but not highly accurate, since it is difficult to quantify the pressure on a shovel. A cone penetrometer measures the force needed to push a standard rod with a sharp tip through the soil. The penetrometer is a very reliable tool for quickly assessing whether there is a compacted layer in the soil. Moreover, because several readings can be made only inches apart, the penetrometer can be used in seedbeds with little disturbance to seedlings. Because penetrometer readings are relative, nursery managers must establish standards for their own soil conditions. This can be done by taking readings in areas where seedlings are showing visual symptoms of compaction and comparing them with readings taken in soil of the same type in which healthy seedlings are growing. Using these standards, managers can identify compacted areas before seedlings begin to show symptoms. If symptoms are already evident, a penetrometer can determine whether compaction is the problem.

Soil compaction may be confused with:
Phytophthora root rot
Nematode damage
Mineral nutrient problems

Ring infiltrometer—Poor drainage due to compaction can be diagnosed with a ring infiltrometer, which is a circular metal ring or tube that is pushed into the soil and filled with water. The time it takes for the water level to drop a designated distance inside the ring is an indication of the permeability of the soil. The slower the water moves into the soil, the more serious the compaction. A related but simpler technique is to dig a series of small holes at several depths in the test area, fill them with water, and monitor the water level.

Figure 32-5. Soil type, moisture content, and equipment use are all factors in soil compaction. Lifting seedlings when soil is too wet can be particularly damaging to soil.

Predisposing factors

Compaction in agricultural soils is primarily a function of soil type, soil moisture content, and equipment use. Each soil has its own characteristic response to compactive forces which depends on soil mineralogy and texture and the type and amount of organic matter in the soil. Soil mineralogy and texture are very important factors. Finer-textured silts and clays are more subject to compaction than coarser-textured sands. Because soil structure is improved with humus—the end product of the decomposition of organic matter—soils containing high organic matter levels are resilient and resist compaction.

Soil moisture content is one of the most critical factors. Within a given soil textural class, compaction increases with moisture content. The timing of heavy equipment use is also critical; many compaction problems result from using tractors and other equipment during excessively wet periods, especially during the winter lifting season (Figure 32-5).

Loss potential

Compaction is rarely a direct cause of mortality, but its effects can severely reduce the number of shippable seedlings per unit area of seedbed. Growth losses due to compaction result in a higher cull rate and poorer overall stock quality. Compaction losses generally show up on the grading table in the following cull categories: stunted and chlorotic seedlings, sparse or diseased roots, and mechanical damage to root systems.

Stunting and chlorosis caused by soil compaction begins in the first year and often carries over into the second. Growth losses can be considerable in 1+0 stock types, but the impact on 2+0 seedlings can be minimized with corrective cultural practices.

Poorly developed root systems are a result either of the adverse growing environment or the activity of root-disease organisms in compacted soils. Because of their minimal root systems and related poor root-to-shoot ratios, seedlings from compacted soils are normally culled during the grading process.

Moreover, seedlings growing in compacted soils often suffer extensive root damage when they are harvested. Depending on the amount of compaction present and the type of lifting method used, such damage can result in very high culling losses.

Root injuries, especially minor root infections, are often difficult to recognize on the grading table. If these compaction-related problems are not identified during grading and packing, seedlings with inferior root systems will perform poorly in the field when outplanted.

Management

The best management practice is to prevent compaction in the first place. Nursery managers can use the following techniques to prevent compaction or minimize its effects:

1. Selection of seedbeds. Growers should identify and map compacted areas, leaving them unplanted until corrective action can be taken. Stock types that are most sensitive to compaction, such as 1+0 seedlings, should be planted in the best soils available.

2. Maintenance of organic matter. Green-manure crops, cover crops, and organic-matter amendments can increase, or at least maintain, the level of organic matter in the soil.

3. Subsoiling. This specialized form of tillage, also called deep ripping or chiseling, breaks up compacted layers at depths greater than 12 inches. The tool most commonly used for this operation is the subsoiler, which is designed to fracture compacted soil layers or pans. Soil moisture content is critical for successful subsoiling. If conditions are too wet, the subsoiler tines will slice through the soil instead of shattering it. If it is too dry, blocks of compacted soil will resist being fractured. The proper soil moisture level will vary with soil type; each nursery must determine the proper conditions for its own soils. A minimum of two passes should be performed, with the second pass at an angle of 30 to 45 degrees from the first. The tines should not be drawn too deeply on the first pass. It is more effective to set the tines relatively shallow initially and then lower them on the second and third passes.

4. Minimizing the use of heavy equipment. In new or recently subsoiled seedbeds, use of heavy equipment should be kept to a minimum. In fact, the first three passes of a heavy machine over an uncompacted nursery bed are the most damaging. The type of equipment used is also important. Equipment operators should be instructed always to use the smallest tractor that will perform the task. Dual-tire and crawler tractors should be used whenever possible because they compact the soil less than single-tire tractors. The best time to operate heavy equipment on most soils is when they are dry. Unfortunately, certain nursery operations, such as harvesting of seedlings, must be conducted during the winter season when soils are wet and most subject to compaction.

5. Wrenching. After the seedlings emerge, compaction can be mitigated to some extent by wrenching the seedbed. Wrenching consists of drawing a horizontally mounted angled blade under the seedlings, which shatters the soil around their roots. As with subsoiling, the proper soil moisture content and blade depth must be tested at each nursery to achieve the proper results. Wrenching is the only practical means of reducing compaction after the crop has been sown.

Selected references

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