CHAPTER 1—BASIC CONCEPTS OF SOIL MANAGEMENT

By: Jack T. May
Forest Nursery Consultant
Dadeville, AL
(Professor Emeritus,
University of Georgia)

TABLE OF CONTENTS

LIST OF TABLES

---

*The pages in each chapter in this handbook are numbered independently of the other chapters. The first numeral refers to the chapter, followed by the page number in that chapter.

List of Tables (continued)

LIST OF FIGURES

INTRODUCTION

Intensive management is needed to grow 700,000 to 800,000 plantable seedlings per acre in a nursery. This requirement is particularly strong when the nursery is in production for many years. The nursery soil and the practices for its management are the core of the entire seedling production program. Southern pine seedlings are an outstandingly valuable crop, at between $8,000 and $15,000 per acre of seedlings (1980 values).

Soils differ in many characteristics from nursery to nursery and even within a single nursery. Consequently a knowledge of soil properties and the effects of nursery management practices is extremely important.

PHYSICAL CHARACTERISTICS

Soil is the primary medium for plant growth. Its characteristics have resulted from the forces of climate and living organisms (including man) acting upon the parent material, over time. The three physical phases of soil are: solid, liquid and gas. The solid phase is a mixture of mineral and organic particles—humus and partly decayed residues of dead plants and soil animals. This provides the skeletal framework of the soil.

A system of pores not only permeates the soil but also is continuous with the outer atmosphere. The pore space is shared jointly by (1) the liquid phase, which consists of water with various quantities of dissolved substances and (2) by the gaseous phase which makes up the soil atmosphere. The solid phase of the soil is relatively stable in its composition and organization. In contrast, the other two phases are constantly changing as a result of the continuous interchange of water and air between the soil pores and the outer atmosphere. The volume that will be occupied by each component in a loam soil of good tilth is approximately: 45 to 48 percent mineral matter; 2 to 5 percent organic matter; 25 percent water and 25 percent air (figure 1-1).

Soil Texture

Soil texture refers to the relative proportions of the various size groups of individual soil grains in a mass of soil. Specifically, it refers to the proportions of clay, silt and sand smaller than 2mm in diameter.

Several classifications exist; the USDA Forest Service system (USDA 1961) is used here (table 1-1). Sand particles vary from 2.0 to 0.05 mm in diameter, in contrast to silt particles which vary from 0.05 to 0.002 mm. Both sand and silt mainly consist of minerals derived from parent rock, unchanged by weathering. In contrast, the clay fraction (<0.002 mm) consists predominantly of colloidal minerals formed as products of weathering. The actual size distribution can only be determined by laboratory analysis. Reasonably accurate determinations of broad soil textural classes can be made in the field by feeling with the fingers, supplemented by examination under a hand lens. (Appendix 1-1). Specific details of field

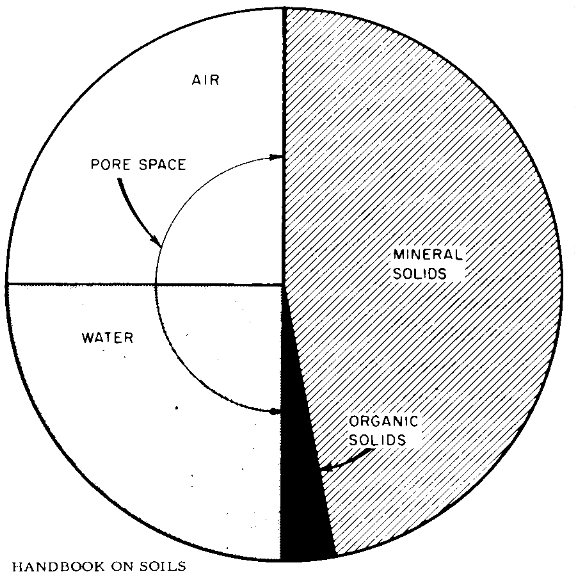


Figure 1-1. – Volume composition of an "average" soil.

From: Handbook on Soils, USDA Forest Service 1961

determinations are included in chapter 2 Site Selection. The Textural Triangle is represented in Figure 2-1 (chapter 2).

Table 1-1.—Percentages of sand, silt, and clay in several textural classes.

Textural name (Soil class)	ange in percent		
	Sand	Silt	Clay
Sand 1/	85-100	0-15	0-10
Loamy sand 1/	70-90	0-30	0-15
Sandy loam 1/	43-80	0-50	0-20
Loam	23-52	28-50	7-27
Silt loam	0-50	50-88	0-27
Silt	0-20	88-100	0-12
Sandy clay loam	45-80	0-28	20-35
Clay loam	20-45	15-53	27-40
Silty clay loam	0-20	40-73	27-40
Sandy clay	45-65	0-20	35-55
Silty clay	0-20	40-60	40-60
Clay	0-45	0-40	40-100

[1] Coarse : Greater than 25 percent coarse sand.

Fine : 50 percent or more fine sand; less than 25 percent coarse sand.

Very fine: 50 percent or more very fine sand.

Source: U. S. Department of Agriculture, Forest Service. Handbook on Soils, FSH 2559.2. Washington, D.C.: U. S. Department of Agriculture, Forest Service [Unpublished administrative document]. Rev. 1966. 296 p.

Sand particles may be 90 to 95 percent quartz—e.g., in soils derived from sedimentary deposits. Alternatively, sand may include substantial portions of feldspar, mica or calcium carbonate, depending on the parent material. Clay particles have these important properties: they can hold nutrients and water required by plants, and they swell or shrink as the soil becomes wetter or drier—depending on the mineralogy of the clay.

An ideal nursery soil should be well drained and have about 10 percent clay and 15 percent silt. Soils within these limits fall into the sand, loamy sand and light sandy loam texture classes. The coarser textured soils warm up earlier in the spring, are usually well drained and easily cultivated. Lifting seedlings is easier from those soils, as less soil adheres to the roots. Winter work is difficult and may become impossible on the finer textured soils in wet periods. The finer the texture, the easier it is to create a plow sole or cultivation pan resulting in poor internal drainage. The spaces between individual clay particles in clay soils are minute and natural drainage channels occur only between soil aggregates. Normally, when filled with water, the spaces between individual clay particles will not drain under the force of gravity; natural drainage channels are open only after some drainage has occurred.

Soil Structure

The sand, silt and clay particles of soils rarely exist as discrete units or single particles but usually as aggregates of particles. These aggregates collectively comprise the soil structure and may consist of compound particles, clusters or primary particles which are separated from each other by weak bonding or by an air space. The natural structural units found in soils as a result of soil-forming processes are called peds. Other natural units are clods and concretions. Clods are formed by plowing and concretions result from the irreversible cementing of soil grains together by localizing concentrations of certain compounds such as iron or manganese oxides or lime.

Because soil structure is not easily measured and there are no precise expressions for structure, descriptions must be used. Basic geometric forms of structure in southern nurseries are (1) blocky, (2) spheroidal and (3) structureless (figure 1-2). The structure is blocky when the peds are cubic with three dimensions of the same order of magnitude arranged around a point and the surfaces are casts of molds formed by faces of the surrounding peds. With spheroidal structure (crumb or granular), the curved surfaces are not related to the faces of the surrounding units. Soil is structureless when primary particles have no definite arrangement. Plowing and mechanical lifting of seedlings when the soil is too wet or too dry or pulverizing the soil with a rototiller may destroy a granular or blocky structure.

The size of individual structural units is indicated by the terms "very fine", "fine", "medium", "coarse" and "very coarse" and varies with the structural type. The grade of the soil structure may be expressed as *weak*, if the structural units are not very evident in the soil mass;

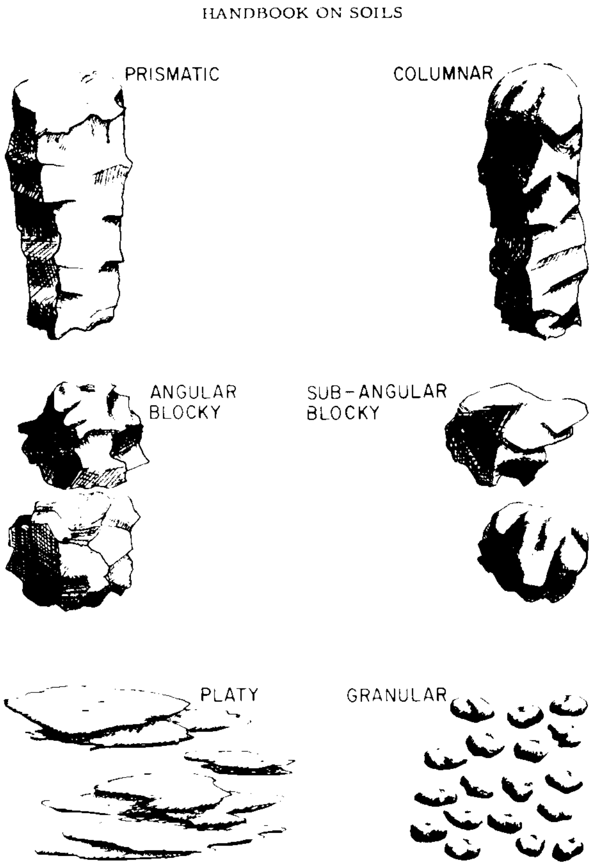


Figure 1-2. – Types of soil structure.
From: Handbook on Soils. USDA Forest Service 1961

moderate, if they are evident, but are not distinct; and *strong*, if very evident in the soil.

Sands generally have a single-grain structure. Organic matter tends to form sand into fine or medium aggregates that break up easily. Silty or clayey soils tend to have medium to coarse and moderate to strong subangular or angular blocky structure. Platy, prismatic and columnar forms of structure are rare in soils of southern nurseries.

Structural stability relates to the permanence of soil aggregates and is important to the physical character of the soil. The degree of stability is a reflection of the chemical and biological factors of the soil. Factors influencing the stability of soil structure are:

1. kind of ions countering the negative charge of the clays
2. cementation by lime, silica and sesquioxides
3. organic matter

Maximum bonding and stability is afforded by Ca^{++}, Mg^{++}, Al^{+++}, i.e. bonds of high valence.

The effect of organic matter is due both to noncoherent coatings of humic substances that prevent the coalescence of neighboring soil particles, and the mucilagenous materials or organic colloids that bind clay and other soil grains into stable aggregates.

The capacity of any soil to support growth of plants, and the response of the soil to management, depend as much on the soil's structure as on its nutrient level. In dense, weakly structured soils, there may be insufficient oxygen to supply the needs of plant roots and microorganisms. Infiltration and percolation of water may be too restricted. As a result, the growth of plants is retarded.

Management and modification of soil structure is primarily associated with the control of soil organic matter. Desirable surface soil structure results from the combination of three factors:

1. physical effects (freezing and thawing, wetting and drying).
2. chemical effects (presence of adequate bases such as calcium).
3. biological action (return of plant or animal residues to the soil for decomposition).

Bulk Density

Bulk density of a soil is the dry weight of a soil per unit of soil volume. The bulk density of a soil is least immediately after cultivation. Equipment operation may compact the soil to a depth of 2 to 4 inches or more. Rain and irrigation water will compact the soil and increase the bulk density, especially if the soil surface is bare. Organic soils have a lower bulk density than mineral soils, and additions of organic matter to mineral soils will reduce bulk density.

Bulk densities of several textural classes of forest soils range from about 1.27 g/cc for loams, to 1.38 g/cc for clays, to 1.43 g/cc for sands (USDA 1961). The average bulk density for agricultural soils in Georgia is about 1.38 g/cc. A variation of from 1.20 to 1.80 g/cc may be found in sands and sandy loams. Contrary to popular belief, even sandy soils can become very compact. Very compact subsoils and plow layers, regardless of texture, may have bulk densities as high or higher than 2.0 g/cc. Penetration of the soil by roots is difficult above a bulk density of 1.4. It is severely restricted at 1.6 and prevented at 1.8.

Particle density of mineral soils is usually defined as the mass or volume weight of a unit volume of soil solids, eliminating all pore space, expressed as g/cc. The particle density of mineral soils over the world varies from approximately 2.60 to 2.80 with an average of approximately 2.65 g/cc.

Soil aeration, permeability to water and the space available for root growth and water storage decreases as bulk density approaches particle density.

When the bulk density of soil is known in terms of grams per cubic centimeter, its approximate dry weight in pounds per cubic foot may be found by multiplying by 62.4, the standard weight of a cubic foot of water. Clayey and silty surface soils may vary from 65 to 100 pounds per cubic foot, while sands and loamy sands may vary from 75 to 110 pounds (table 1-2).

The actual weight of a soil may also be expressed in terms of an acre-foot, i.e., a volume of soil 1 acre in area and 1 foot deep. The weight of an acre-foot of mineral soil ranges from about 3 million to 4.5 million pounds of dry mineral particles. Figures of 2 million pounds per acre-inches (in the southern region) or 2.5 million pounds for an acre-furrow slice (in the northern region) are commonly used as the weight of agricultural soils. The use of this quantity is convenient for nurserymen because the additions of fertilizer material can be readily related to the manner in which the amounts of nutrients are frequently expressed for soil analysis data. If the amount of P in a soil sample is 50 parts per million (ppm), it is the same as 100 parts per two million (pp2m) or 100 pounds per acre of P in the upper 6 inches.

Table 1-2. — Representative bulk densities for several textural classes.[1]

Soil-texture class	Bulk density	
	Grams per cubic centimeter	Pounds per cubic foot
Sand	1.43	89.2
Loamy sand	1.35	84.2
Sandy loam	1.36	84.9
Sandy clay loam	1.36	84.9
Loam	1.29	80.5
Silt loam	1.27	79.2
Silty clay loam	1.34	83.6
Clay loam	1.44	89.9
Silty clay	1.35	84.2
Clay	1.38	86.1
Coarse	1.38	86.1
Medium	1.28	79.9
Fine	1.37	85.5

[1] Adapted from USDA Forest Service, Southern Forest Experiment Station, Occasional Paper 166.

Bulk density values may be used to convert moisture percentage values (oven-dry weight basis) to inches or centimeters of water which is the normal form for expressing precipitation or irrigation water. For example, if the amount of water in the soil is 15 percent oven dry weight and the bulk density is 1.3 g/cc water percent (by volume) = water percent (by weight) (bulk density)

$$= 15 \times 1.3 = 19.5 \text{ percent}$$

This water percent by volume may be expressed more conveniently in either inches or centimeters.

$$\text{Inches of water} = \frac{\text{percent water by volume}}{100} \times \text{soil depth (inches)}$$

$$= \frac{19.5}{100} \times 12 = 2.34 \text{ inches of water in 12 inches of soil}$$

$$= \frac{19.5}{100} \times 7 = 1.36 \text{ inches of water in 7 inches of soil (plow layer depth)}$$

$$= \frac{19.5}{100} \times 1 = 0.195 \text{ inches of water in 1 inch of soil.}$$

$$\text{Centimeters of water} = \frac{19.5}{100} \times 17.8 \text{ (centimeters)}$$

$$= 3.47 \text{ cm water per plow layer depth (17.8 cm)}$$

$$= 0.195 \text{ cm of water in 1 cm of soil}$$

Also see Soil Moisture: Chapter 11.

Pore Space

The pore space of a mineral soil is that portion occupied by air, water, soil organisms and plant roots. The amount of pore space is determined largely by the arrangement of the solid particles (figure 1-3). If particles tend to lie close together, as in sands or compact subsoils, the total porosity is low. If they are arranged in porous aggregates, as is often true of soils high in organic matter, the pore volume per unit total volume will be high. Two types of individual pores generally occur in soils: macropores and micropores. Macropores characteristically allow the ready movement of air and percolating water. In spite of the low total porosity, the movement of air and water is surprisingly rapid in sandy soils because of the dominance of the macropore.

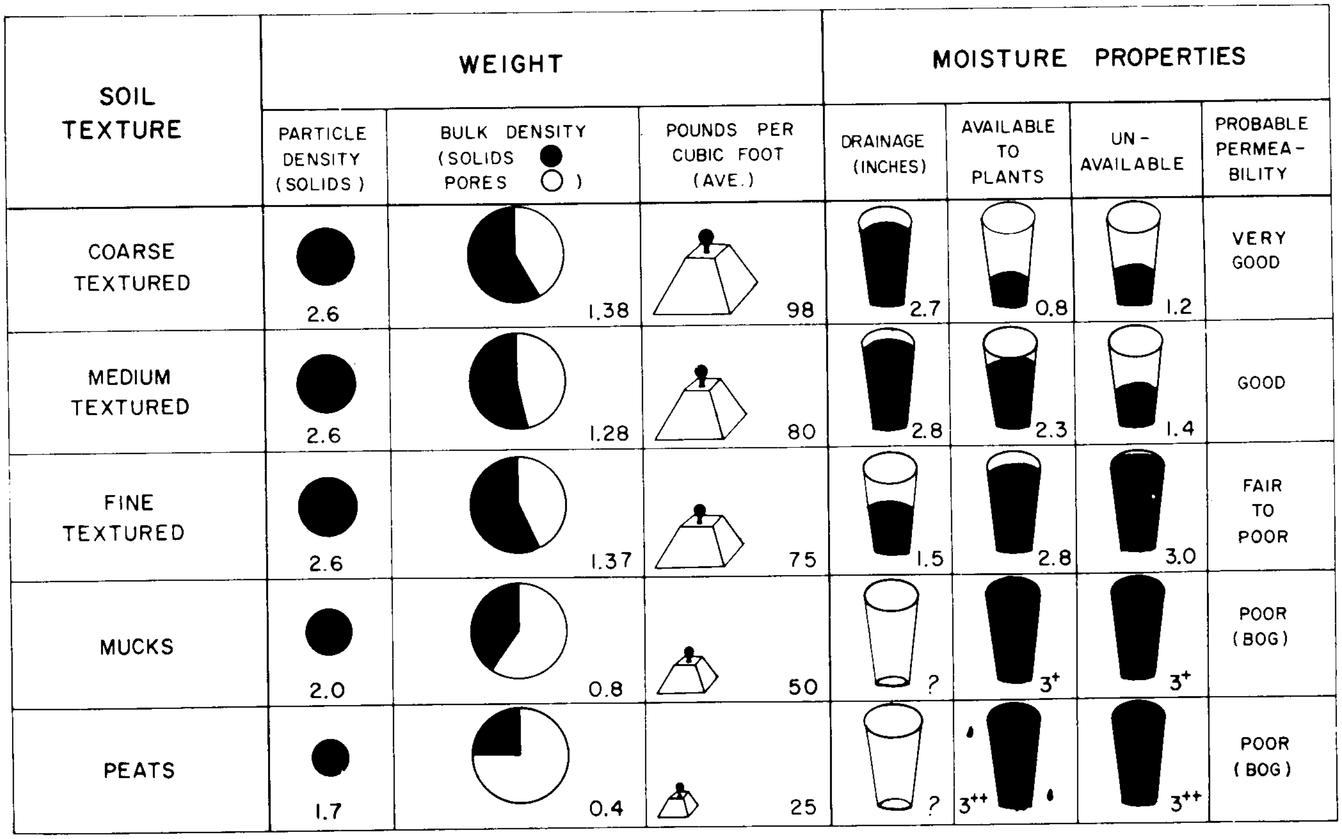
In fine-textured soils with the micro type of pore, air and gas movement are relatively slow while water movement is restricted largely to slow capillary movement. Therefore, micropores act as reservoirs holding water for root absorption. If these micropores remain full of water for long periods of time, aeration would be inadequate for satisfactory root development and desirable microbial activity.

Continuous cultivation or cropping of seedlings results in a decrease in organic matter and a consequent lowering of granulation, a reduction of macropores and the total pore space, and a more or less proportional rise in the micropore space.

Germination of seeds and seedling growth in soils of excessively small pore space is limited because of (1) lack of oxygen and (2) restricted root or shoot penetration that results from hard, impenetrable crusts that may form on the surface. Small amounts of silt or clay can form a crust on the surface layer of sandy or silty soils after a rain or irrigation.

Organic Matter

The organic content of a soil is derived from the remains of plants and animals. Upland virgin mineral forest



SOIL TEXTURE	WEIGHT			MOISTURE PROPERTIES			
	PARTICLE DENSITY (SOLIDS)	BULK DENSITY (SOLIDS ● PORES ○)	POUNDS PER CUBIC FOOT (AVE.)	DRAINAGE (INCHES)	AVAILABLE TO PLANTS	UN-AVAILABLE	PROBABLE PERMEA-BILITY
COARSE TEXTURED	2.6	1.38	98	2.7	0.8	1.2	VERY GOOD
MEDIUM TEXTURED	2.6	1.28	80	2.8	2.3	1.4	GOOD
FINE TEXTURED	2.6	1.37	75	1.5	2.8	3.0	FAIR TO POOR
MUCKS	2.0	0.8	50	?	3+	3+	POOR (BOG)
PEATS	1.7	0.4	25	?	3++	3++	POOR (BOG)

Figure 1-3.—Soil weight and moisture properties as affected by texture. From: Handbook on Soils, USDA Forest Service 1961

soils in the South may have organic matter levels of 2 to 10 percent. Similar soils that have been cultivated for several decades may have organic matter levels of about 0.5 to 3.0 percent, depending on the cropping system and the extent of erosion.

Organic matter is important in a forest tree nursery because it alters physical, chemical and biological properties of the soil, thus affecting tree growth. Organic matter improves the structural aggregation of both clayey and sandy soils, aids tillage, reduces erosion, increases soil porosity, aids water infiltration and retention, retains nutrients against leaching, makes root penetration easier and reduces lifting damage.

The soil properties altered to the highest degree by an increase in organic matter are: (1) cation exchange capacity (CEC), (2) storage of nutrient elements, (3) chelation of some nutrients; and (4) buffering action.

The CEC of cultivated sandy soils with kaolinitic clay components is about 1 to 10 m.e.*/100 gm. Analysis of 53 soil samples from a new forest tree nursery on excellent farm land gave a CEC range of 1.09 to 3.45 m.e./100 gm, with a mean of 2.09 m.e./100 gm. Soil texture was either sandy loam or loamy sand. Organic matter content ranged from 0.8 to 1.3 percent, averaging 1.0 percent. The incorporation of organic matter is the only practical method to increase the CEC of these soils, as organic matter has a CEC range of 200 to 400 m.e./100 gm. In the sandy soils of the Coastal Plain, the CEC increases at the rate of 2 m.e./100 gm for approximately each 1 percent increase in organic matter (Peach 1939).

Organic matter serves as a reservoir of some nutrients. Virtually all of the nitrogen and phosphorus that have not been added recently as mineral fertilizers are present in the soil in the organic form. The availability of micronutrients, especially boron and copper, is closely controlled by the organic fraction.

Chelating compounds[1] are normal constituents of both the solid organic and the soluble organic materials in the soil solution. They are especially effective in retaining certain minor elements such as iron and zinc. These elements are held in the soil solution in a form that will not precipitate and become unavailable to growing seedlings.

The buffer capacity of a soil refers to its ability to resist a change in acidity. The principal factors influencing buffer capacity are (1) the amount and kind of clay, and (2) the amount of organic matter. Soils having greater amounts of clay and organic matter have greater buffer capacities. Clays with a non-expanding lattice such as

---

*See milliequivalent weight in section on Chemical Properties of Soils.

[1] Chelates consist of the element held in the center of a large organic molecule in a manner that protects the element from immediately reacting with the soil and becoming unavailable before the plant has a chance to absorb it.

kaolinite have a low buffer capacity. The clay fraction of the soils in the southern coastal plain is primarily kaolinitic, although some other clay minerals such as vermiculite, illite, gibbsite, goethite and amorphous iron oxides may be present. The maintenance of a relatively high organic matter content is the only practical method of maintaining a favorable buffer capacity. This is especially important in nursery soils with high pH values (6.0 ±) and extremely low levels of calcium and magnesium.

The biological influences of soil organic matter in forest tree nurseries are almost as important as the physical and chemical properties. The biological effects of organic matter include the mineralization of nitrogen and phosphorus, symbiotic and non-symbiotic nitrogen fixation, an increase in the availability of phosphorus and potassium, suppression of pathogens, enhancement of mycorrhizal development, and the degradation of certain pesticides.

For a short time after the application of organic materials with a high carbon to nitrogen ratio, such as sawdust, nitrogen and phosphorus become tied up very rapidly. Soon thereafter, nitrogen and phosphorus start being mineralized (released) and this mineralization continues slowly over a long period of time. Organic matter also serves as the energy source for free-living organisms in the soil which fix atmospheric nitrogen. Other organisms that are associated with plant roots, such as the *Rhizobium*, also use soil organic matter for their energy until they become established in root nodules. The microorganisms that are responsible for the breakdown of organic matter in the soil simultaneously carry on a number of other important metabolic processes. They enzymatically attack mineral materials in the soil. While decomposing the organic matter, the microorganisms are active in releasing phosphorus and potassium from the mineral material thus increasing the availability of these nutrients to seedlings and cover crops.

There is strong evidence that the proper types and amounts of organic matter added to the soil will reduce the activity of root pathogens. (Campbell, Hendrix and Powell 1972; Berbee 1973; Davy 1965, 1968; Garren, May and Walsh 1955; Maki and Henry 1951). This effect is one of the beneficial functions of saprophytic microflora and is possibly a result of several factors. Examples include competition for nutrients, production of antibotics, production of high levels of CO_2 in the soil atmosphere, direct parasitism of, or antagonism to, the pathogenic fungi themselves, and probably numerous other reasons. When large quantities of sawdust are applied to the soil, pathogens decease and antagonists and cellulose destroyers increase.

During the past three decades, forest nursery practice has included the wide use of chemicals such as Mylone, Vapam, Vorlex, Trizone, Dacthal, Eptam, Treflan, D-D, etc. These toxic chemicals may provide some immediate benefits, but they may also have a very long-lasting, detrimental effect on the soil ecosystem. Two conflicting views are; (1) the continuing use of chemicals is justified by the high cost of the seedling crop and the adverse effects of a shortage of seedlings on the planting program, and (2) drastic and continuing chemical treatments of the soil for pest control are certain to adversely affect the soil ecosystem.

During the 1970's, residual effects of biocides were observed in several nurseries. Symptoms included reduction of root systems, chlorotic foliage, stunted seedlings and a complete absence of mycorrhizae. Complete inactivation of eradicants or biocides may be a lengthy process, but the use of organic matter supplements and catch or cover crops is a relatively fast and simple ameliorative measure.

Forest litter such as leaf mold, duff or raw humus is the best organic additive to biodegrade chemicals and to reclaim soil fertility. This activity is carried out by many diverse microbes in the litter. They have an enormous destructive as well as creative capability. An addition of a mere 5 cubic yards of leaf litter per acre constitutes an important amelioration of biocide-treated soils (Iyer and Wilde 1973).

In northern Europe, England, Canada and the Lake States, peat is a major organic additive. The large external and intercellular adsorbing surfaces and high exchange capacity of peat exert a strong effect on pesticides by adsorbing and complexing their toxic ingredients. Sawdust, upon activation, acquires very high biodegrading and soil ameliorating properties. Herbaceous plants such as cover crops serve an important role as decontamination crops. They help detoxify pesticide-treated soils by the uptake of certain compounds, particularly those containing nitrogen. They also supply nutrients to organisms that breakdown pesticides. The suitability of different plant species depends on their soil requirements and their tolerance to applied chemicals. In general, plants with extensive root systems work best to inactivate pesticides.

The development of mycorrhizae on roots of coniferous seedlings may be enhanced by proper management of the organic matter in nursery soils (Davey 1955; 1965). The status of mycorrhizal fungi is covered in chapter 13.

Soil Air and Water

The amount of water that can be contained in a particular soil depends on the total pore space of the soil, which in turn depends on both texture and organic matter content. Thus the moisture-holding properties of a soil increase with an increasing content of silt, clay and organic matter (figure 1-3). Maximum water holding capacity would be obtained if some drainage restriction allowed all of the pore space in a volume of soil to become filled completely. Under such conditions, coarse-textured soils could contain an average of 38 percent moisture, medium textured soils 42 percent; and fine-textured soils 44 percent.

Completely saturated or water-logged soils are not desirable for seedling growth. However, this condition can develop in a nursery as shown in the following example. The soil was a sandy loam over a sandy clay loam. Precipitation for three consecutive years exceeded 70 inches annually. Cultivation and lifting under wet conditions created an impervious plow pan about 6 to 7 inches below the surface which restricted downward percolation of water. The soil was relatively dry below this compact layer. Consequently, the top soil remained almost saturated during the growing season—resulting in poor seedling growth and small root systems. Excess precipitation became overland flow or runoff, with erosion of seedbed shoulders, alleys, and drainage channels. There was not sufficient acreage to rotate seedling crops and break up the soil compaction. A major renovation of the soil was needed to breakup the hard pan and restore internal drainage.

The soil behaves much like a sponge in taking up and holding water. The first property of a soil in this regard is its ability to allow water to infiltrate the surface and percolate throughout the body of the soil. A high degree of aggregation of the surface soil presents numerous, relatively large pores for the infiltration of water. A soil with a preponderance of fine pores will have a low infiltration rate. Thus a tight, massive or sealed surface layer hinders infiltration. If the rate of application of water to the surface from heavy rainfall or excessive irrigation exceeds the infiltration rate then runoff will occur, with possible erosion damage.

The forces holding water in the soil are primarily surface tension or surface attraction. The pore size is related to soil structure, and to the size of the soil particles both mineral and organic. The large pores in sandy soils will not hold water very tightly and hence most of the rain or applied water is pulled down by gravity and carried away as deep soil drainage. If the soil particles are small, the small pores, sometimes called capillaries, will hold the water much more tightly and little is lost to deep drainage. Thus, as clay and organic matter contents increase, the soil has a larger retentive capacity, and loses increasingly less of its moisture to drainage.

When the soil receives water on the surface as precipitation or irrigation, the water will move downward into the soil as a front. Above the front, the soil is moist and below the front it is relatively dry. The front will continue to move downward as long as water is added to the surface, unless the front reaches an impervious layer. The infiltration and percolation rates are not fixed, but change with the moisture condition of the soil. Within the soil, the water will move from conditions of low force or suction (moist conditions) to those of high force or suction (dry conditions). The pattern of pore spaces within the soil is of great importance in any consideration of soil-water-plant relationships (Armson and Sadreika 1974). A soil with a mixture of pore sizes represents a more desirable condition than one with all large or all small pores. The large pores will facilitate infiltration and rapid movement within the soil and the fine pores will ensure an adequate retention of water for plant use. When there are textural or structural discontinuities in the soil rooting zone, there may be associated differences in soil moisture movement which may affect seedling development.

In soils with adequate drainage, i.e., no restrictions, water will pass through the soil until the forces holding moisture are equal to the force of gravity. The moisture condition of the soil above the front is said to be at field capacity. This moisture level depends mostly on texture and organic matter content. *Field capacity* is defined as the maximum amount of water that a soil will hold after unrestricted drainage. This term pertains to the normal moisture content of a soil that has been thoroughly wet and has not lost moisture from plant use or evaporation. Coarse-textured soils average 12 percent; medium-textured soils 24 percent and fine-textured soils 35 percent moisture at field capacity (table 1-3). The force holding this moisture is about 5 pounds per square inch or 1/3 atmosphere (Figure 1-4).

Only part of the moisture held in a soil at its field capacity is available for plant growth (see chapter 11, figure 11-2). Most plants can extract moisture until the forces holding the moisture to the soil particles are equal to the forces which bring about the uptake of moisture by the plant. Beyond this point, the more succulent plants will wilt and growth of others will be restricted. Figure 1-5 shows the water-air relationships within the soil. See chapter 11 for a more detailed discussion of plant and soil water relationships.

Table 1-3. — Soil moisture contents at various moisture levels and soil textures.

Soil texture	Saturated	Field capacity	Wilting point	Available to plants
		percent		
coarse	38	12	7	5
medium	42	24	9	15
fine	44	35	18	17

CHEMICAL PROPERTIES

The basic properties of soils result from a combination of physical, chemical and biological characteristics. Chemical properties modify the soils' physical and biological properties and vice versa. The chemical nature of the soil controls the supply and availability of mineral nutrients for the growth of plants and affects soil acidity.

Atmospheres		
0	-	Saturation
1/3	-	Field capacity
15	-	Wilting point
31	-	Hygroscopic Coefficient
1000	-	Air dry
10,000	-	Oven dry

Figure 1-4. – Atmospheres of tension.

The principal chemical properties of soils that affect nursery soil management are: (1) the chemical nature and mineralogy of clays, (2) the relative acidity of the soil system and the factors that influence it; and (3) the supply and availability of mineral nutrients for plant use.

Most of the chemical activity in the soil occurs in the clay and organic fractions—the individual particles that are very small, i.e., less than 0.002 mm in diameter. These small particles are not small enough to dissolve, nor are they large enough to be inactive and essentially inert like insoluble sand and silt particles. In the soil, organic matter is closely associated with and often bonded to the clay particles.

The following terms and definitions are associated with soil chemistry:

Anion. A negative ion, e.g., CO_3^{--}, HCO_3^-, SO_4^{--}, PO_4^{---}, $H_2PO_4^-$.

Cation. A positive ion, e.g., H^+, K^+, CA^{++}, Mg^{++}, Al^{+++}, NH_4^+.

Adsorption. The increased concentration of molecules or ions at a surface, including exchangeable cations and an ions on soil particles.

Cation exchange.—The attraction and subsequent interchange of a cation in solution with another cation on a surface of active material.

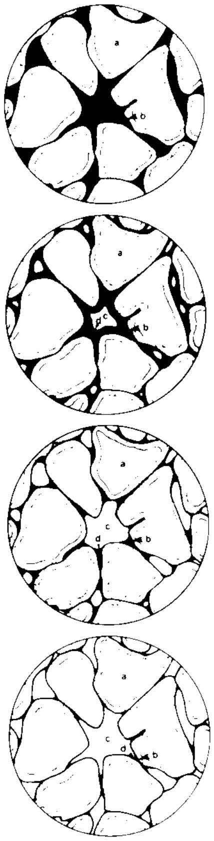
Cation-exchange capacity (CEC).—The total quantity of cations that can be adsorbed by the active material. The value is usually expressed in milli-equivalents per 100 grams of oven dry soil.

Equivalent weight.—The weight in grams of an element, ion or compound that combines with or replaces 1 gram of hydrogen. It is the atomic weight or formula weight divided by its valence.

Milliequivalent weight. One thousandth of an equivalent weight.

Flocculation. Aggregation of small masses.

Dispersed soil. Soil that has little or no resistance to the slaking action of water. Also, it is soil in which the clay readily forms a colloidal suspension.



1) Soil Saturated:

All the interstices in the soil are filled with water and the soil lacks air. The matric potential is very low (-0.1 Bar). Growth is not possible because the stock cannot absorb water owing to lack of air. Transpiration and photosynthesis are negligible.

2) Soil Draining and Close to Field Capacity

The large interstices are emptying and are partially filled with air. The menisci at air-water boundaries have low angles of curvature, so the matric potential is low (-0.1 to -0.3 Bar). Growth will be excellent because both water and air are in excellent supply.

3) Soil Drying

The large and some of the medium interstices are empty and filled with air. The menisci at the air-water boundaries increase in angle of curvature as the soil dries and the matric potential is rising. Growth will be satisfactory unless a high atmospheric evaporative demand causes daytime stress.

4) Soil dry

The large and medium interstices are empty and filled with air. The menisci at the water-air boundaries have high angles of curvature causing high matric potential (-3.0 Bar). Root extension will be negligible and top growth will be severely limited by long periods of stress.

Figure 1-5. – Water and air within a nursery soil.
From: North American Forest Tree Nursery Soils Workshop. Suny. 1980.
R.J. Day

Colloidal State

A colloid is an extremely small particle with special properties not possessed by larger soil particles. Nearly all clay in soils is colloidal and most colloidal clay is crystalline. Principal exceptions are amorphous clays and hydrous oxides of iron, silicon and aluminum. Organic soil colloids are a temporary end product of the decomposition of plants and animals. Humus is the term used to designate organic matter of colloidal size (less than 0.002 mm).

Properties of soil colloids that are important in nursery soils are:

1. The large surface area available on the particles in relation to their weight.
2. The negative charges on the surfaces of the colloids.
3. The particles will pass through an ordinary filter paper, but not through some membranes, such as a plant cell wall.
4. The individual particles are not visible even with the aid of a light microscope.
5. The individual particles will only very slowly settle out of solution unless flocculated. A mass of particles appears as a clay skin or film on the surface of the soil from which water has evaporated. This film is very noticeable on many seedbeds.

Clay Minerals

Clay minerals are usually classified into three groups: kaolinite, montmorillonite and hydrous mica (illite and vermiculite).

Kaolinite is a two-layer clay mineral. One layer consists of aluminum and oxygen and one layer of silicon and oxygen. The structure of kaolinite is a 1:1 nonexpanding lattice. The exchange of cations on the particle is restricted to the broken edges of the mineral, and the average CEC is in the range of 2 to 16 me/100 g.

Montmorillonite is a 3-layer clay mineral with two layers of silicon and oxygen separated by one layer of aluminum and oxygen. Between each two layers of silica-alumina-silica is space that expands when moisture is present. In this space, as well as on the edges, cations such as calcium, magnesium, potassium, sodium, and ammonium are held in exchangeable form, and are available to plants. The structure of montmorillonite is a 2:1 expanding lattice with an exchange capacity within the range of 80 to 100 me/100 g.

Illite is similar in structure to montmorillonite with a 2:1 silica:alumina ratio in its structure. However, it does not expand when wet. Illite has a special characteristic of rapidly fixing large numbers of potassium ions between the nonexpanding plates. The CEC range is about 20 to 40 me/100 g (fig. 1-6).

The dominant clay in nurseries in the southern region is kaolinite, but other clays are present in soils throughout the region. The mineralogy of many of the soils can be obtained from the Soil Conservation Service, USDA or from the Soil Science Departments at the land grant universities.

Cation Exchange Capacity (CEC)

Because many cations in the soil are plant nutrients, the CEC is a measure of the soil's ability to hold nutrients and is also a very valuable measure of the soil's potential fertility status (fig. 1-7). In many southern nurseries, the CEC for the soil may be as low as 1.0 to 2.0 me/100 g. If an increase in CEC is desired it can only be done effectively by increasing the organic matter content of the soil. Peat is one of the most frequently added organic materials in northern nurseries, but it is not economically feasible to use in southern nurseries.

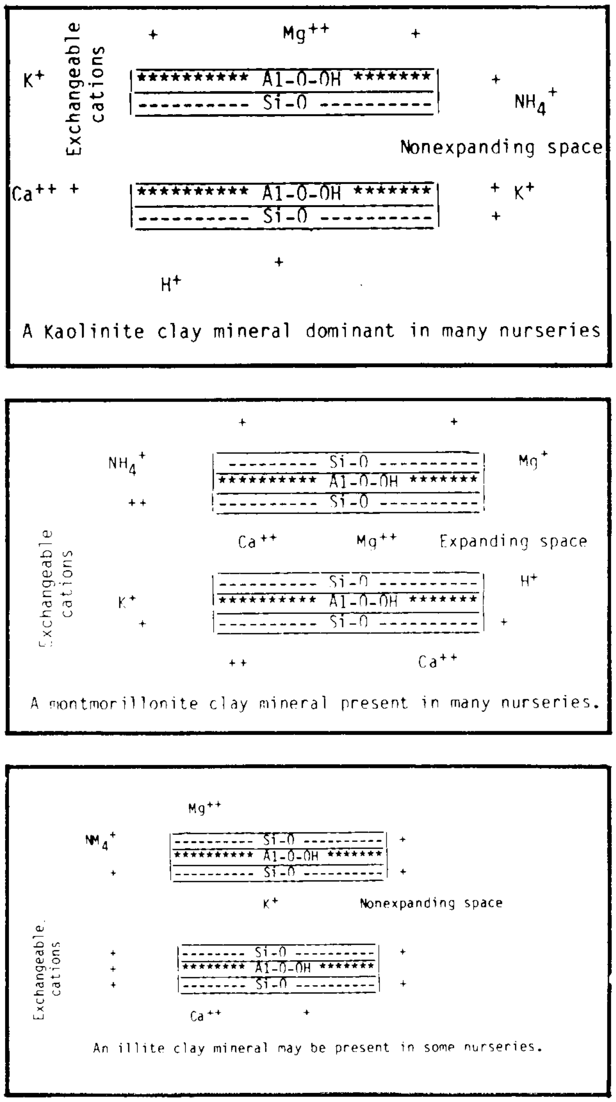


Figure 1-6.—A schematic presentation of the lattice structure of basic clays. From Donahue, Schickluna and Robertson; and other sources.

Additives such as sawdust, shavings, bark, straw and cover crop materials generally have lower CEC values than does peat. As a general rule a 1-percent increase in organic matter concentration in the soil results in an increase in the soil CEC of about 2 me/100 g. Wilde (1958) recommends a CEC range of 7 to 10 me/100 g for nursery soils.

Soil Reaction (pH)

Many physical, chemical and biological processes in the soil, including plant growth depend on soil pH. The pH value of a soil indicates whether it is acid, neutral or alkaline (figure 1-8). Neutrality occurs at pH 7 which is the pH of pure distilled water. At neutrality the concentration of OH^- ions and H^+ ions is the same, because these ions are derived in equal quantities from the ionization of water. In alkaline systems, the OH^- ion concentration exceeds that of H^+; in acid systems the reverse is true. Several systems of expressing ranges of pH are available but the following is most widely used:

Neutral pH 6.6 - 7.4

Acidity	*Alkalinity*
Slight pH 6.0 - 6.6	Slight pH 7.4 - 8.0
Moderate, pH 5.0 - 6.0	Moderate pH 8.0 - 9.0
Strong, below pH 5.0	Strong, above pH 9.0

Specifically, pH is a measure of the active hydrogen ions in the soil. The pH value is defined as the logarithm of

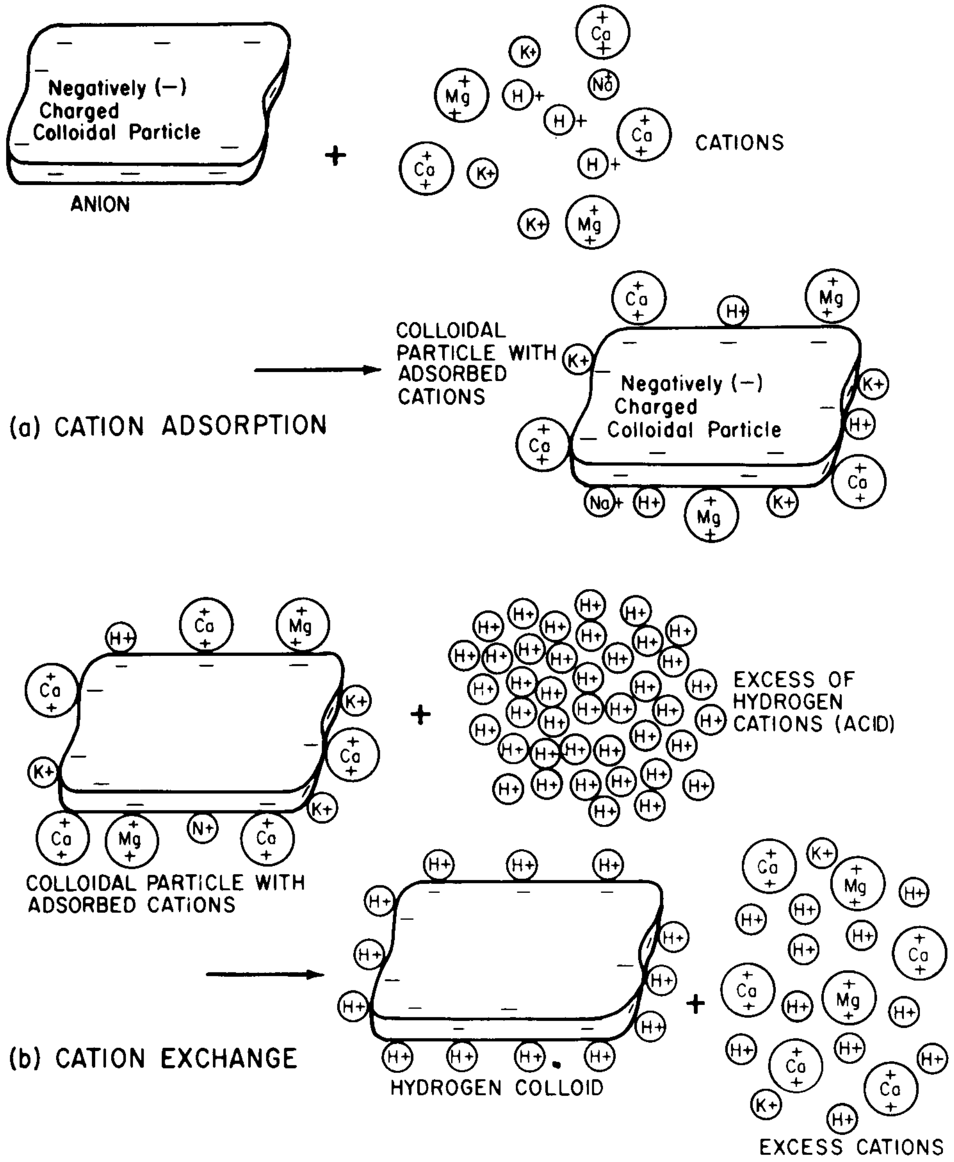


Figure 1-7.—Diagrammatic scheme showing (a) cation adsorption and (b) cation exchange. From Handbook on Soils, USDA Forest Service, 1961.

the reciprocal of the H⁺ ion concentration, i.e., $\text{pH} = \log \frac{1}{(H^+)}$.

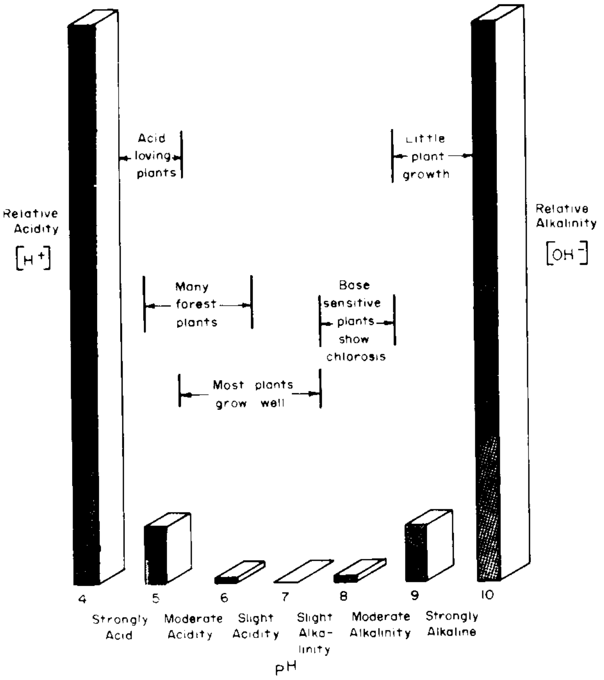


Figure 1-8.—Changes in hydrogen-ion and hydroxl-ion concentrations as a function of pH. From Handbook on Soils, USDA Forest Service, 1961.

The pH value of a soil is not a fixed quantity but will vary depending on the colloidal complex and its associated ions, cation exchange capacity, moisture content, carbon dioxide content (concentration), time of year and type of crop or ground cover. The pH values tend to be higher in cool moist weather or in winter than in hot dry weather or summer. An increase in soil water causes the pH to rise in value. Soil reaction tends to be different under a crop than for fallow land. Differences in pH values of less than 0.3 are not significant and can be ignored.

Soil reaction has a very strong effect on the availability of plant nutrients (figure 1-9). Primary nutrients, phosphorus, nitrogen, and potassium as well as the secondary nutrients—sulfur, calcium and magnesium—are more available at pH 6.5 to 7.5 than at any other pH values. Molybdenum availability is also similar to that of the primary minerals. Minor elements—iron, manganese, boron, copper and zinc—are less available at pH 6.5 than at more acid reactions. The quantity of soluble iron, aluminum and manganese generally increases as soil acidity increases. Both iron and aluminum form compounds of low solubility by combining with phosphate ions in acid soils. Under strongly acid conditions when soluble phosphate fertilizers are applied to the soil, they quickly form insoluble compounds and the efficiency of the applied phosphate is greatly reduced (table 1-4).

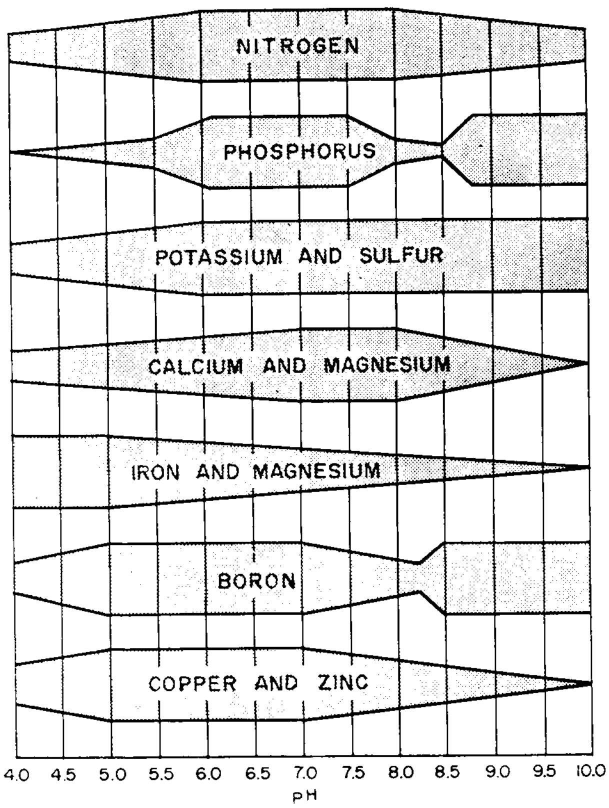


Figure 1-9.—Relative availability of plant nutrients as influenced by pH. The width of the bar indicates the level of availability. From Handbook on Soils, USDA Forest Service, 1961.

BIOLOGICAL PROPERTIES

Most plants grow reasonably well over a fairly wide range of pH values even though they tend to perform best at one specific pH range. Most southern conifers grow best in a soil with the pH between 5.0 and 6.0. Eastern red cedar will generally do better on soils with a higher pH value. Most of the potential cover crops require moderately acid to slightly acid soils for optimum growth (pH 5.5-6.5).

The birth of a soil as a natural body and a productive medium takes place when the geologic matrix is invaded by organisms. Soils of virgin forests have a more complex and yet a more favorable balance of biological properties than agricultural soils. The forest floor usually consists of several distinct layers of vegetative remains. The surface layer, or litter, is made up of partly decomposed leaves, needles, roots, twigs, cones or other plant residues. This layer is superimposed on another layer of partly decomposed plant residues. A lower third layer consists of thoroughly decomposed material which is said to be completely humified. Legions of beetles, larvae, centipedes, millipedes, ants, sow bugs, ticks, mites, rotifers, nematodes, protozoa, algae, bacteria, actinomycetes, and fungi contribute the end product of their metabolism and their dead bodies to the forest soil.

This residue of dead plants and animals becomes the source of life for other organisms. These organisms devour this residue and release simple inorganic compounds. Much of the labor in decomposition of crude organic leftovers is performed in a very inconspicuous and unspectacular manner by the fungi.

Table 1-4. – Soil reaction, lime requirements and fertility conditions.

pH	4.0	4.5	5.0	5.5	6.0	6.5	6.7	7.0	8.0
Acidity		Strongly acid		Moderately acid		Slightly acid		Neutral	Weakly alkaline
Lime requirements		Lime needed except for crop requiring acid soil		Lime needed for all but acid-tolerant crops		Lime not generally needed			No lime needed
Fertility conditions		Phosphates fixed			Phosphates soluble				Phosphate fixed
		Calcium, magnesium and potassium leach		Calcium, magnesium and potassium present in optimum quantities					Boron, iron, manganese and potash may be deficient
		Iron, aluminum, and manganese are soluble				Desirable bacterial and actinomycete activity			
		Fungi thrive							
		Bacteria and actinomycetes languish				Nitrogen freely fixed			

Cultivation of Virgin Soil

Cultivation of a virgin soil produces the following changes: the humus content is reduced, at first rapidly and then more slowly until an equilibrium is attained. The rate of reduction depends upon the soil, the climatic conditions, and the manner of cultivation. In cultivation of the soil, the top layer, including both living and dead materials, is turned over. The rapidly decomposing organic residues that were on the surface are now under the surface, and living material is killed and mixed with residues already dead and decomposing. The lower layer of soil, which was protected, is now brought to the surface. Harrowing or other cultivation brings this fresh soil into more or less intimate contact with air, sunlight and the daily variations of heat, cold and drought. The whole layer of soil from the surface to the lower layer of the plow zone becomes an aerobic environment in which microorganisms find conditions favorable for development. This results in great changes in soil flora and fauna.

Conditions become favorable for the decomposition of organic matter and the release of nitrogen, phosphorus and potassium. The greatest activity occurs wherever green plants are left to decompose in a mixture of dead or dying material.

Addition of Plant Residues

When plant residues are added to the soil, they are attacked by a great variety of microorganisms including bacteria, fungi, actinomycetes, protozoa, earth worms, and insect larvae (table 1-5). For their growth and development, all soil organisms require supplies of energy in addition to several essential elements such as carbon, hydrogen, nitrogen, phosphorus, potassium and sulfur. The source of energy is from the oxidation of simple inorganic substances or complex organic substances, i.e., the organic matter in the soil. Carbon comes from carbon dioxide. Oxygen and hydrogen compounds are usually present in soils in sufficient quantities, although oxygen may be deficient in poorly drained soils. Nitrogen, one of the most important elements in the nutrition of microbes, may be used in the form of complex organic substances or in simple inorganic compounds like ammonium nitrate.

Soil conditions that influence the specific type and activity of microbial populations are temperature, light, moisture, aeration, acidity, organic matter and mineral salts. Most soil organisms function best at a temperature of about 95 °F. Most soil microorganisms are injured by direct sunlight, and many are killed when exposed to it.

Table 1-5. – Important groups of soil organisms in nursery soils.

- I. Bacteria
  - A. Heterotrophic
    - 1. Nitrogen fixers
      - (a) Symbiotic
      - (b) Nonsymbiotic
        - (1) Aerobic
        - (2) Anaerobic
    - 2. Those requiring fixed nitrogen
      - (a) Spore formers
        - (1) Aerobic
        - (2) Anaerobic
      - (b) Nonspore formers
        - (1) Aerobic
        - (2) Anaerobic
  - B. Autotrophic
    - 1. Nitrite formers
    - 2. Nitrate formers
    - 3. Sulphur oxidizers
    - 4. Iron and manganese oxidizers
    - 5. Those that act on hydrogen and various hydrogen compounds
- II. Fungi
  - A. Principal functions
    - 1. Aggregate stabilization
    - 2. Decomposition of organic residues
    - 3. Molds keep decomposition process when bacteria and actinomycetes are slow.
  - B. Hosts
    - 1. Parasitic - disease producing
    - 2. Saprophytic - aids in decay
    - 3. Symbiotic - helps plants (Mycorrhizae)
  - C. Types
    - 1. Yeasts or yeast-like fungi
    - 2. Molds
    - 3. Mushrooms
- III. Actinomycetes - Decompose organic material, especially cellulose and other resistant forms.
- IV. Algae - some fix atmospheric nitrogen
- V. Nematodes
  - A. Those that feed on decaying organic matter
  - B. Those that feed on earthworms, protozoa, bacteria, etc.
  - C. Those that infest the roots of higher plants

The optimum amount of moisture for most soil organisms is between 50 and 70 per cent of the total water-holding capacity of the soil. However, most soil organisms can withstand rather wide extremes in soil moisture content. The development and activities of soil organisms are greatly affected by the concentration and availability of certain gases, particularly oxygen, carbon dioxide and nitrogen. Oxygen is needed for the oxidation processes; carbon dioxide as a source of carbon, and nitrogen for the nitrogen fixing organisms. Abundant oxygen favors the activities of the nitrite and nitrate formers, the nitrogen fixers, fungi, actinomycetes and other organisms that oxidize organic matter.

The degree of acidity of the soil has a particularly important influence on the activities and relative abundance of the different groups of soil organisms. Usually, the beneficial organisms function best in a soil that is approximately neutral in reaction. As a rule, actinomycetes prefer a reaction of 7.0 to 7.5; bacteria and protozoa from 6.0 to 8.0 and the fungi from 4.0 to 5.5. However, each group of organisms can function over a much wider pH range.

Organic Matter as an Energy Source

Because organic matter is the source of food and energy for the majority of soil organisms, the nature of the material is especially important. For example, organic additives and plant material from cover crops can be divided into three categories:

1. Those that contain a certain balanced proportion of available carbohydrates to nitrogen.
2. Those that contain an excess of nitrogen, or more than is required to decompose the carbohydrates;
3. Those that contain an excess of carbohydrates and lignin over nitrogen.

The third group, including both legumes and non-legumes along with sawdust, bark, etc. is low in nitrogen. Materials in this group decompose more slowly than those in the other categories, liberate no nitrogen at first, and leave a large amount of humus. Only when the nitrogen content of a plant is above 1.7 per cent or the C/N ratio less than 15 to 20 is there enough nitrogen to supply the requirements of the decomposing microflora (table 1-6). Organic matter is discussed in more detail under *Organic Matter Supplements* and *Cover Crops*, later in this chapter and also in Chapter 12.

Table 1-6. — Carbon-nitrogen ratio, yields and composition of organic matter sources.

Nature of material	Weight of crop 5-year average		Nitrogen content of tops and roots. 2-year average	Total nitrogen per acre in green manure	Carbon-nitrogen ratio
	Total dry weight per ac. pounds	percent of dry weight in roots	percent	pounds	
*Winter vetch	3,812	20.8	3.49	133	-
*Crimson clover	3,049	21.3	3.03	92	12-16:1
*Winter wheat	2,089	39.3	1.63	34	-
*Winter rye	2,463	35.5	1.29	32	
Young rye	-	-	-	-	20-36:1
Mature rye	-	-	-	-	350:1
Weeds only	1,263	7.9	1.50	19	-
Peat	-	-	-	-	10-20:1
Corn stalks	-	-	-	-	40:1
Straw - oats	-	-	-	-	80:1
Sawdust	-	-	-	-	400:1

*Seeded in standing corn and plowed under the following spring (weight does not include corn). Compiled from several sources.

Mycorrhizae

The need of conifers for ectomycorrhizal associations, especially in the treeless area of the Great Plains has been widely reported (Hatch 1936; White 1941; Goss 1960). In some instances, southern pines have remained inactive or even have died without successful inoculation with suitable ectomycorrhizae (Wakeley 1954). Numerous species of ectomycorrhizal fungi occur over most of the southern pine region, and natural seedbed inoculation in most southern pine nurseries is automatic. The most prevalent species is *Thelephora terrestris*, which thrives under standard nursery operating conditions. Other species that have been observed on southern conifers include: *Amanita* spp. *Amanitopsis vaginata*, *Boletinus* sp., *Boletus luteus*, B. sp., *Cantharellus cibarius*, *Cenococcum grondiforme*, *Cortinarius* spp., *Laccaria (Clitocybe) laccata*, *Lactarius* spp., *Leucopaxillus albissimus*, *Pisolithus tinctorius*, *Rhizopogon* spp., *Paxillus* spp., *Russula lepida* and *Scleroderma vulgare*.

Environmental conditions affect both the occurrence and development of mycorrhizae in nurseries and in the forests. Mycorrhizae develop slowly in highly fertile soils, perferring abundant sunlight and low to moderate soil fertility. Many species of mycorrhizal fungi are not particularly aggressive invaders, i.e., they may be crowded out by other microorganisms.

Some tree species develop more abundant root systems and survive and grow better when infected with a specific mycorrhizal fungus. One ectomycorrihzal fungus, *Pisolithus tinctorius*, (*Pt*), has increased the survival and growth of several pine species used to reforest severely disturbed lands and droughty, infertile land (Marx, Bryan and Cordell 1976; Marx and Bryan 1975; and Marx 1975).

The Forest Service's Institute for Mycorrhizal Research and Development and Southern Region have recently developed techniques for commercial production and practical nursery seedbed inoculations with the vegetative mycelium inoculum of *Pt*.

The inoculum is injected into nursery seedbeds following fumigation with methyl bromide at the rates of 300 to 350 pounds of fumigant per acre. Seeding follows inoculation. Spore inoculation may also be used, but has been less effective than the vegetative inoculum.

Ectomycorrhizae formed by Pt may be visible on pine feeder roots within 6 to 10 weeks after seed germination. Fruiting bodies (basidiocarps) begin to develop in late summer or early fall during moist weather. Inoculation of the soil with *Pt* has significantly increased total ectomycorrhizal development on seedlings of all pine species studied. There have also been significant increases in the seedling fresh weights—both roots and stems. Nursery soil that has been artificially inoculated with *Pt* and produced a crop of seedlings may be mixed with uninfested, fumigated soil to spread the organism. Inoculum or *Pt*-infested soil may also be added to the soil in the fall and over-winter without any appreciable loss of *Pt* viability. However, special precautions are warranted in utilizing this technique to avoid contaminating uninfested soil with undesirable pathogenic fungi, nematodes, insects, and weed seeds as well as the desirable mycorrhizal fungi.

Marx (1975) lists the following benefits of mycorrhizae to tree growth:

1. Tremendous physical increase in the absorbing surface of the root system. This increase is produced by the growth of both mycorrhizae and hyphae from the mycorrhizae into the soil.
2. More selective ion absorption and accumulation, especially phosphorus.
3. Solubilization of normally insoluble minerals and their constituents.

Thelephora terrestris.

Pisolithus tinctorius.

Figure 1-10. – Common ectomycorrhizal fungi in southern nurseries.

4. Increased longevity of feeder root function; mycorrhizal roots persist longer on root systems than do non-mycorrhizal roots.
5. Resistance to feeder root infections caused by pathogens, such as *Phytophthora* and *Pythium* spp. present in many forest and nursery soils.
6. Increased tolerance to soil toxins (inorganic and organic), extremes of acidity, and high soil temperatures.

The main disadvantages are:

1. The uncertainty of success after inoculation.
2. Availability of inoculation equipment.
3. Availability of inoculum.
4. Costs of inoculum and application.

The loss of ectomycorrhizal fungi from nursery soils by fumigation is usually not a problem because these fungi produce wind-disseminated spores periodically throughout the year to recolonize the soil. However, deficiencies of ectomycorrhizal fungi in previously fumigated soils have been reported. Lack of colonization of the soil from airborne spores could result from unfavorable weather conditions. Mycorrhizal fungi rarely exist in an active physiological state in nursery soil in the absence of pine seedings. However, they may remain in a dormant condition, as spores or resistant hypae, in soil for many years.

A great deal of up-to-date information on mycorrhizae is included in publications by Cordell and Marx (1980), Wilcox (1980), Marks and Kozlowski (1973), and Hacskaylo (1971).

Many pesticides tend to curtail the natural or artifical development of mycorrhizae in nursery soils and their use should be limited to a minimum. Some fungicides, however, (i.e., captan and benlate) recently have been shown to enhance ectomycorrhizal development on southern pine seedlings.

SEEDLING-SOIL RELATIONSHIPS

It is a common rule of agriculture that no crop can be grown successfully on the same soil over a successive number of years without the use of soil amendments to maintain the productive capacity of the soil. The production of 700,000 to 800,000 plantable seedlings per acre within a 9-to 10-month period makes a tremendous demand on physical, chemical and biological properties of the soil.

Tree seeds are usually planted in the spring—which is usually a moist to wet season. The soil must be cultivated, fertilized, treated with pesticides and prepared for sowing by the middle of April. Little leeway exists to schedule the presowing and sowing operations. Frequently, the operations are carried out under less than optimum soil moisture conditions. The cultural operations such as spraying for fusiform rust control must be carried out regardless of the effects on alleys or seedbeds.

Seedlings are lifted during the winter and early spring months—December to March—when soil moisture conditions are frequently unsuitable for any kind of soil manipulation. All of the seedling is removed except the small feeder roots that are stripped from the seedling during the lifting operation. Soil particles attached to roots are removed with the seedling, in contrast to most other crops where at least some roots, stems and leaves are returned to the soil. In one nursery established on virgin forest soil, one half of the original top soil was lost during a 12 year period (Muller, 1964). By the end of the lifting season, the soil tilth has been badly damaged or even destroyed.

Beneficial and pathogenic microorganisms are destroyed or their populations reduced if fumigants or other biocides are used before seedbed preparation or during the growing season. Frequently pathogenic organisms reinvade more rapidly than the saprophytic or beneficial organisms.

The dry weight of plant material removed per acre for a crop of seedlings may generally be within the range of 5 to 10 tons (table 1-7).

Table 1-7. — Comparative weights of coniferous seedlings and quantity of oven dry material removed.

Species	Seedlings O.D. wt.	Weight per Acre[1]
	(Grams)	(Tons)
Slash pine 1-0[2]	4.5	8.2
Shortleaf pine 1-0	3.9	7.0
Loblolly pine 1-0	1.1 - 6.6	2.0 - 11.8
Longleaf pine 1-0	8.3	14.0
White pine 3-0	4.4 - 6.0	7.8 - 10.7
Red pine 3-0	6.6 - 10.0	11.8 - 17.8
Jack pine 2-0	2.0 - 4.8	3.6 - 8.6
Scots pine 2-0	2.8 - 7.4	5.0 - 13.2

Source: Armson and Sadreika 1974; May 1957; Switzer and Nelson 1967.

[1] Based on an average density of about 30 plantable seedlings per square foot.

[2] 1-0 refers to one year old seedlings; 2-0 to two year old seedlings, etc.

The amounts of major nutrients removed with each crop are generally within the range of: 100 to 200 pounds of nigrogen (N) per acre; 16 to 28 pounds of calcium (Ca); and 13 to 20 pounds of magnesium (Mg) (May, 1964; Switzer and Nelson, 1967). The foliar nutrient levels of most conifer seedlings of plantable size are in the same general range. Table 1-8 compares the foliar nutrient levels for several conifers with averages for field crops and grasses. Nutrient concentrations in the foliage of

Table 1-8. — Relative range of foliar nutrients.

	SPECIES									
Nutrient	Slash Pine 1-0	Lob. Pine 1-0	Jack Pine 2-0	White Pine 3-0	Red Spruce 3-0	Douglas fir 2-0	Healthy Conifers	Deficit Conifers	Field Crops	Grasses
	percent									
N	0.98- 2.16	--	1.82- 2.38	1.65 1.97	1.32 2.05	1.28 2.00	1.3- 3.0	<1.10	1.50 5.00	1.20- 1.60
P	0.12- 0.43	0.09 0.25	0.17- 0.22	0.15 0.26	0.16 0.21	0.14- 0.35	0.1- 0.3	<0.09	0.20- 0.34	0.10- 0.40
K	0.23- 1.75	0.28- 0.98	0.63- 1.75	0.56 1.39	0.67- 0.80	0.50- 1.00	0.5- 1.6	<0.40	1.0 - 5.0	1.50- 3.00
Ca	0.05- 0.79	0.08- 0.38	0.20- 0.36	0.20 0.71	0.23- 0.66	0.22- 0.40	0.12- 0.70	<0.12	0.50- 0.70	0.20- 0.40
Mg	0.08- 0.26	0.07- 0.21	0.08 0.11	0.08 0.13	0.10- 0.12	0.06- 0.11	0.70- 0.20	<0.05	0.15- 1.80	0.10- 0.25
S	--	--	--	--	--	0.17 0.24	0.15- 0.30	<0.10	0.10- 0.24	0.20±
							ppm			
Fe							50-100	< 30	50-450	
Mn							100-5000	-	25-300	
Zn							10-125	< 5	15-95	
Cu							4-12	< 3	5-65	
Mo							0.05-0.25	-	0.6-5.0	
B							10-100	< 3	6-20	
Cl							10-3000	-	100-4000	

Source: Armson and Sadreika, 1974; Landis, 1977; May, Johnson and Gilmore, 1962; Steinbeck, May and McCreery, 1966.

seedlings can vary with age and vigor as well as nutrient concentrations in the soil or growth medium.

Observations and production records for nurseries during a half century indiciate that there are no clear and concise guidelines for the management of nursery soils and that practices should be determined by local conditions using the best information available. Some general nursery soil management guidelines are:

1. A continuing loss of soil is associated with seedling production. With fine-textured soils this loss can become critical as the organic matter content declines and the percent of silt and clay increase.
2. Lifting operations become increasingly difficult in fine-textured soils unless a high level of organic matter is maintained.
3. Some soils have reserve levels of all nutrients, except nitrogen, in quantities sufficient to maintain continuous production of seedlings for an extended period.
4. In some soils the level of all nutrients is so low that a crop of seedlings cannot be produced without an abundant amount of fertilizers.
5. Problems with diseases increase with the age of the nursery, and by continuous cropping, decline in organic matter, deterioration of soil structure, and continuous use of biocides.
6. Without a continuing fertilizer program, fertility in all soils will decrease, but the magnitude and nature of the decline varies among different soils.
7. In many soils, the organic matter content cannot be maintained or increased much above the irreducible minimum (about 0.3 to 0.8%) using a 1:1 rotation (1 year in seedlings and 1 year in cover crops) without the addition of large quantities of organic matter.
8. The morphological and possibly the physiological characteristics of seedlings decline with any general reduction in soil fertility.

Rotations

An open and flexible attitude must be maintained about rotations, organic matter additives and cover crops. Economic and biological considerations along with local availability of materials will usually determine the best course of action.

The most frequently used rotations in southern nurseries in recent years have been: 1:1, 2:1, and 2:2 (table 1-9). Occassionally other rotations have been used. A few areas, under very intensive management, have been in seedling production for many consecutive years without rotation. This practice requires heavy annual applications of organic matter additives on most soils and a judicious use of mineral fertilizers.

Rotations have been based primarily on the area available for growing seedlings, the production demand for any one year, and the kind of pesticide treatment used. The sites for many nurseries were selected on the basis of a 1:1 rotation. When the demand for seedlings increased, the alternatives were to change to a 2:1 or to a 3:1 rotation or to increase the acreage available for seedbeds. The first alternative was usually the most expedient at the time.

When some of the biocides such as methyl bromide became available their effectiveness was found to sometimes extend over a 2-year period. A 2:2 rotation would spread the cost of the treatment over two seedling crops rather than one.

Table 1-9. — Crop rotations used in southern forest nurseries.

ROTATIONS	YEARS IN SEEDLINGS	YEARS IN COVER CROP	ADVANTAGES	DISADVANTAGES
1:1	1	1	Maximum flexibility to adjust to changing soil conditions.	Difficult to increase soil organic matter.
2:1	2	1	Fumigation cost spread over two years.	(Same as above)
3:1	3	1	Fumigation cost spread over three years.	(Same as above)
1:2	1	2	Three cover crops can be grown in 2 years, a summer cover crop, a winter cover crop, and a second summer crop.	Perennial species may be difficult to eradicate. Pathogenic organisms may become well established.
1:3	1	3	Deeprooted perennial species can be used to break up subsurface compaction, increase subsurface organic matter, and improve internal water movement. Intensive use of cover crops may increase organic matter.	
2:2	2	2	Fumigaton costs spread over two or three years. Intensive use of cover crops may increase organic matter.	Lack of flexibility since land is tied up for two or three years.
2:3	2	3		

With a 1:1 or 2:2 rotation it is possible to maintain or increase slightly the organic matter content with the use of soil additives in addition to the use of cover crops. Without supplemental, bulky, organic matter, the level may remain constant or drop slowly to its minimum level.

When bulky organic material is not available, the alternative is to modify the rotation in favor of cover crops such as a 1:2 or a 1:3 or a 2:3 rotation. These rotations should improve the soil structure, porosity, level of available nutrients, seedling quality and improve lifting on fine-textured soils. The nutrients provided by many of the common sources of organic material are listed in table 1-10. Many of the nurseries established in the 1970's have sufficient acreage to operate on a 1:2 or a 1:3 rotation.

Organic Matter Supplements

The optimum levels for organic matter content in nursery soils have not been fully established. Wilde (1958) suggested a minimum of 2 per cent but preferred higher levels (Wilde and Krause 1959). Most nursery soils in England have an organic matter content within the range of 2 to 6 per cent Aldhous (1972). In the warm humid climate of the southern states, levels of 2 percent for coarse-textured soils and 3 per cent for fine-textured soils may be the maximum obtainable.

Two sources of organic matter are soil additives and cover crops. Bulky materials used in the past include manure, peat, rice straw, tobacco "waste", sugar cane bagasse, chicken house litter, sewage sludge; planner mill shavings, pole peelings, pine cones, bark and sawdust.

Bagasse and sawdust were originally composted. At the Ashe Nurery in Mississippi, it was found that shredded or chopped bagasse spread directly on the field and disked into the soil was about as effective as composted material, so the process of composting was discontinued. Sawdust received the same fate. After the early 1950's, fresh or raw sawdust was applied directly ahead of the cover crop. Davey (1965, 1972) suggested that it was probably better to supplement the sawdust with nutrients and compost it prior to soil application. Unfortunately, the time and effort required to compost enough sawdust for 40 or more cubic yards per acre never seemed to be available.

May (1957) applied fresh pine sawdust to both cover crops and to seedling crops during a six year period at the J. M. Stauffer Nursery in Alabama. Rates of 68, 100, 200 and 270 cubic yards per acre were used on a medium textured soil. Organic matter content was maintained at a nearly constant level with the application of 100 cubic yards prior to the cover crop on a 1:1 rotation. On a 2:1 rotation 200 cubic yards of sawdust per acre was also effective in maintaining constant organic matter levels. Applications of 200 cubic yards of sawdust per acre did not affect germination of seed or the survival of seedlings. The percentage of Grade 1 seedlings (Wakeley 1954) was reduced by the application of 200 cubic yards of sawdust per year during the growing of consecutive crops of seedlings, but increased when a cover crop-seedling rotation was used. Lower amounts of composted sawdust may possibly have given comparable results.

Where sawdust, chips, or bark are available, nurseries must buy the material in competition with paper mills and others using the materials for fuel or processing. Sources of other bulky organic material, such as sewage sludge, are often limited or the transportation costs are prohibitive. Organic materials now under evaluation include cotton gin waste and municipal leaf litter.

Table 1-10. —Nutrient elements contained in one ton of organic material.[1]

Plant material	C/N ratio	N	P	K	Ca	Mg
		- - - - - - - -lbs- - - - - - -				
Barley straw		17	2.4	25.1	3.3	0.8
Buckwheat straw	80	25	1.3	19.2	9.9	1.4
Flax straw		23	1.6	16.7	10.4	-
Oat straw		13	1.7	20.8	5.0	1.7
Rye straw		10	2.6	14.2	3.1	0.8
Wheat straw		10	1.3	10.0	3.0	0.7
Bean straw or hay		28	2.6	31.7	-	-
Cow peas straw or hay		50	4.8	29.2	17.9	-
Field peas straw or hay		20	1.7	17.1	28.1	-
Soybeans straw or hay		46	6.1	18.3	17.6	4.6
Alfalfa straw or hay		94	8.7	70.0	39.8	8.6
Lespedeza straw or hay		37	8.9	33.7	19.9	-
Millet straw or hay		25	3.9	25.0	5.5	-
Corn Stover	60	20	2.6	23.3	6.9	5.0
Kentucky bluegrass hay		26	4.7	35.0	5.9	-
Needles Jack pine		12	0.8	3.2	12.3	-
Needles Norway pine		13	1.3	4.8	19.3	-
Needles White pine		13	1.6	3.3	21.7	-
Sawdust	400	4	0.9	3.3	-	-

---

[1] Compiled from several sources; varies with soils, amount of fertilizer applied, and years.

Cover Crops

Orginally legumes were generally preferred for green manure, catch or cover crops in southern nurseries because they were supposed to provide much-needed nitrogen to the soil (Wakeley 1954). Field peas of the Whipporwill variety were sown in April or early May and again in late July and early August. Claypeas, cowpeas, soybeans, velvetbeans, *Crotalaria* and *Sesbania* were used, but with only one planting per season. Although ground cover was usually good, yield of dry matter was low—1 to 3 tons of tops per acre. At the Ashe Nursery, crops were also used in the alleys between seedbeds to control erosion of bed shoulders and the alleys. Vetch was used in alleys of winter-sown seedbeds and a low lespedeza was used in alleys of spring-sown seedbeds.

The use of nonlegume cover crops increased rapidly in the 1950's with the use of sudangrass, sorghum, sudangrass-sorghum hybrids, millet and corn. The Edwards Nursery in North Carolina was one of the first southern nurseries to use a rotation with a cover crop for 2 or 3 years., i.e., a 1:3 rotation (Brenneman 1966).

New varieties of grain crops, grasses and other species are providing increased yields of fiber and resistance to many soil pathogens, especially nematodes. Also, varieties are being developed for specific climatic zones and soil types (table 1-11). A species or variety that may be very successful in the Carolina-Virginia region may not be as adaptable in Texas, Oklahoma, Arkansas, or Louisiana.

Table 1-11. — Ranges in pH suitable for some cover crops.

Plant	Optimum pH range	Plant	Optimum pH range
corn	5.5 - 7.5	fescuegrass	4.5 - 7.0
oats	5.0 - 7.5	sudangrass	5.0 - 6.5
rye	5.0 - 7.0	sorghum-sudan	5.0 - 7.0
wheat	5.0 - 7.5	millet	5.0 - 6.5
sorghum	5.0 - 7.0	lupine	5.0 - 7.0
soybeans	6.0 - 7.5	peas	6.0 - 7.5
lespedeza	4.5 - 6.5	vetch	5.2 - 7.0

Potential yields of different species and varieties are affected by dates of sowing, soil types, climatic zones and soil amendments. General ranges of oven-dry, aboveground material for major species are: silage sorghums—12 to 15 tons per acre, silage corn—6 to 9 tons per acre, sundangrass-sorghum hybrids—6 to 12 tons per acre, and millets—6 to 10 tons per acre.

These 1:3 or 2:3 rotations eliminate the costly operations of fertilizing, seedling and cultivating several crops during the 3-year period. In table 1-12, species listed in the 1:3 or 2:3 rotations develop abundant root systems and provide about as much dry matter below the ground as above. Bahiagrass, and the other species to some extent, provide deeply rooted systems that tend to ameliorate the effects of plow soles or other compacted soil layers. These plants effectively maintain good soil structure, aeration and large pores. When fumigation is required for rootrot control, the 2:3 rotation allows the cost of fumigation to be spread over two seedling crops.

Table 1-12. — Common cover crops used in southern nurseries.

Rotation	Cover Crop
1:1	corn, sorghum, sudan-sorghum hybrid, millet, pigeonpeas, field peas, soybeans, velvetbeans, crotalaria, and sesbania
1:2 or 2:2	First Crop: corn, sorghum, sudan-sorghum hybrids, millet, peas or beans Winter Crop: rye, wheat, oats, lupine, vetch and ryegrass. Second summer crop same as first crop
1:3 or 2:3	Bahia grass, fescue grass, lespedeza--use for 3 years

The best combination is probably a high-yield coarse fiber crop followed by a winter crop, which is then followed by a millet or a sudan-sorghum hybrid or possibly a legume during the summer.

Resistance to pathogens should be considered in selection of cover crops. Also, consider the place of each species in the rotation. The southern States afford a very favorable climate for many plant pathogens—some of which are always present in the soil or on various weed hosts. Both legumes and nonlegumes are host to a number of bacteria, viruses, fungi and nematodes. Some destructive diseases of both cover crops and seedlings are caused by fungi that live on organic matter in the soil, sometimes for many years.

Some fungi produce numerous, persistant sporelike structures called sclerotia which assure long survival of the organism. Excessive buildup of sclerotia may occur with continuous cropping of a single species or specific host plants. *Macrophomina phaseoli* (sterile stage *Sclerotium*) (*Rhizoctonia bataticola*) is particularly prevalent in warm soils and attacks a varied range of host plants including most species of beans, peas, corn, sorghum, and pine seedlings. Some varieties of cover crops are resistant to both fungi and nematode pests; and others are highly susceptible. Resistance to charcoal (black) rootrot is an inherited trait in sorghum. Nematode and rootrot resistance should be considered in selecting a cover crop.

PESTICIDE INTERACTIONS

In recent years nursery pest control efforts have focused on the development of new pesticides rather than the concern for an ecological balance within the nursery.

Pesticides that have been used include soil sterilants, fumigants, fungicides, nematicides, insecticides, herbicides, repellants, growth regulators, defoliants, desiccants and associated surfactants, emulsifiers, spreaders, stickers, wetting agents, carriers, diluents, absorbents, and coating agents.

Wilde (1958) was one of the first to emphasize the deleterious effects of pesticides on the productivity of nursery soils. Today, persistence in the soil of many pesticides, their interactions within the soil, and the resulting effects on the growth and development of seedlings is of great concern.

The longevity of pesticides in the soil is related to several processes that inactivate and decompose these chemicals. Examples are absorption on mineral, organic or soil particles, volatilization, leaching, plant uptake, chemical alteration, photo decomposition and microbial decomposition. The rate at which these factors act on a particular pesticide is regulated by the pesticide's chemical composition, mineralogy of the soil, clay, silt, and organic content of the soil, and the environment of the area, especially precipitation and temperature.

Pesticide Persistence in the Soil

Some pesticides, such as methyl bromide, may disappear within 2 to 4 days. Eptam disappears in 3 to 10 weeks, while others such as BHC (benzene hexachloride) and chlordane may remain for a year or more. Many herbicides that persist from one season to the next can injure sensitive plants. The triazine herbicides (e.g., atrazine, simazine) applied as pre-emergent herbicides for selective weed control in corn, sometimes persist and injure sensitive seedling crops the next year.

Some persistent pesticides may accumulate in the soil from repeated application. Volatilization, leaching from the soil, and degradation by soil microorganisms may account for loss of a major part of some pesticides that disappear rapidly. The longer a pesticide persists in the soil, the greater the probability that several processes will become involved in its inactivation and disappearance. Some organic pesticides that persist for several months create a long period for the recolonization of soil micro-organisms.

Soil persistence problems and hazards related to pesticide usage in nurseries may be placed in four categories:

1. Accumulation of pesticides from application rates that exceed the rate of dissipation from the soil.
2. Injury to seedlings or to other crops.
3. Toxic residues that may injure beneficial soil micoorganisms.
4. Unlawful residues in crops.

Repeated applications of pesticides often produce an accumulation of residues in a narrow zone where the chemicals attain a concentration far exceeding that of a single application. Uneven distribution of chemicals leads to their very high, local concentration in the soil. High residual levels of BHC and chlordane have decreased yields and affected the quality of some crop plants. High levels of other pesticides, and some fertilizers, will decrease the availability and uptake of nutrients. Many pre- and post-emergence herbicides, when applied above recommended rates, will injure or kill pine seedlings. Frequently the injury or abnormality resembles a nutrient deficiency or a pathogen problem. Trifluralin and Caparol injury resemble copper toxicity symptoms. Many chemicals used as nematicides such as Vorlex, ethylene dibromide (EDB), dibromochloropropane (DBCP) and 1,2-dichloropropane (D-D) are toxic to seedlings when applied to the soil, but after 3 to 4 weeks this effect is rarely noticeable.

Methyl bromide and ethylene dibromide leave a bromide residue in the soil that is sometimes toxic to plants. Methyl bromide and certain other soil fumigants may kill beneficial soil organisms as well as soil pests. Normal decomposition of organic matter into ammonia, then nitrite, and finally nitrate may be disturbed so that toxic substances accumulate. For example, in a sterilized soil high in organic matter, ammonia or nitrate may accumulate to a toxic level. Yet in other soils, fumigation seems to be a growth stimulator—probably because more nitrogen is made available to the seedlings from the decomposition of soil microorganisms.

Some organic pesticides induce highly undesirable changes in morphology, anatomical and physiological properties of seedlings. Among these changes are: abnormal stimulation of top growth, high increase in succulence of seedlings with subsequent reduction of specific gravity of lignified parts, and shortened root systems, including their absorbing surfaces. These unfavorable modifications usually result from unbalanced nutrition, especially nitrogen and phosphorus. Some organic biocides increase the supply of available nitrogen by eliminating microbiotic consumers of nitrates and ammonia and by enriching the rootzone in proteinaceous tissues of controlled organisms. Eradication of mycorrhizae-forming fungi may greatly retard the uptake of phosphorus by seedlings even when phosphorous is abundant in the soil in an available form (Iyer 1964; 1970).

The effects of many pesticides are subject to environmental variables in soils such as texture, temperature, moisture and organic matter. The effects of soil organic matter on the effectiveness and the persistence of pesticides is recognized by both the manufacturers and the Environmental Protection Agency. Some specifications provide for different rates of application on sandy, loamy, and clayey soils and for high and low levels of organic matter. Some pesticides are prohibited on soils with organic matter levels less than 1 percent.

Several materials different in chemical nature may be equally effective on certain pests. If there are two, three or four useful materials, one can be used one year and another the next year. By alternating chemicals, the rates of pesticides may be reduced and resistant organisms will not result.

Measures to Minimize Unfavorable Reactions of Pesticides

1. Read and heed the label. Do not use pesticides under conditions for which they are not recommended.
2. Use the lowest rate of pesticide to obtain the degree of control required.
3. Apply the pesticides uniformly.
4. Use a seedling-cover crop rotation that permits as much of the pesticide use as possible with the cover crop.
5. Rotate the use of pesticides when two or more chemicals can give equally effective control.
6. Cultivate the soil deeply and thoroughly after a pesticide application.

REFERENCES

Aldhous, J. R. Nursery Practice. Forestry Commission Bull. No. 43. London: Her Majesty's Stationary Office. 1972. 184 pp.

Armson, K. A. Sadreika V. Forest Tree Nursery Soil Management and Related Practices. Otawa, Ontario. Ministry of Natural Resources. 1974. 177 pp.

Berbee, J. G. Chemical and biological control of Cylindrocladium root rot in conifer nurseries. In: Proceedings, Northeastern Area Nurserymen's Conference. Broomall, PA: US Department of Agriculture, Forest Service, Northeastern Area. 1973. pp 29-31.

Brenneman, D. L. 1966. The use of corn as a cover crop in forest tree nurseries. In: Proceedings Southeastern Area Forest Nurserymen Conference. Atlanta, Ga: US Department of Agriculture, Forest Service, Southeastern Area; 1966. 111-114.

Campbell, W. A.; Hendrix, F. F., Jr.; Powell, W. M. Pythium and nematode implicated in root rot. Tree Planters' Notes 23(1): 5-7. 1972.

Cordell, Charles E.; Marx, Donald H. Ectomycorrhizae: Benefits and practical application in forest tree nurseries and field plantings. In: Proceedings North American For. Tree Nursery Soils Workshop. July 28 - August 1, 1980. Syracuse, NY: SUNY College of Env. Sci. and For.; 1980. 217-224.

Davey, Charles B. Decomposition of sawdust of deciduous and coniferous trees under the influence of *Coprinus ephemerus* (Bull.) Fr. Ph. D. Thesis. Madison, WI: University of Wisconsin. 1955.

Davey, Charles B. Functions and management of organic matter in forest nursery soil. In: Proceedings, Nursery Soil Improvement Sessions. Syracuse, N.Y.; State University College of Forestry at Syracuse University; 1965. 39-50.

Davey, Charles B. Soil Organic matter. In: Proceedings, Southeastern Area Forest Nurserymen Conferences. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area: 1968; pp 12-17.

Davey, Charles B. Nursery soil management. In: Proceedings, Southeastern Area Forest Nurserymen Conferences. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area: 1972: 182-187.

Donahue, Roy L.; Shickluna, John C.; Robertson, Lynn S. Soils: An introduction to soils and plant growth, 3rd ed. Englewood Cliffs, N.J: Prentice-Hall, Inc. 1971. 587.

Garren, Kenneth H.; May, Jack T.; Walsh, Charles. Microorganisms in nursery seedbed soils. Tree Planters' Notes 21: 21-23. 1955.

Goss, R. W. Mycorrhizae of ponderosa pine in Nebraska grassland soils. Research Bull. 192. Lincoln, NE: Nebra. Agr. Exp. Sta. 1960. 47 p.

Hacskaylo, Edward. (Ed) Mycorrhizae. Proceedings of the First North American Conference on Mycorrhizae, April 1969. Misc. Publication 1189. Washington, D.C: U.S. Department of Agriculture. 1971. 225 p.

Hatch, A. B. The role of mycorrhizae in afforestation. Journal of Forestry. 34:22-29. 1936.

Henderson, Gray S., Stone, E. L. Jr. Interactions of phosphorus availability, mycorhizae, and soil fumigation on coniferous seedlings. American Society of Agronomy, 1967 Annual Meeting, Nov. 5-10, 1967. Agronomy Abstracts. 1967. p. 134.

Iyer, J. G. Effect of Craig Mylone herbicide on the growth of white spruce seedlings. Tree Planters' Notes No. 66:4-6. 1964.

Iyer, J. G. Biocides, fertilizers, and survival potential of tree planting stock. Tree Planters' Notes 21(3):25-26. 1970.

Iyer, J. G. and Wilde, S. A. Inactivation of biocides in tree nursery soils. In: Proceedings, Northeastern Area Nurserymen's Conference. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area. 1973. 23-28.

Landis, Thomas D. Analysis and interpretation of foilage nutrient levels in tree seedlings. In: Proceedings, Intermountain Nurserymen's Association: Manhattan, KS: Kansas State University, Department of Forestry. 1977. 111-116.

Lipas, E. J. Dynamics of nutrient elements in soil of Wisconsin forest nurseries. Madison, WI: University of Wisconsin; 1968. M.S. thesis.

Maki, T. E.; Henry, Berch W. Root-rot control and soil improvement at the Ashe Forest Nursery. Occasional Paper 119. USDA Forest Service. New Orleans, LA. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 1951.

Marx, Donald H. Mycorrhizae of forest nursery seedlings. In: Forest Nursery Diseases in the United States. Agric. Hand. 470. Washington, D.C: U.S. Department of Agriculture; 1975:35-40.

Marx, D. H.; Bryan, W. C. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infested with the fungal symbiont *Pisolithus tinctorius*. For. Sci. 21(3):245-254. 1975.

Marx, Donald H.; Bryan, William C.; Cordell, Charles E. Growth and ectomycorrhizal development of pine seedlings in nursery soils infested with the fungal symbiont *Pisolithus tinctorius*. For. Sci. 22:91-100. 1976.

Marks, G. C.; Kozlowski, T. T. ed. Ectomycorrhizae, their ecology and physiology. New York: Academic Press. 444 p. 1973.

May, Jack T. Effects of soil management practices in a forest tree nursery on soil properties and on loblolly pine seedlings. Michigan State University. 228p. 1957. PhD. thesis.

May, Jack T. The forest nursery and its soils. In: Proceedings Region 8 Forest Nurserymen's Conference. Morganton, NC and Oklahoma City, OK, Aug. 19, 20, 1964 and Sept. 16, 17, 1984, Atlanta, GA: U. S. Department of Agriculture, Forest Service, Southern Region; 1964: 3-9

May, Jack T., Johnson, Henry H., Gilmore, A. R. Chemical composition of southern pine seedlings. Ga. Forest Res. Council Paper 10. Macon, GA: Georgia Forest Research Council; 1962. 11p.

McComb, A. L. The relation between mycorrhizae and the development and nutrient absorption of pine seedlings in a prairie nursery. Journal of Forestry. 36(11): 1148-1154. 1938.

Muller, C. A. Production goals, cost reduction and quality stock production. In: Proceedings, Region 8 Forest Nurserymen's Conferences. Morganton, N.C. and Oklahoma City, OK, Aug. 19-20, 1964 and Sept 16, 17, 1964. Atlanta, GA: U. S. Department of Agriculture, Forest Service, Southern Region; 1964: 78-83.

Peach, Michael. Chemical studies on soils from Florida citrus groves. Fla. Agric. Expt. Sta. Bull. 340. Gainesville, FL: University of Fla; 1939.

Steinbeck, Klaus; May, Jack T.; McCreery, Robert A. Growth and needle color abnormalities of slash pine seedlings caused by nutrient treatments. Ga. For. Res. Council Paper 38. Macon, Ga: Georgia Forest Research Council. 1966. 9p.

Switzer, G. L.; Nelson, L. E. Seedling quality strongly influenced by nursery soil management, Mississippi study shows. Tree Planters' Notes 18(3) 5-14. 1967.

USDA Forest Service. Handbook on Soils, FSH 2559.2 Washington, D.C. 1961 296 p.

Wakeley, Philip C. Planting the Southern Pines. Agriculture Monograph No. 18. Washington, D.C: U. S. Department of Agriculture; 1954. 233p.

White, D. P. Prairie soil as a medium for tree growth. Ecology 22: 398-407. 1941.

Wilcox, Hugh E. Effects of mycorrhizae on growth and morphogenesis of tree seedlings. In: Proceedings, North American Forest Tree Nursery Soils Workshop, July 28 - August 1, 1980. Syracuse, N.Y.: SUNY College of Environmental Science and Forestry; 1980: 205-216.

Wilde, Sergei A., Forest Soils: their properties and relation to silviculture. New York: The Ronald Press Co.; 1958. 537p.

Wilde, S. A. and Krause, H. H. Soil analysis in service of nursery practice. Tree Planters' Notes 37:1-5. USDA Forest Service. Washington, D.C. 1959.

APPENDIX 1-1.—KEY FOR FIELD IDENTIFICATION OF SOIL TEXTURE

- **A. Soil, when pinched between the thumb and finger, crumbles, will not form a ribbon.**
  - B. Soil, squeezed in hand when dry, falls apart readily; if squeezed when moist, forms a cast that breaks if not handled very carefully. Individual sand grains can be readily seen and felt, characteristic of <u>sandy loam</u>.
  - B. Soil, squeezed in hand when dry, forms a cast that bears careful handling; if squeezed when moist, forms a cast that can be handled quite freely without breaking. Soil is smooth. Sand grains are not readily evident.
    - C. Soil is slightly plastic when moist, but not greasy. Gritty when dry, not floury. Color is brown or dark grey, characteristic of loam.
    - C. Soil is greasy when moist, floury when dry. When wet, it runs together and puddles. Color is light grey to nearly white, characteristic of <u>slit loam</u>.
- **A. Soil, when pinched between the thumb and finger, forms a "Ribbon", at least barely sustaining its own weight.**
  - D. Ribbon breaks easily, barely sustains own weight.
    - E. Individual sand grains can readily be seen and felt. Moist soils is pliable. Color is usually brownish yellow to brownish red, characteristic of <u>sandy clay loam</u>.
    - E. Soil is smooth, sand grains are not evident. Moist soil is somewhat plastic.
      - F. Soil is heavy and greasy when moist. Color is dull grey, sometimes contains iron concretions, characteristic of <u>silty clay loam</u>.
  - D. Ribbon is long and flexible, strong.
    - G. Individual sand grains can readily be seen and felt. Moist soil is somewhat pliable. Color is usually bright red or yellow, characteristic of <u>sandy clay</u>.
    - G. Sand is not evident. Moist soil is plastic.
    - H. Color is usually grey, sometimes contains iron concentrations, characteristic of <u>silty clay</u>.
    - H. Color is usually dark red, often mottled with grey or yellow, characteristic of <u>clay</u>.