The Container Tree Nursery Manual

Volume Two
Containers and Growing Media

Chapter 2
Growing Media

Thomas D. Landis, Western Nursery Specialist, USDA Forest Service, State and Private Forestry, Portland, OR

•

Landis, T.D. 1990. Containers and growing media, Vol. 2, The Container Tree Nursery Manual. Agric. Handbk. 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 41-85.

Contents

2.2.1 Introduction

2.2.1.1 Terminology

Many different terms have been used for the **artificial soil** used in container nursery culture, including **potting soil, potting mix, soil mix, compost, and growth medium.** It is inappropriate to use the term **soil** when referring to these materials, however, because soil is rarely a component of growing media in container tree nurseries in the United States and Canada. The term mix is sometimes used because many of these materials are composed of several different components, although some forest nurseries use only one material- for example, peat moss-as a growing medium. To avoid confusion and remain consistent, therefore, the terms **growing medium** (singular) and **growing media** (plural) will be used throughout this manual because they are the most appropriate terms and least likely to cause confusion. The aqueous solution absorbed by and surrounding the growing medium particles will be called the **growing medium solution** or **medium solution.**

2.2.1 .2 The need for ":artificial soil"

When people first began to grow plants in containers, they used ordinary field soil but soon found that this practice created cultural problems. The very act of placing soil in a container produces horticultural conditions that are different from those of unrestricted field soil.

Restricted volume. Plants growing in containers have access to a very limited amount of growing medium compared to field-grown plants (Swanson 1989). Forest tree seedlings, in particular, are grown in small-volume containers, ranging from as small as 40 to over 700 cm' (2.5 to 45 cubic inches). This limited rooting volume means that seedlings have only small reserves of available water and nutrients and that these essential resources can change quickly (Van Eerden 1974).

Perched water table. By their very nature, containers create a perched water table because water cannot drain freely from the bottom of the container (Swanson 1989). The layer of saturated growing medium created at the bottom of the container has profound effects on the physical and horticultural properties of growing media. (See chapter 2, volume four of this manual.)

Imbalance of soil microorganisms. Native soils contain myriad microorganisms, some beneficial and some pathogenic. These organisms exist in a natural state of balance in field soils, but when these soils are placed in containers in the favorable growing environment of a greenhouse, many problems can develop. The high-fertility, high-moisture regimes used to promote rapid seedling growth favor the development of pathogenic organisms, such as damping-off fungi, but do not favor growth of most beneficial mycorrhizal fungi.

Lack of soil structure. Texture (particle size) and structure (particle aggregations) are basic physical properties of soil that create porosity. Although a given growing medium has texture, based on the size of the various component particles, the concept of soil structure does not apply to artificial growing media because the individual particles of the various components do not bind together. The regular cultivation program and organic amendments that farmers use to maintain favorable structure **(tilth)** in field soil are obviously impossible in container nursery culture. Therefore, the textural properties of growing media components must be carefully chosen and blended to produce the right mixture of porosity that will persist over the growing cycle.

2. 2.1.3 History of artificial growing media

Because of the problems with field soil in containers, growers began supplementing soil with other materials to develop a mixture that would be suitable for container culture. The first systematic search for a uniform, standardized growing medium began in England in the 1930's when the John Innes Horticultural Institute developed a loam-based compost that was amended with peat moss, sand, and fertilizers (Bunt 1988). By the early 1950's, the first truly artificial growing media were created at the University of California; they were composed of various proportions of fine sand and peat moss with supplemental fertilizers (Matkin and Chandler 1957). The Cornell Peat-Lite Mixes, the predecessors of modern growing media, were developed at Cornell University in the 1960's using various combinations of peat moss, vermiculite, and perlite (Mastalerz 1977).

2.2.2 Functions of a Growing Medium

Plants growing in containers have certain functional requirements that must be supplied by the growing medium (Mastalerz 1977).

2.2.2.1 Water

Plants require a large, continuous supply of water for growth and other physiological processes, such as transpirational cooling, and this water must be supplied by the growing medium. Liquid water is held both externally and internally by the growing medium until it is needed by the seedling: externally in the relatively small pores between the particles and internally in the interior space of porous materials like peat moss. Because of the limited volume of small containers, the growing medium must have a high water-holding capacity to supply water to seedlings from one irrigation to the next.

2.2.2.2 Air

Plant roots consist of living tissue and must expend energy for growth and physiological processes, such as absorption of mineral nutrients from the medium solution. The energy for these physiological activities is generated by aerobic respiration, which requires a steady supply of oxygen. The byproduct of this respiration is carbon dioxide, which can accumulate to toxic levels if it does not disperse to the atmosphere. Therefore, growing media must be porous enough to provide efficient exchange of oxygen and carbon dioxide. Because oxygen diffuses through water only 1/10,000 as fast as through air, this gas exchange must take place in the larger, air-filled pores in the growing medium. These large pores are a direct function of media particle size, arrangement, and amount of compaction.

2.2.2.3 Mineral nutrients

With the exception of carbon, hydrogen, and oxygen, plants must obtain all 13 essential mineral nutrients from the growing medium solution. Many mineral nutrients, including the ammonium form of nitrogen (NH_4) potassium (K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}), exist in the growing medium solution as electrically charged cations. These nutrient ions remain in the medium solution until plant roots take them up and utilize them for growth and tissue maintenance or, because of their positive electrical charge, they become adsorbed onto negatively charged sites on certain types of growing medium particles. This supply of adsorbed nutrients, which is measured by the **cation exchange capacity** (CEC), provides a reservoir of mineral nutrients to support plant growth between fertilizer applications.

2..2.2.4 Physical support

The final function of the growing medium is to anchor the seedling in the container and support it in an upright position. This support is a function of the bulk density (relative weight) and the rigidity of the growing medium. Weight is important for large, individual containers that stand alone (Maronek and others 1986) but is inconsequential for the small-volume, aggregated container types that are typically used in forest tree nurseries. The rigidity of a growing medium is a function of the compressibility and compaction of the growing medium particles, and the size of the container.

2.2.3 Characteristics of an Ideal Growing Medium

There is no single growing medium that can be used for all purposes, but lists of general horticultural properties are provided by Hartman and Kester (1983), James (1987), and Swanson (1989). For container tree nurseries, a well-formulated growing medium will have most of the following properties, which can be separated into cultural characteristics (those that influence seedling growth) and operational characteristics (those that affect nursery operations).

2.2.3.1 Characteristics relating to seedling growth

The cultural characteristics of a growing medium are the properties that affect its ability to consistently produce crops of healthy tree seedlings under the cultural practices in a container tree nursery: slightly acid pH, high cation exchange capacity, low inherent fertility, adequate porosity, and freedom from pests.

***Slightly acid* pH**. pH is a measure of relative acidity or alkalinity of a substance, on a logarithmic scale from 0 to *14;* values below *7.0* are acidic and values above *7.0* are alkaline. Materials used to formulate growing media can differ considerably in pH. Peat mosses are usually acidic in nature, depending on the constituent plant species and local water quality, whereas vermiculite can range from neutral (pH *7.0)* to mildly alkaline (Bunt *1988).* PH ranges for the four principal growing media components used in container tree nurseries are listed in table 2.2.1. The final pH of a growing medium will depend on the proportion of the ingredients, their original pH, and subsequent cultural practices, especially fertilization and irrigation. Irrigation water is usually circumneutral or slightly alkaline, and so a normally acidic growing medium will typically rise *0.5* to 1.0 unit of pH (that is, become more alkaline) through the growing season (Gladon *1988).*

The principal cultural effect of pH in mineral soils is its influence on availability of mineral nutrients, especially micronutrients; several mineral nutrients can become unavailable or even toxic at exteme pH values. Comparison of the effect of pH on the mineral nutrient availability of mineral and organic soils (such as most growing media) shows that maximum availability for organic soils is one full point lower (pH 5.5) than for mineral soils (pH 6.5) (fig. 2.2.1). Control of pH is less critical in container nurseries, where all essential mineral nutrients can be supplied with fertilization. Most plants can grow within a relatively wide range of pH values if micronutrients are supplied in the proper form and in the proper ratio (Bunt 1988).

The pH can also affect the numbers and types of microorganisms in growing media, including fungal pathogens. Fusarium spp. are more virulent in neutral to alkaline conditions, and losses to damping-off fungi increase at pH values above 5.9 (Handreck and Black 1984). Most of this information applies to native soils, however, and less is known about the effects of pH on pathogen activity in artificial growing media. One recent study on a root disease of Douglas-fir container seedlings revealed that disease losses were more severe at pH 4.0 (94%) than at pH 5.0 (10%) or pH 6.0 (4%) (Husted 1988).

On an operational basis, therefore, container nursery managers should strive to maintain the pH of their growing media in the slightly acidic range of pH *5.5* to *6.5.* (See chapter 1 in volume four of this manual for a more detailed discussion.)

Table 2.2.1—*Characteristics of various components of growing media*

Medium component	Dry bulk density (kg/m^3)	pH range	Mineral nutrients	Sterility	Cation exchange capacity: Weight (meq/100 g)	Cation exchange capacity: Volume (meq/100 m^3)
Sphagnum peat	96.1—128.2	3.5—4.0	Minimal	Variable*	180.0	16.6
Vermiculite	64.1—120.2	6.0—7.6	K-Mg-Ca	Yes	82.0	11.4
Perlite	72.1—112.1	6.0—8.0	None	Yes	3.5	0.6
Pine bark	128.2—448.6	3.3—6.0	Minimal	Variable*	52.6	15.3

* Some peat sources have tested positive for pathogenic fungi, whereas other types of sphagnum peat and composted bark have been shown to contain beneficial organisms that can effectively suppress disease.
Source: *adapted from Biamonte (1982).*

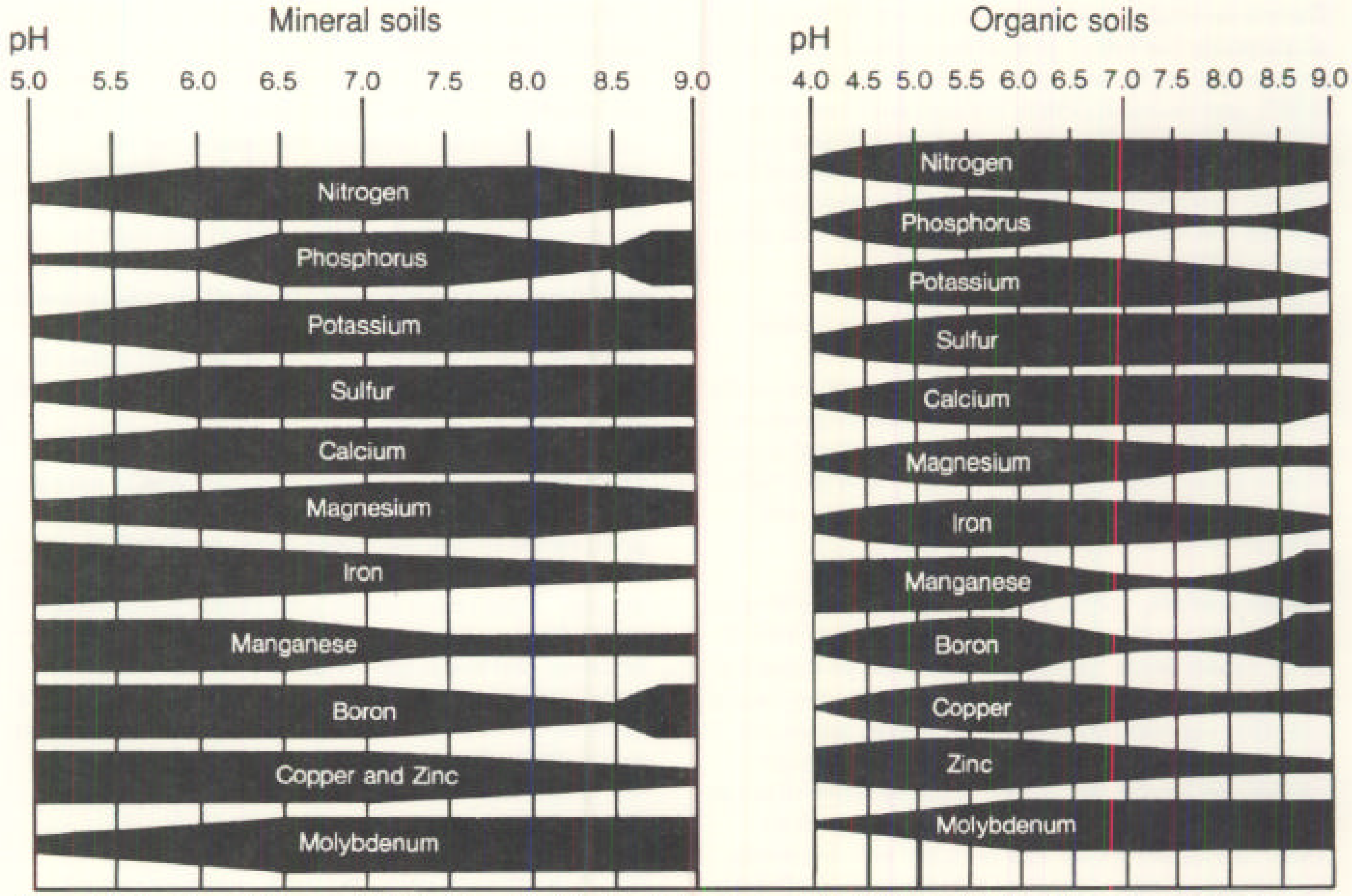


Figure 2.2.1—*The relative availability (the wider the band, the more available the nutrient) of the various mineral nutrients is different for mineral-based and organic-based soils. Maximum nutrient availability for mineral soils is pH 6.5, compared to 5.5 for organic soils (Kuhns 1985).*

High cation exchange capacity. The ability of a material to adsorb positively charged ions, the **cation exchange capacity** (CEC), is one of the most important factors affecting the fertility of growing media. The CEC can be defined as the sum of the exchangeable cations, measured in units called **milliequivalents** (meq), that a material can adsorb per unit weight or volume—the larger the number, the greater the nutrient-holding ability. The primary cations involved in plant nutrition are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and ammonium (NH_4^{+}), listed in order of decreasing retention on the CEC sites (Bunt 1988). Many micronutrient ions are also adsorbed, including iron (Fe^{2+} and Fe^{3+}), manganese (Mn^{2+}), zinc (Zn^{2+}), and copper (Cu^{2+}). These nutrients are stored on CEC sites on growing medium particles until they are taken up by the root system (fig. 2.2.2).

CEC has traditionally been measured on a weight basis for field soils, but CEC per volume is more meaningful for soil-less growing media, because of the relatively low bulk density of most media and the small volumes of the containers. Realistically, plants grow in a volume rather than a weight of growing medium, and volume is now the generally accepted basis for measuring CEC for horticultural purposes (Bunt 1988). CEC values for some typical growing medium components are compared in table 2.2.1. Vermiculite and peat moss have the highest CEC values, whereas inorganic materials such as perlite and sand have very low CEC values. In a list of CEC values for some of the standard growing media (table 2.2.2) (Bunt 1988), the peat–vermiculite medium has the highest CEC by a considerable margin.

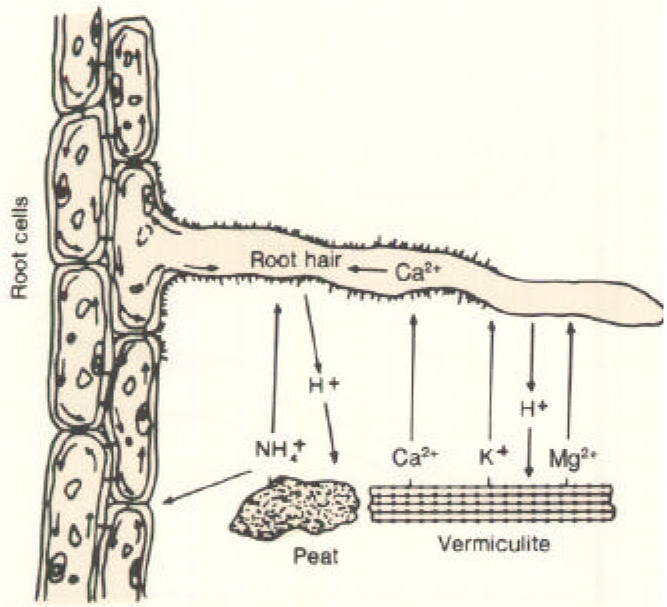


Figure 2.2.2—*The cation exchange capacity of growing media particles provides a fertility reserve that supplies mineral nutrients to the seedling root system between fertilizer applications (adapted from Davidson and Mecklenberg 1981).*

Table 2.2.2—*Cation exchange capacities for some standard growing media*

Growing medium composition	Cation exchange capacity Weight (meq/100 g)	Cation exchange capacity Volume (meq/100 cm³)
Peat moss–vermiculite (1:1)	141	32
Peat moss–sand (1:1)	8	5
Peat moss–perlite (1:3)	11	1
Pine bark–perlite (2:1)	24	5

Source: adapted from Bunt (1988).

High CEC values are desirable for growing media because they maintain a fertility reserve that supports plant growth between fertilizer applications. The CEC can also hold cations in the growing medium against leaching, which can be very significant with the high irrigation rates used in most container tree nurseries. Certain growing medium components are better at resisting leaching than others, and generally speaking, the higher the CEC value for a medium, the greater its resistance to leaching. Comparing the amount of mineral nutrients recovered from two different types of growing media in the same volume of leaching water shows that the peat-vermiculite medium retained more nutrient cations than the peat sand medium (fig. 2.2.3). Interestingly, the nitrate form of nitrogen (NO;) was heavily leached from both types of growing medium because it is a negatively charged anion, which are repelled by the negatively charged cation exchange sites. Some materials have the ability to retain a small amount of anions—an **anion exchange capacity.** Whether this applies to nutrient ions like phosphate (PO_4^-) is unclear however. Black (1988) reports that considerably more soluble P was leached from a 1 :1 peat-vermiculite medium than from a mineral soil. Bunt (1988), although stating that PO_4^- is leached from most types of growing media, showed that vermiculite apparently has a limited ability to absorb $P0_4^-$ ions (fig. 2.2.3).

A growing medium with a high CEC has another desirable property that is of interest to the container nursery manager. Because it is able to selectively adsorb and release cations from the growing medium solution, such a growing medium can buffer the seedling root system against sudden changes in pH or salinity (Whitcomb 1988).

Low inherent fertility. It may seem incongruous at first, but an initially low fertility level is actually a desirable attribute for growing media used in container nurseries (Mastalerz 1977, James 1987). Maintaining high levels of mineral nutrients, especially nitrogen, during seedling germination and emergence is unwise because of the possibility of encouraging damping-off fungi. In addition, many species of tree seedlings do not require any fertilization for the first few weeks of growth (except perhaps for phosphorus, which is best supplied through a nutrient injection system). Carlson (1983) reported that newly germinated seedlings took up few mineral nutrients until 2 weeks after germination, and Barnett and Brissette (1986) stated that the seed megagametophyte (endosperm) provides ample supplies of phosphorus and other essential mineral nutrients for early germinant growth.

The most important benefit of low initial fertility is that nursery managers can completely control mineral nutrient concentrations in the growing medium solution through fertilization. Inherently fertile growing media or media amended with incorporated fertilizers make it impossible to completely control seedling nutrition during the growing season. Growing media that contain slow-release fertilizers should not be stored for more than a few days because fertilizer salts can build-up and

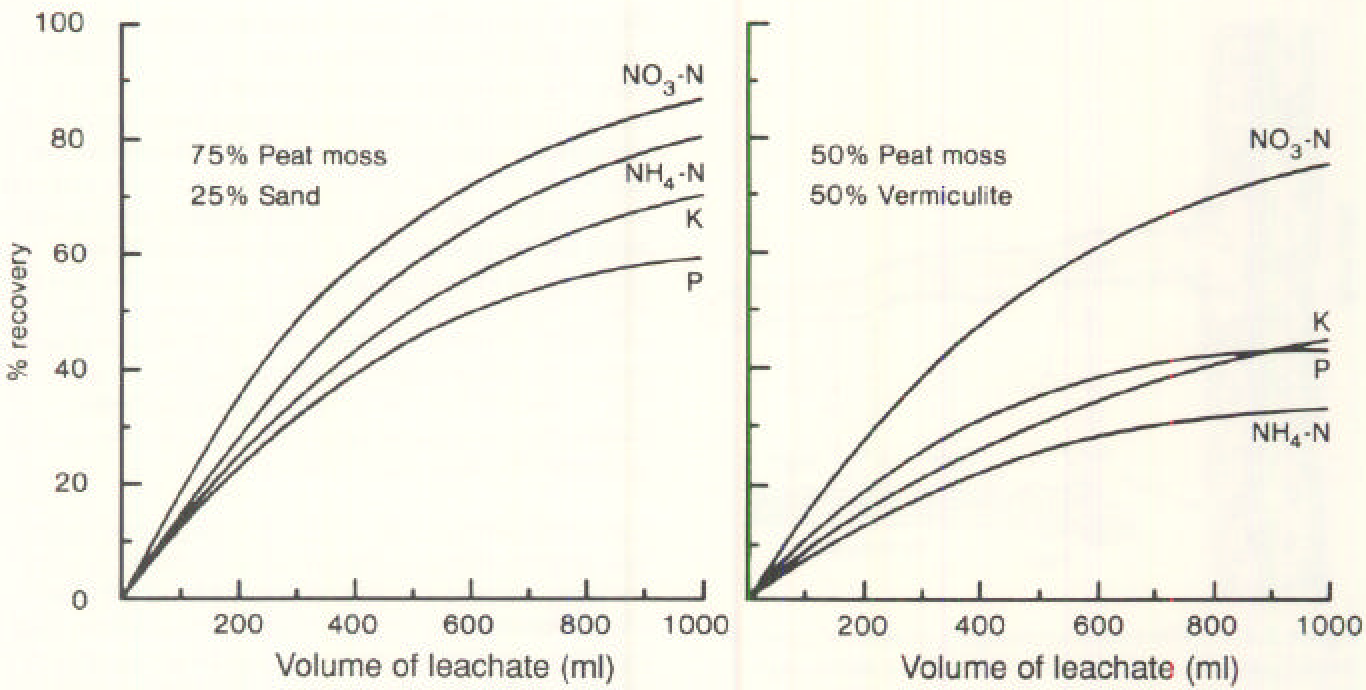


Figure 2.2.3—*The substitution of vermiculite* **(right)** *for sand in a peat moss–sand growing medium* **(left)** *greatly increases the cation exchange capacity and therefore reduces the amount of mineral nutrients lost to leaching; that is, it decreases the percentage of nutrients recovered in the leachate (adapted from Bunt 1988).*

possibly harm germinating seedlings (Handreck and Black 1984). Most container tree nurseries in North America are equipped with liquid fertilizer injection systems that allow custom fertilization at any time. Even though many brands of commercial growing media contain a starter dose of fertilizer, this practice cannot be recommended. A low initial fertility allows the container nursery manager to custom-fertilize at any time during the rotation and control seedling growth and phenology. The ability to completely leach all nutrients out of the growing medium and change nutrient ratios before the hardening period is often used to initiate bud set and cold hardiness (see chapter 1, volume four of this manual).

Most of the components of growing media used in container tree nurseries are inherently infertile (table 2.2.1), but there are some exceptions. Mastalerz (1977) reported that vermiculite contains "large amounts" of potassium and magnesium that are available for plant growth, although tests of peat-vermiculite media revealed only small amounts of these nutrients (table 2.2.3). Peat moss contains between 1 to 2.5%, nitrogen,

Table 2.2.3—*Mineral nutrient analysis in a standard peat–vermiculite (2:1) growing medium*

Nutrient	Symbol	Units	Value
Mineral levels			
Ammonium nitrogen	NH_4–N	ppm	1.56
Nitrate nitrogen	NO_3–N	ppm	0.00
Phosphorus	P	ppm	1.30
Potassium	K	ppm	5.19
Calcium	Ca	ppm	1.83
Magnesium	Mg	ppm	1.19
Iron	Fe	ppm	0.143
Manganese	Mn	ppm	0.046
Copper	Cu	ppm	0.000
Zinc	Zn	ppm	0.002
Boron	B	ppm	0.031
Molybdenum	Mo	ppm	0.010
Other nutrient indices			
pH	—	—	4.06
Electrical conductivity	EC	µS/cm	1.00

Source: Scarratt (1986).

which is in an organic form and therefore not immediately available for plant uptake (Bunt 1988). The grade of peat moss is important, however, because the more decomposed forms, such as peat humus, may contain enough nitrogen to be a problem to seedling culture (see section 2.2.4.2).

Scarratt (1986) analyzed a standard peat-vermiculite growing medium for a variety of mineral nutrients and other chemical properties and found very low levels of all nutrients. Most micronutrients were present in very low concentrations, and copper (Cu) was completely absent (table 2.2.3). Commercial brands of growing media vary in their initial fertility levels, because many media contain supplemental amounts of fertilizer. Sanderson (1983) reviewed the fertility of 23 different brands and found that nitrate levels ranged from 3 to 154 ppm, phosphorus from 1 to 112 ppm, potassium from 8 to 244 ppm, and calcium from 100 to 3,160 ppm. Handreck and Black (1984) noted that growing medium components can contain varying levels of fertility, making it difficult to achieve uniformity between batches. These data indicate that growers should be aware of the fertility levels of their growing media and should routinely analyze growing media nutrient levels (see chapter 1, volume four of this manual).

Certain components of growing media can have a negative effect on fertility, however, and compete with the seedling for nutrients. Uncomposted organic materials, such as sawdust or bark, can tie-up a significant amount of nitrogen because the microorganisms that decompose these organics require high levels of this nutrient. Some types of pine bark can remove iron from the growing medium solution, and vermiculite can tie-up both iron and phosphorus (Handreck and Black 1984).

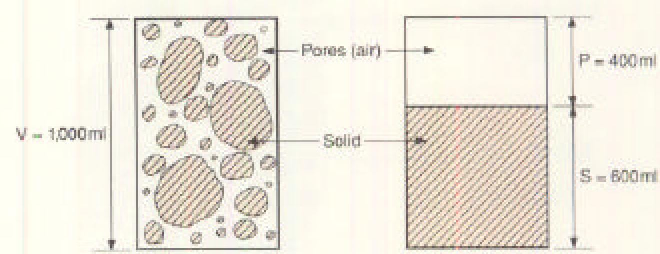
Proper balance of pore sizes. There is probably no other physical property of growing media that has been so thoroughly discussed and investigated as porosity. This attention is well deserved, however, because the relative pore space of a growing medium affects every aspect of seedling growth in containers. A properly balanced pore structure means good gas exchange for the root system, which directly affects all root functions such as water and mineral nutrient uptake. Milks and others (1989) state that plants growing in small containers often have growth problems due to poor aeration or low water-holding capacity of the growing medium. Aeration porosity is considered to be the most important physical property of any growing medium (Johnson 1968, Bragg and Chambers 1988).

A growing medium is composed of solid particles and the pore spaces that exist between them; these pore spaces are as important horticulturally as the particles themselves. The amount of pore space is expressed in terms of percent porosity and is a function of the size, shape, and spatial arrangement of the individual growing medium particles in the container (fig. 2.2.4).

Porosity can be functionally divided into three parts—total porosity, aeration porosity, and water-holding porosity (Bethke 1986, Handreck and Black 1984):

Total porosity. Total porosity is the measure of the total pore space of a growing medium, expressed as the percentage of its volume that is not filled with solid particles. For example: 1,000 ml of growing medium with a total porosity of 40% has 400 ml of pores and 600 ml of solid particles (fig. 2.2.4).

Aeration porosity. Aeration porosity is the measure of that part of the total pore space that is filled with air after the growing medium is saturated with water and then allowed to drain freely. The pores that contain air are relatively lame and are termed **macropores** (fig. 2.2.5).



$$\text{Total porosity (\%)} = \frac{P}{V} \times 100$$

In this example:

$$\text{Total porosity} = \frac{400\text{ ml}}{1{,}000\text{ ml}} \times 100 = 40\%$$

Figure 2.2.4—*A given volume of ovendry growing medium is composed of solid particles and the spaces (pores) that surround them. The total porosity is the proportion of the total volume of the growing medium that is not solid matter (adapted from Handreck and Black 1984).*

Water-holding porosity. Water-holding porosity is the measure of that part of the total pore space that remains filled with water after the growing medium is saturated with water and allowed to drain freely. The pores that contain water are relatively small and are termed **micropores** (fig. 2.2.5).

The porosity characteristics of a growing medium (the relative proportion between aeration porosity and water-holding porosity) depend on the types and sizes of the growing medium components. Bugbee and Frink (1986) varied the size of peat moss and vermiculite particles to produce growing media with aeration porosities from

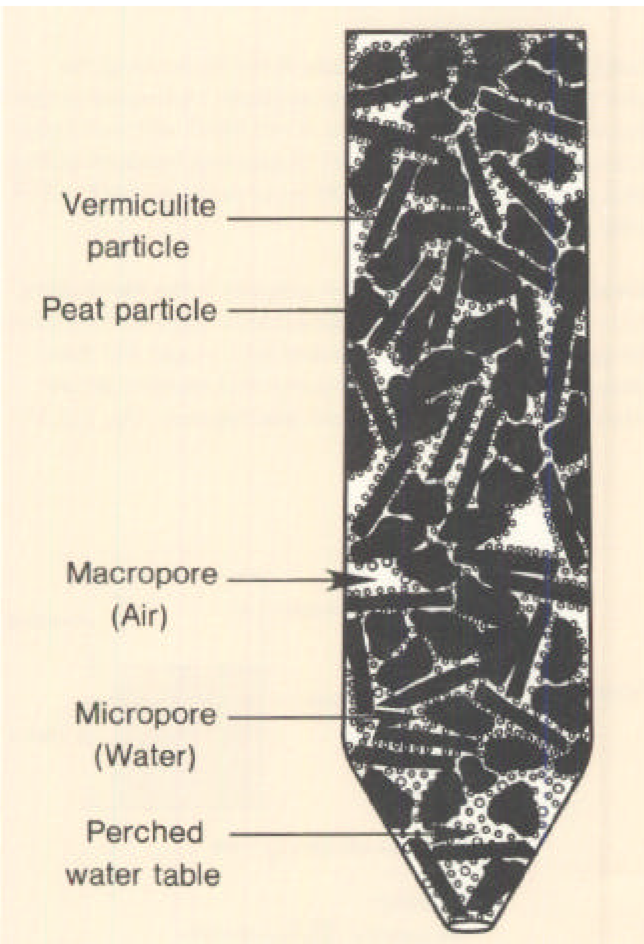


Figure 2.2.5—*The total porosity of a growing medium consists of relatively large macropores, which together constitute the aeration porosity, and relatively small micropores, which constitute the water-holding porosity. All containers also produce a perched water table, which creates a zone of saturated growing medium at the bottom of the container.*

1 .0 to 33.6% by volume. Total porosity remained constant with the increase in aeration porosity, but water-holding porosity decreased linearly.

Porosity can be measured in several different ways—aeration porosity can be measured by either volumetric or gravimetric means (Bragg and Chambers 1988). A relatively simple procedure for estimating total porosity, aeration porosity, and water-holding porosity is described in table 2.2.4.

Recommendations for the total amount and type of pore space for container growing media vary considerably. Handreck and Black (1984) reported that well-formulated growing media contain about 60 to 80% total porosity. Havis and Hamilton (1976) stated that the total porosity of a growing medium should exceed 50%, and that the aeration porosity should be 20 to 25%; Whitcomb (1988) recommended a higher aeration porosity of approximately 25 to 35% for container tree seedlings. Puustjarvi and Robertson (1975) recommended an even higher aeration porosity value of 45 to 50% because of the high oxygen demand ofroots in greenhouse environments. This wide variation in porosity recommendations also reflects the physical characteristics of the different types of growing media and different ways in which porosity can be measured. A well-formulated growing medium will contain a mixture of macropores, for aeration and drainage, and micropores, for water-holding ability (fig. 2.2.5). The ratio of macropores to micropores varies considerably between different growing medium mixtures, however, and the porosity characteristics of a given medium cannot be predicted from the porosity of its individual components. Beardsell and others (1979) found that, although total porosity can be predicted from bulk density for certain growing media, the aeration and water-holding porosity cannot.

Factors affecting porosity. The porosity of a growing medium will vary with the characteristics of its components, the degree of medium compaction within the container, and the container height. In fact, container height is actually the principal factor controlling aeration porosity of growing media in a container (Milks and others 1989). There are four factors that affect porosity characteristics in containers: individual particle size, particle characteristics, particle size mixture, and changes in porosity over time.

Individual particle size. In bareroot seedling nurseries, soil structure is one of the most important properties

Table 2.2.4—*Determining the porosity characteristics of growing media: total porosity, aeration porosity, and water-holding porosity*

Equipment

1. Container with a drainage hole at the bottom.
2. Plug or waterproof tape for sealing the drainage hole.
3. Graduated cylinder or some other way of measuring liquid volume.
4. Watertight pan wider than the bottom of the container.

Procedure

1. Seal the drainage hole in the container and fill it with water. Measure the volume of water in the container and record as "container volume."
2. Empty and dry the container and fill it with growing medium. Slowly saturate the growing medium by gradually pouring water onto the surface. Continue adding water over a period of several hours until the growing medium is completely saturated (the surface glistens). Record the total volume of water added as "total pore volume."
3. Place the container over the watertight pan and remove the seal from the container drain holes. Allow all the free water to drain out of the container (this may take several hours). Measure the amount of this drainage water and record as "aeration pore volume."
4. Compute the total porosity, aeration porosity, and water-holding porosity as follows:

$$\textit{Total porosity}\ (\%) = \frac{\text{total pore volume}}{\text{container volume}} \times 100\%$$

$$\textit{Aeration porosity}\ (\%) = \frac{\text{aeration pore volume}}{\text{container volume}} \times 100\%$$

$$\textit{Water-holding porosity}\ (\%) = \text{total porosity} - \text{aeration porosity}$$

Standard

The aeration porosity should be approximately 25 to 35% for forest tree seedlings.

Source: adapted from Gessert 1976 and Whitcomb 1988.

affecting soil porosity but, in container nurseries, porosity is determined mainly by the range of particle sizes present in the growing medium (Handreck and Black 1984). Large particles do not pack together as closely as small particles and therefore produce greater total porosity. Aeration porosity and water-holding porosity have a complementary relationship: as the size of the particle increases, the water-holding porosity decreases and the aeration porosity increases (fig. 2.2.6).

The particle size that generates the proper mix of porosity apparently varies with the type of material. For peat moss, a particle size between 0.8 mm (0.03 inch) and 6.0 mm (0.24 inch) is recommended. If the peat particles are smaller than about 0.8 mm (A in fig. 2.2.6), micropores predominate, and the growing medium can easily become waterlogged. As the particle size increases, the ratio of macropores to micropores increases until, above about 6.0 mm (B in fig. 2.2.6), macropores predominate and the growing medium will not retain enough water for plant growth (Puustjarvi and Robertson 1975). The ideal particle size range for pine bark, on the other hand, is somewhat smaller. Handreck and Black (1984) reported that particles smaller than 0.5 mm (0.02 inch) had the most significant effect on the aeration and

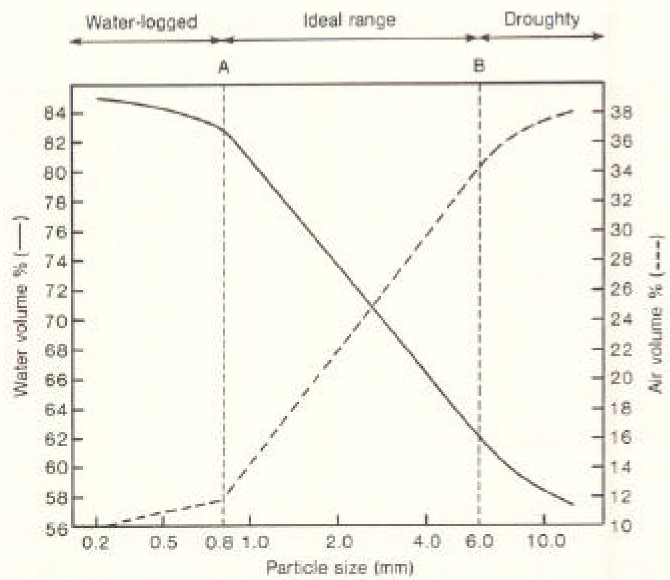


Figure 2.2.6—*Porosity in a growing medium is partially a function of particle size. As the particle size increases, the relative proportion of micropores decreases and the proportion of macropores increases and vice versa. This conceptual diagram was developed for a pure peat moss growing medium by Puustjarvi and Robertson (1975); the concept would be the same, although the numerical values would be different, for other growing media components.*

water-holding characteristics of the growing medium. They found that aeration porosity was decreased most by bark particles smaller than 0.25 mm (0.01 inch), whereas available water was increased more by particles in the range 0.10 to 0.25 mm (0.004 to 0.010 inch). The ideal size for sand is: 60% of the particles between 0.25 and 1.00 mm (0.01 and 0.04 inches), with no more than 3% smaller than 0.1 mm (0.004 inch) or larger than 2 mm (0.08 inch) (Swanson 1989).

Particle characteristics. The physical and chemical properties of the particles themselves also affect the porosity of a growing medium. Some components, such as peat moss and vermiculite, can be compressed, whereas others, such as perlite and bark, retain their original size under compression. Peat moss and especially vermiculite are fragile and can be easily broken into smaller particles during mixing and handling. Adding moisture to peat-vermiculite media during mixing can actually maintain the integrity of the particles (Milks and other 1989). The irregular surface texture of perlite particles generates macropore space (Moore 1988). Some organic components, especially uncomposted sawdust and bark, shrink during decomposition.

The particles of many growing medium components are not solid but contain internal spaces; this **internal porosity** is important to the horticultural properties of a growing medium. Some dense materials, such as sand particles, have essentially no internal pore space, whereas other materials, such as peat moss, vermiculite, and pine bark, have a substantial amount of internal porosity. The internal pore space of pine bark particles was determined to be about 43% of its total volume (Pokorny 1987). In addition to affecting the bulk density, this internal porosity may influence the moisture-holding and nutrient-holding properties of a growing medium. Although internally held water is considered by some researchers to be unavailable to plants (Spomer 1975), Pokorny (1987) demonstrated that seedling water uptake is increased by root penetration of pine bark particles. The spongy structure of sphagnum peat moss and vermiculite particles reflect high internal porosity, which is one reason for their popularity as growing medium components in container tree nurseries. Other porous materials, such as perlite, have sealed pores and therefore cannot absorb moisture. For example, perlite particles hold consistently less moisture and therefore provide more aeration than pumice particles of the same size (Johnson 1968). Because of these desirable properties, perlite is often added to a growing medium to increase the aeration porosity.

A comparison of the porosity characteristics for some common growing medium components (table 2.2.5) further illustrates the variation between different materials. Peat moss has the highest total and water-holding porosity because it has high internal pore space; fir bark has the lowest water-holding porosity because it is suberized and therefore water repellent.

Particle size mixture. Because growing media are usually a mixture of two or more components with a variety of particle sizes, the arrangement of the individual particles and their relationship to each other affects porosity. Whenever particles of different sizes are mixed together, the resultant volume is always less than the sum of the original volumes because the smaller particles fill in the pores between the larger ones. This is especially significant with angular particles such as some types of sand in which the pyramid-shaped particles are able to pack tightly together.

Table 2.2.5—*Comparison of dry and wet bulk densities and porosities for standard growing media components*

Component	Bulk density (kg/m³)		Porosity relationships (% by vol)		
	Dry	Wet	Water–holding	Aeration	Total
Sphagnum peat moss	104.1	693.7	58.8	25.4	84.2
Hypnum peat moss	185.8	310.8	59.3	12.4	71.7
Vermiculite	108.9	640.8	53.0	27.5	80.5
Perlite	96.1	394.1	47.3	29.8	77.1
Fir bark	184.2	333.2	15.0	54.7	69.7
Sand	1,497.9	1,842.3	33.7	2.5	36.2

Source: modified from Johnson (1968).

Changes in porosity over time. The porosity of a given growing medium also changes over time because of decomposition of medium particles, siltation from irrigation and gravity, and root ingrowth. Langerud (1986) concluded that a physically stable medium is needed that can maintain the critically important balance between aeration and water-holding ability. Beardsell and others (1979) found that fine particles of pumice settled to the bottom of the container where they filled in between the larger particles and caused drainage problems. Many growers fail to appreciate the amount of pore space that becomes filled with roots; in fact, tree seedlings are expected to produce enough roots to form a relatively firm root plug at the end of the growing season. As new roots are produced, they penetrate and then expand to fill up the larger air-filled pores of the growing medium, gradually reducing the aeration porosity. This problem is more serious for larger tree seedlings that are grown for more than one growing season. To counteract this effect, growers should use a coarse, well-aerated growing medium that, although requiring more irrigation when the seedlings are small, will provide adequate air exchange when the seedlings mature.

Freedom from pests*.* One of the most serious problems with soil-based growing media is that native soil can contain a variety of pests, such as pathogenic fungi, insects, and nematodes, and weed seeds. Because of these pests, soils need to be pasteurized with heat or sterilized with chemicals before they are used in growing media. With the advent of artificial growing media, the use of pasteurization has decreased substantially be cause most of the commonly used components are considered to be pest-free (James 1987). Vermiculite and perlite are rendered completely sterile during manufacturing, when they are exposed to temperatures as high as 1 ,000 °C (1,832 °F). The pest-free status of peat moss is subject to debate (table 2.2.1). Bluhm (1978) reports that, although some peat moss products are advertised as "sterile" or "pest-free," peats have been shown to contain pathogenic fungi, weed seeds, and nematodes. Baker (1985) stated that water molds and other root-rotting fungi have been found in commercial peat moss from several geographic areas, including Canada. Bunt (1988) concluded that peat is not technically sterile, but because the microorganisms that it contains are not usually pathogenic, it is not usually sterilized before use (see chapter 1, volume five of this manual).

Some recent studies have found that some types of sphagnum peat moss actually inhibit certain pathogenic fungi, such as *Pythium* spp. Wolffhechel *(1988)* inoculated *Pythium* into samples of sphagnum peat moss from five different locations and found considerable variability in their receptivity to the pathogen. Because it could be destroyed by heat pasteurization or fungicide treatment, this ability to suppress *Pythium* was attributed to the presence of beneficial microorganisms. Growing media formulated with this disease-suppressive peat moss could inhibit the development of *Pythium*-related damping-off and root rot. One commercial supplier, Ball Seed Company, has already released a peat-based growing medium that is "naturally suppressive" to Pythium diseases.

2.2.3.2 Characteristics that affect nursery operations

In addition to container characteristics that influence seedling growth, nursery managers must consider growing media properties that relate to the operational aspects of container tree nursery management. Factors such as cost and availability, uniformity and reproducibility, bulk density, dimensional stability, durability and ease of storage, ease of mixing and loading, rewettability, and the ability to produce a firm root plug are also important in the selection of a growing medium or individual components.

Reasonable cost and availability. Cost is one of the most significant, yet often overrated, factors in selecting growing media or their components. Because growing media have such an overriding effect on container seedling growth, nursery managers should not make cost the determining factor when selecting a medium. Swanson (1989) stated the case well-price should not be the first priority in choosing a commercial growing medium or medium components, unless it is essentially prohibitive.

Availability has an effect on other operational aspects of a growing medium, especially uniformity and cost (Swanson 1989). Most of the materials used to formulate growing media are inexpensive in themselves but are bulky and sometimes heavy and therefore expensive to ship. Primarily because of shipping costs, a material that is inexpensive in one location may be prohibitively expensive in another. Many components are produced in restricted geographic areas and are either difficult to obtain or prohibitively expensive in other areas. Sphagnum peat moss is easily accessible and relatively cheap in Canada and the northern United States but is considered uneconomical in many parts of the world. Sand, on the other hand, is a growing medium component that is found worldwide at a relatively low cost. Prices of media components also may change: materials that are initially inexpensive, such as pine bark, may become costly due to high demand and competition with other uses (Whitcomb 1988).

High degree of uniformity and reproducibility. Both the components and the resultant growing media must be uniform in quality and reproducible from batch to batch. Some materials, such as peat moss and sand, can vary considerably between locations. Although **peat moss** is used as a generic term, the quality of this popular growing medium component varies with respect to the type of plant that composes the peat and the climate under which the peat was deposited. Mastalerz (1977) recommends standardization of growing media and medium components to ensure that each batch has the same physical, chemical, and biological properties. A growing medium that varies in physical or chemical characteristics can cause serious problems with irrigation, fertilization, and other cultural practices (see section 2.2.5.1). A good growing medium must also be reproducible in order to guarantee crop uniformity and maintain crop production schedules (Whitcomb 1988). The ability to consistently reproduce a uniform growing medium from crop to crop is one of the most important cultural factors in successful container tree nursery management.

Low bulk density. The bulk density of a growing medium is defined as weight per unit volume and is usually expressed in grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3); the English units are pounds per cubic foot. The bulk density of a specific growing medium is a function of three factors:

- The bulk densities of the particles composing the medium.
- The compressibility of the particles.
- The arrangement of these particles with respect to one another.

Bulk densities of different growing medium particles vary considerably depending on their chemical composition and physical structure. Although Handreck and Black (1984) estimated the bulk density of average mineral particles at approximately 2.6 g/cm^3 (162.3 pounds per cubic foot) and average organic matter particles at 1 .55 g/cm^3 (96.8 pounds per cubic foot), such averages are of limited usefulness because the compressibility and arrangement of the particles also affect bulk density values. Mineral particles can vary from solid sand to highly porous vermiculite, and organic particles from rigid bark to spongy peat moss.

The bulk density of a growing medium in a filled container is also a function of the internal arrangement of the individual particles. Although Beardsell and others (1979) found that total porosity could be predicted from bulk density for some types of growing media, aeration and water-holding porosity are often related to how densely the medium is compacted during the filling process (compaction is discussed in detail in section 2.2.7).

Bulk density is traditionally measured on an ovendry weight basis, but wet bulk density is also important for operational reasons. Some materials, such as peat moss and vermiculite, are able to absorb many times their own weight in water. Nelson (1978) reported that a growing medium consisting of vermiculite and perlite had a bulk density of around 0.51 g/cm^3 (32 pounds per cubic foot) when saturated, compared to a dry weight of only 0.10 g/cm^3 (6.5 pounds per cubic foot). Growers interested in keeping their media light in weight may want to consider perlite as a component because this material is relatively hydrophobic. A growing medium consisting of a mixture of peat moss and perlite would, therefore, have a saturated weight much lower than that of a peat moss-vermiculite mixture (Whitcomb 1988).

Both dry and wet bulk densities for common growing medium components are listed in table 2.2.5. Some materials, such as peat moss and vermiculite, have much higher wet bulk densities than dry bulk densities. Sand has obviously the highest values because of its higher particle density, and the small difference between the wet and dry values reflects a low water-holding capacity. In ornamental nurseries, the high bulk density of sand adds stability to single, free standing containers so that top-heavy plants do not blow over; this property is inconsequential for the small, aggregated containers used in most forest tree nurseries. Dry bulk density is operationally important for shipping and handling of dry medium components, but wet bulk density affects the handling and shipping of the container seedlings when the growing medium is saturated. Based on ease of handling, therefore, components with low bulk densities would have an advantage in container tree nurseries.

Dimensional stability. A growing medium should not shrink or swell excessively during use. Bilderback (1982) lists three different types of volume changes that can occur.

1. Shrinkage due to expansion and contraction. Materials such as peat moss can shrink during periods of alternating wetting and drying. Harlass (1984) reported that if some peat-based media are allowed to dry out excessively, they can pull away from the container wall, making uniform rewetting difficult.

2. Decomposition of organic materials. Organic components that were not properly composted will lose volume as they decompose (see following section on durability and ease of storage).

3. **Space-volume shrinkage.** Small particles can fill in the pore spaces between larger particles; the greater the difference in particle sizes, the greater the change in volume. Whitcomb (1988) discussed the poor aeration that resulted when fine vermiculite particles were carried to the bottom of the container with percolating irrigation water, filling the pore spaces and raising the level of the perched water table. Sand or pumice with a range of particle sizes is also not recommended because the smaller particles gravitate to the bottom of the container over time and reduce porosity.

***Durability and ease of storage*.** Most of the popular components of growing media are durable and will not decompose or otherwise change over time. Uncomposted organic materials can decompose considerably during the cropping cycle and are therefore not recommended for growing media (Nelson 1978). Composted organic materials, including sawdust, wood chips, and bark, can be used, however. Pine bark does not change volume appreciably because of its slow decomposition rate, but even so most nursery managers prefer aged or composted bark (Bilderback 1982). Peat moss can vary considerably in its degree of decomposition, which can be rated on a 1 to 10 scale using the von Post system IPuustjarvi and Robertson 1975).

Initially sterile materials that are ordered in bulk quantities can be contaminated with weed seeds or other pest propagules during storage. For this reason, batches of premixed growing medium or medium components should be purchased in sealed plastic packages and stored out of direct sunlight, which will rapidly break down the plastic covering.

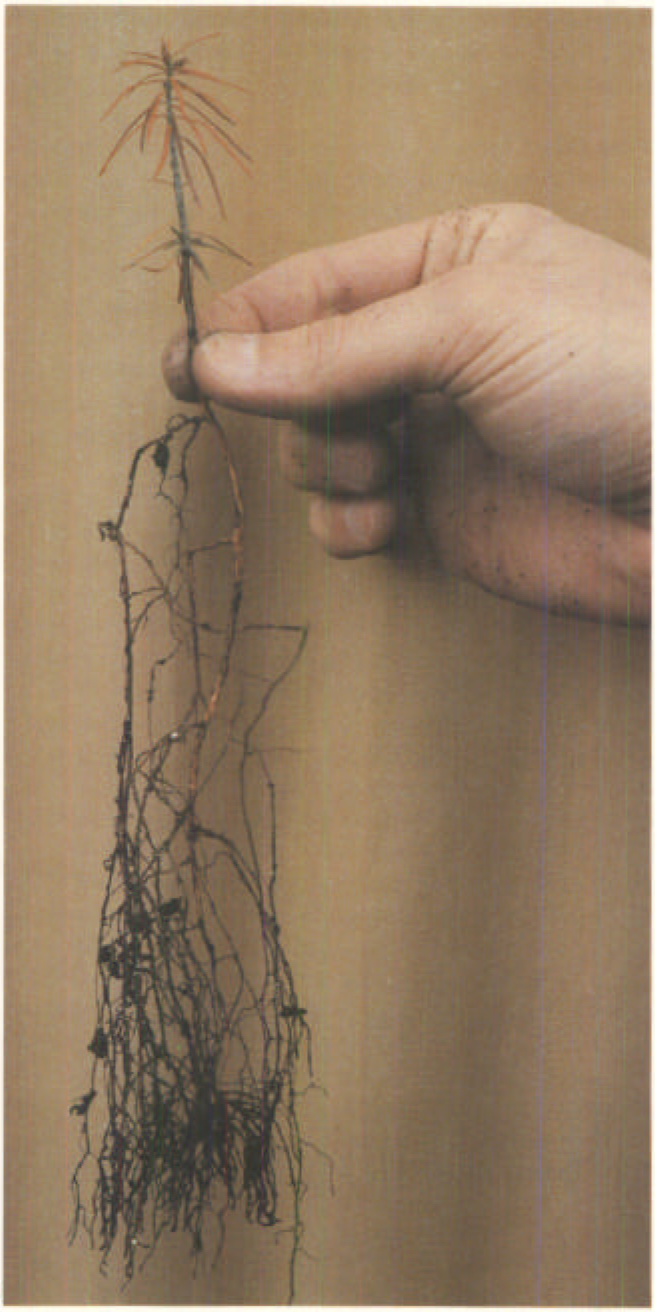
***Ease of mixing and filling into containers*.** This factor is particularly important for nursery managers who custom mix their own batches of growing media. Uniform mixing can be difficult to achieve because of differences in the bulk density, particle size, and moisture content of]he various components. Growing medium components should not aggregate or clump during storage and should flow easily during the mixing and filling operations. Peat moss and pine bark are shipped relatively dry but must be thoroughly wetted before mixing; this can be operationally difficult, however, because these organic materials are often hydrophobic at low moisture contents (see section 2.2.5.4 for more information on wetting agents). Flowability is especially important when filling the small-volume containers typically used in forest tree nurseries. These containers have correspondingly small top diameters that "bridge" easily and prevent the medium particles from flowing and uniformly filling the container.

Ease of rewetting. Some components, such as peat moss and bark, can become hydrophobic if allowed to dry out excessively, which can reduce irrigation infiltration rates. This problem is particularly serious during the dormancy induction period, when container managers withhold irrigation to induce seedling moisture stress. Bunt (1988) stated that the difficulty in rewetting peat is due to a film of air trapped on the surface of the peat particles and to the presence of iron humates, which repel water. Bark particles can also be difficult to rewet, and Pokorny (1979) stated that this hydrophobicity is caused by both physical and chemical factors: most bark particles are covered with organic chemicals that resist water absorption and their rough surfaces create a surface tension that also physically repels water. Bilderback (1982) recommended using surfactants if the hark is below 35% moisture content. Surfactants, also called wetting agents, are routinely added during the mixing procedure to increase wettability of growing medium components (see section 2.2.5.4 for more information on surfactants).

Promotion of firm root plug formation. This operational characteristic is unique to forest tree nurseries because the shippable seedlings are removed from the container before planting. Container seedlings are expected to maintain a firm root plug during handling, shipping, and planting. A cohesive, resilient plug is especially important when the seedlings are planted with a dibble or other planting tool that makes a hole the same size and shape as the container. The growing medium and other cultural practices must be designed to promote adequate root growth throughout the container so that a firm root plug develops by the end of the growing season (fig. 2.2.7A). Growing media that do not pack evenly in the container or inhibit aeration can result in a poorly formed root system that does not extract easily from the container or does not maintain the integrity of the root plug during handling and shipping (fig. 2.2.713). Lackey and Alm (1982) rated "styroplug quality" of conifer seedlings grown in 6 different types of growing media and found that two brands of commercial growing media produced plugs with the highest quality rating. Tinus (1974) evaluated the survival and growth of ponderosa pine seedlings with different "root plug integrity" ratings; both survival and growth decreased significantly as the root plug deteriorated (table 2.2.6).

A

Figure 2.2.7—*The root system of container tree seedlings should form a firm plug* **(A)** *when extracted from the container. A poorly formulated growing medium can create conditions unfavorable for root growth, and the resultant seedling root system will not form a plug* **(B)**.



B

Table 2.2.6—*Effect of root plug integrity on the outplanting survival and growth of ponderosa pine container seedlings*

Root plug integrity(%)	First-year survival (%) 1972	1973	First-year growth (cm) 1972
100	95 a	92 a	4.2 a
75	90 ab	72 b	3.7 b
50	85 b	78 b	3.0 c
25	87 b	40 c	3.0 c
0	79 c	15 e	2.6 c

Values in columns with no letters in common differ significantly (p = 0.05).
Source: adapted from Tinus (1974).

2.2.4 Components Used in Formulating Growing Media for Tree Seedlings

Although pure peat is used in some northern container tree nurseries, most modern growing media consist of two or more different **components** that are selected to provide certain physical, chemical, or biological properties. Other **amendments,** such as fertilizer or wetting agents, are sometimes added during the mixing process. For purposes of clarity, a growing medium component usually constitutes a large percentage (>10%) of the mixture, whereas an amendment is defined as a supplemental material that contributes less than 10%, to a medium (Gladon 1988) (amendments will be covered in section 2.2.6).

The Container Nursery Survey revealed that only 5 materials were used for growing media in forest tree nurseries in the United States and Canada: peat moss, sawdust, sand, vermiculite, and perlite.

A typical growing medium used in horticulture today is a composite of two or three components. Mixtures of organic and inorganic components are popular because these materials have opposite, yet complementary, physical and chemical properties. Beardsell and others (1979) found that some of the physical properties of growing medium mixtures, such as water-holding ability, can be predicted from the characteristics of the individual components.

2.2.4.1 Organic components

Function of the organic component. Organic materials are desirable components of growing media because they generate a large proportion of micropores, and thus produce a high water-holding capacity, yet are resilient enough to resist compaction. Organic matter also has a high CEC and can therefore retain nutrient ions against leaching and provide a buffer against rapid changes in salinity.

The amount of organic material used in growing media varies considerably, generally ranging from 25 to 50% (by volume), but sometimes up to 100% (Mastalerz 1977). Joiner and Conover (1965) found that the best proportion of organic material was from 40 to 50%, and Harlass (1984) reported that mixes containing more than 50% organic matter may actually have less pore space.

Although many different types of organic matter have been used for growing media in ornamental container crops (Mastalerz 1977, Bunt 1988), peat moss is the most commonly used organic material in forest tree nurseries. The only other organic material reported in the Container Nursery Survey was sawdust, which was mentioned by only two nurseries.

Peat moss. Although samples of peat moss may appear similar, they can have very different physical and chemical properties. Peats are formed when partially decomposed plants accumulate under water in areas with low temperatures and low oxygen and nutrient levels (Peck 1984). Peats can be composed of several species of plant including mosses, sedges, and grasses. The species of plant, its degree of decomposition, variation in local climate, and water quality all contribute to differences in peat moss quality and determine its value as a growing media component (Mastalerz 1977).

There are several different systems for classifying peat; for horticultural purposes, the principal plant species and the degree of decomposition are most important. The American Society for Testing Material (ASTM) uses a 5-class rating system based on the type of plant composing the peat and the organic fiber content (Bunt 1988, Mastalerz 1977, Hellum 1975). Analyzing the physical and chemical properties of peat moss is time consuming and technically demanding, and therefore nursery managers generally rely on the information provided by the suppliers. One newly developed analytical procedure, infrared spectroscopy, can determine the botanical composition, degree of humification, cation exchange capacity, nitrogen content, and other physical and chemical properties of a peat sample (Lehtovaara and others 1988). Some physical and chemical characteristics of the principal horticultural grades of peat moss are provided in table 2.2.7, and the four grades can be described as follows.

1. Sphagnum peat moss. This classification requires a minimum 90% organic matter on a dry weight basis, with over 75% of this material being mosses of the genus *Sphagnum.* There are approximately 335 species of sphagnum moss in the world (Puustjarvi 1975); Hellum (1975) reports that there are 25 species in Alberta alone and that *S. fuscum is* one of the most desirable. The stems and leaves of sphagnum peat moss are characteristic, and the fibrous, unicellular structure of the foliage can be diagnostic (fig. 2.2.8). The leaves of sphagnum moss contain a large number of pores that form an internal capillary system capable of storing large volumes of available water; in fact, Peck (1984) estimates that 93% of the water in this internal pore space is available to plants.

Table 2.2.7—*Characteristics of various types of horticultural peat moss*

Type of peat moss	Plant composition	Degree of decomposition	pH	Water-holding capacity (%)	Mineral nutrient content (% ash)	(% N)	Dry bulk density (kg/m³)
Sphagnum peat	*Sphagnum* spp.	Very low	3.0–4.0	1,500–3,000	1.0–5.0	0.6–1.4	72.1–112.1
Hypnum peat	*Hypnum* spp. *Polytrichum* spp. *Sphagnum* spp.	Low	5.0–7.0	1,200–1,800	4.0–10.0	2.0–3.5	80.1–160.2
Reed-sedge peat	Reeds, sedges, grasses, & cattails	Medium	4.0–7.5	400–1,200	5.0–18.0	1.5–3.5	160.2–288.4
Peat humus	Not identifiable	High	5.0–7.5	150–500	10.0–50.0	2.0–3.5	320.4–640.8

Source: modified from Lucas and others (1965).

In addition to their physical characteristics, types of peat moss can be identified by their geographic origin. Sphagnum moss only grows in cool, northern climates. Hellum (1975) stated that desirable sphagnum bogs are found only in the boreal forest and that peat bogs in the southern part of Alberta contain a low proportion of sphagnum moss because of alkaline water and soil conditions. Most peat mosses produced in the United States contain a low proportion of sphagnum moss, with the exception of those from northern states such as Minnesota, Michigan, Maine, and Washington (Lucas and others 1965).

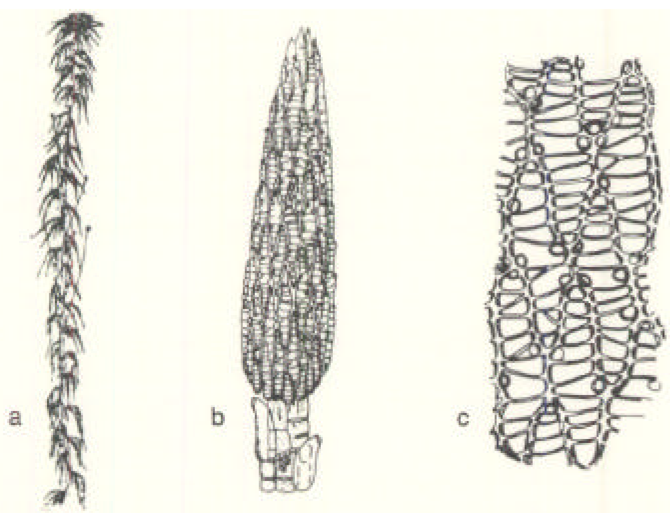


Figure 2.2.8—*Peat moss derived from sphagnum moss plants (for example,* Sphagnum cuspidatum*) can be identified by the characteristic open pore structure of the leaf cells (* **a** *= whole plant,* **b** *= leaf,* **c** *= close-up of internal leaf structure) (modified from Peck 1984).*

There is considerable variation in peat moss quality, even in the type harvested from sphagnum bogs; Carlson (1983) stated that peat moss quality varied not only between different bogs, but even vertically within the same bog. Scagel and Davis (1988) evaluated the physical and chemical properties of peats used in British Columbia container tree nurseries and found highly variable results. A laboratory comparison of the physical properties of four commercial brands of sphagnum peat moss revealed significant differences in many of the properties (table 2.2.8). Carlson (1983) provided standards for physical property tests and recommended that such tests be performed on all potential peat sources.

Peck (1984) distinguished between two different types of sphagnum peat moss: **light peats** and **dark peats.** Light sphagnum peats are so-named because they are light in both color and weight; they have a high volume of internal pores, a large proportion (15 to 40%) of which is classified as aeration porosity. Dark sphagnum peats are twice as heavy as light peats and contain less total pore space, with correspondingly less aeration porosity. The CEC of dark peats is over twice that of light sphagnum peats. Peck (1984) considers dark peats less suitable for long-term container seedling culture because they are less durable and less resilient than the lighter colored peats.

Table 2.2.8—*Four different brands of sphagnum peat moss varied in physical properties affecting conifer seedling growth*

Physical characteristics*	Sphagnum peat moss brands A	B	C	D
Saturated weight (g/l)	718.0	735.0	660.0	685.0
Dry weight after saturation (g/l)	58.0	94.0	64.0	73.0
Ash content (%)	4.3	9.0	8.0	9.1
Bulk density (g/ml)	0.054	0.088	0.060	0.068
Specific gravity (g/ml)	1.53	1.56	1.56	1.56
Total porosity (%)	96.0	94.0	96.0	96.0
Water capacity by volume (%)	62.0	60.0	56.0	57.0
Air capacity (%)	35.0	34.0	40.0	38.0
Coarse–fine ratio	0.35	0.17	0.34	1.60

* Procedures for determining these characteristics and acceptable standards are explained in detail in the source.
Source: Carlson (1983).

2. Hypnum peat moss. The organic matter content of this type of peat moss must exceed 90% of the ovendry weight, more than 50% of which must be composed of mosses of the *Hypnum* genus (Bunt 1988). Hypnum peat moss is generally less expensive than sphagnum moss but may contain weed seeds or plant pathogens because of the conditions under which it was formed (Whitcomb 1988). Mastalerz (1977) reported that much of the peat moss produced in the northern United States contained a high proportion of hypnum mosses. Hypnum mosses decompose more rapidly than sphagnum mosses but are used in the growing media for some horticultural crops, especially for acid-intolerant plants (Peck 1984). Growing media containing a high percentage of hypnum peat moss are not recommended for container tree seedlings.

3. Reed and sedge peat moss. These peats are formed from rushes, grasses, sedges, and similar marsh plants; an ovendry sample must contain a minimum 33% of these materials on a dry weight basis (Bunt 1988). Reed-sedge peat mosses are generally finer textured, more decomposed, and less acid than sphagnum peat moss. Mastalerz (1977) considers this peat moss class unsatisfactory for use in growing media because of its rapid rate of decomposition, fine particle size, and low fiber content.

4. Peat humus. Peat humus includes all types of peat moss that are in such an advanced stage of decomposition that the constituent plants are not recognizable. Peat humus is usually derived from reed-sedge or hypnum peat moss (Lucas and others 1965) and is composed of less than 33% total peat fiber (Bunt 1988). Because this grade of peat moss often contains a high proportion of foreign material such as silt and clay, it is considered undesirable for use in growing media (Mastalerz 1977).

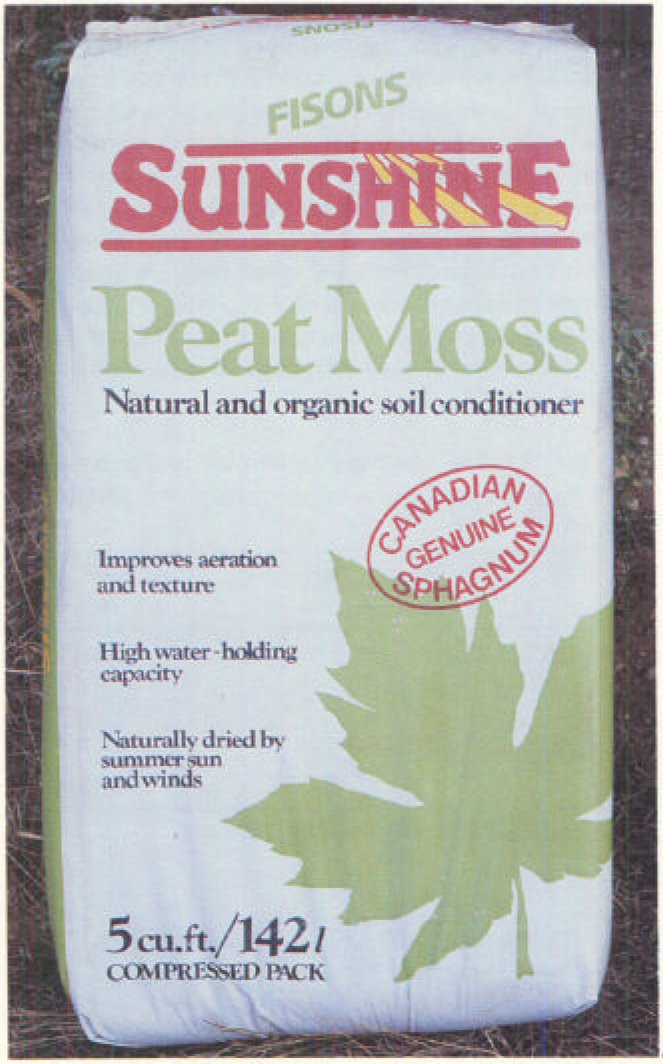
Although other grades of peat moss have some horticultural applications, sphagnum peat moss is the only type that can be recommended for production of container tree seedlings (fig. 2.2.9A). Operational trials comparing growing media containing sphagnum peat moss and media containing other peat moss types have produced startling growth differences (fig. 2.2.913).

In addition to the type of plants, peat texture is determined by the manner in which the peat is harvested and processed. Peat can be harvested from bogs by several processes, including block cutting and hydraulic mining. Block cutting involves cutting slabs of peat from the bog and then shredding the peat to the proper texture, whereas hydraulic mining mechanically shreds the peat and then dredges the liquid slurry from the bog (Helium 1975). The harvesting method can affect the physical characteristics of peat moss, especially the porosity (Wilson 1985). The hydraulic mining process breaks down the structure of the peat particles, causing it to pack more tightly with a resultant loss in total and aeration porosity (table 2.2.9). Block-cut peat is usually preferred for container growing media because of its coarser texture; the ASTM defines coarse peat as having particles larger than 2.38 mm (about 0.1 inch) (Bunt 1988).

Table 2.2.9—*Comparison of porosity characteristics of peat moss obtained by different harvesting techniques*

Characteristic*	Harvesting method: Block cut	Mined
Total porosity	95.4	91.8
Aeration porosity	46.0	32.5
Water-holding porosity	49.4	59.3
Readily available water	18.1	17.5

* Units for each characteristic are relative values obtained from particle size measurements.
Source: adapted from Wilson (1985).



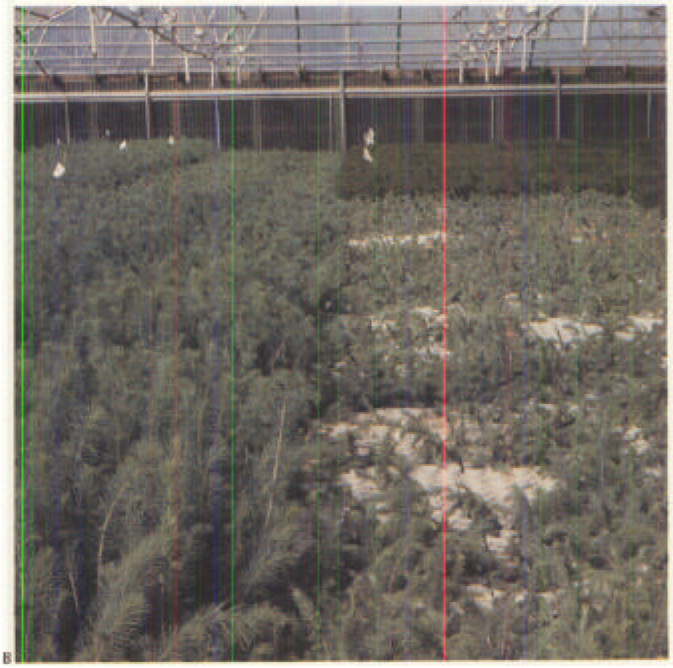


Figure 2.2.9—*Growing media containing sphagnum peat moss (**A; B, left**) have consistently proven superior for the production of container tree seedlings, compared to media composed of lesser grades of peat moss (**B, right**).*

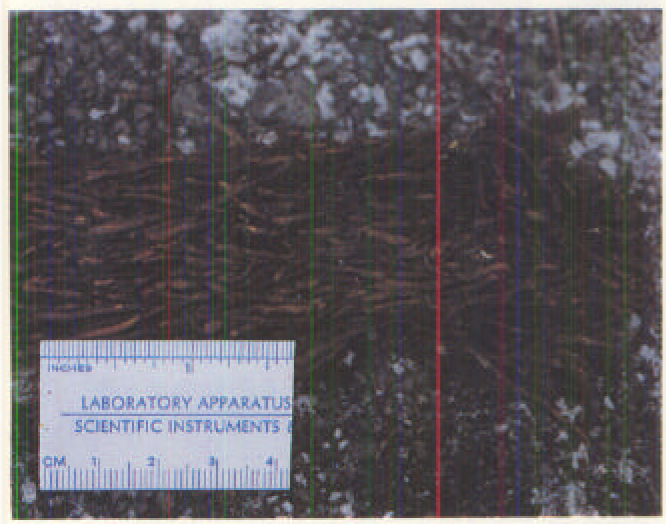


Figure 2.2.10—*Growers sometimes utilize innovative sources of organic matter as a substitute for peat moss in growing media. The bark of tree ferns has been used for the organic growing medium component in tropical climates, where peat moss is prohibitively expensive.*

Composted sawdust, bark, and other organic materials. Although peat moss is the most common organic component used in growing media in container tree nurseries in the United States and Canada, other organic materials have potential, especially in warmer climates where the cost of sphagnum peat moss can be prohibitive (fig. 2.2.10). Wood residues, including sawdust, bark, and wood chips, are alternative organic materials that can be used for growing media, depending on local availability and cost. Sewage sludge and mushroom compost have also been tested in ornamental nursery applications (for example, Chong and others 1988). Lippitt (1989) tested rice hulls as an organic component in a forest nursery and reported that they are cheap, readily available, consistent in quality, resistant to decomposition, and mix well. Bunt (1988) and Mastalerz (1977) discussed alternative organic components that have been used in growing media for ornamental nurseries.

Because of their high carbon to nitrogen ratio (C/N), wood residues must be composted with supplemental nitrogen amendments before use (table 2.2.10). Fresh bark can have a C/N ratio of 300:1 and so is frequently composted before use. Organic materials vary considerably in decomposition rates and in the amount of nitrogen required during composting, even within one genus of tree (table 2.2.1 1). An excellent overview of the biochemistry and methodology of composting is provided by Poincelot (1972), and composting is also discussed in detail in Mastalerz (1977), Bunt (1988), Whitcomb (1988), and Nelson (1978).

Sawdust. Sawdust is commonly used in horticultural growing media and is usually composted before use. Because of the inherent differences in chemical properties between different woods, however, the suitability of sawdust as an organic growing media component is extremely variable. Mastalerz (1977) stated that sawdust from incense-cedar, walnuts, or redwood is known to have direct phytotoxic effects, and Gates (1986) related that sawdust from western red cedar is toxic to many horticultural plants. Stewart (1986) reported that conifers grown on peaty soil types accumulate high levels of manganese, and that sawdust from such trees is phytotoxic if these materials are used for growing media. Worrall (1976) investigated the properties of sawdust from several species of Eucalyptus and found that, even within this one genus, the presence of chemical toxins varied between tree species (table 2.2.11). Only sawdust from sawmills should be considered for growing media because other wood residues may contain preservatives or other harmful chemicals. Sawdust from coastal sawmills can contain high levels of salts, which can also be harmful to seedling growth (Gates 1986). Obviously, sawdust should be chemically tested before it is used in growing media. Another potential problem is uniformity of particle size; particle size analysis of sawdust revealed a considerable amount of variability (Scagel and Davis 1988).

Table 2.2.10—*Nitrogen required for composting various organic materials before use in growing media*

Type of organic material	N (kg/m³)
Sphagnum peat moss	0.04
Redwood bark	0.18
Incense-cedar sawdust	0.47
Redwood sawdust	0.54
Douglas-fir sawdust	0.44
Ponderosa pine sawdust	1.19
Pine bark	1.48
White fir bark	1.90

Source: Johnson (1968).

Table 2.2.11—*The suitability of sawdust as a growing medium component can vary, even with trees of the same genus*

Tree species	Relative concentration of toxins	Relative nitrogen tie-up
Eucalyptus pilularis	8.2	1.0
E. andrewsii	6.5	1.2
E. microcorys	6.1	1.1
E. radiata	4.5	1.2
E. saligna	1.3	1.4

Source: modified from Worrall (1976).

Bark. Tree bark is probably the most promising of alternative organic materials, and when prepared properly, both pine and hardwood bark have found wide acceptance as components of growing media in ornamental container nurseries (Bunt 1988, Mastalerz 1977, Bilderback 1982). Pokorny (1979) reviewed the horticultural properties of pine bark, and Stewart (1986) described the production of a commercially available pine bark product, marketed internationally as Cambark®. A similar bark-based product (Peatgro®) is being used to produce container seedlings in South Africa (Nelson 1989).

Pine bark is naturally acidic, has a low initial fertility, and also possesses many other beneficial properties (table 2.2.1). Bark is usually added to a growing medium to increase its air porosity; as the proportion of bark in bark-vermiculite media was increased, the percentage of air space was significantly increased (Lennox and Lumis 1987). Pokorny (1987) found that bark particles have 43% internal porosity, which contributes water for plant growth. Composted bark has a much higher CEC than raw bark and also has been shown to suppress the activity of pathogenic fungi (Hoitink 1980). Compared to standard peat-vermiculite mixes, growing media containing pine bark had significantly less seedling mortality after inoculation with species of Pythium and Fusarium (Pawuk 1981). In other situations, bark can replace peat for reasons of economy or availability. Milbocker (1987) estimated the cost of pine bark at half the cost of sphagnum peat moss.

Bark is usually incorporated in a mixture with other components. Stewart (1986) recommends adding 25 to 50% pine bark to peat moss to form a well-structured growing medium. The size of the bark particles is important, and Whitcomb (1988) recommends running bark through a hammermill with a 2- to 2.5-cm (0.75- to 1.0-inch) screen to produce a desirable range of particle sizes. Handreck and Black (1984) recommended a mixture of pine bark sizes, including approximately one-quarter to one-third in the < 0.5 mm (0.02 inch) range.

One of the biggest drawbacks of bark is its variability. Nurseries have reported problems in obtaining regular supplies of bark of consistent quality (Lippitt 1989). Two other potential problems with the use of bark are nitrogen deficiency and the presence of organic or inorganic toxins (Bunt 1988). Composting bark with supplemental nitrogen fertilizer supplies the nitrogen that microorganisms require during decomposition. The possibility and degree of phytotoxicity depend on the age of the bark, the season of collection, the species of tree, and the geographical location. Phytotoxicity is apparently related to the monoterpene or manganese content of the bark. More information and treatments for phytotoxicity are provided by Bunt (1988).

Sewage sludge. Sewage sludge is another organic material that has been used as a growing medium component in horticultural nurseries. Sludge is an extremely variable material depending on the raw materials involved and the stage of processing. Chong and others (1988) grew two ornamental woody plants in both primary and secondary sludge from two different paper mills. They reported that the mineral nutrient content of these sludge products was variable, especially for nitrogen, which caused irregular plant growth. Simpson (1985) tested a compost of sewage sludge and wood-waste for production of conifer seedlings but found that this medium was inferior to the standard peat-vermiculite growing medium.

2.2.4.2 Inorganic components

Function of the inorganic component. Inorganic materials are added to growing media to produce and maintain a structural system of macropores that improves aeration and drainage and decreases water-holding ability (Mastalerz 1977). Many inorganic components have a very low CEC and provide a chemically inert base for the growing medium. Inorganic materials with high bulk densities, such as sand, are used to provide stability to large, free-standing containers in ornamental nurseries.

Three different materials are routinely being used as inorganic components in growing media in container tree nurseries in the United States and Canada: vermiculite, perlite, and sand. Based on the 1984 Container Nursery Survey, vermiculite was by far the most commonly used, perlite was second, and sand was mentioned by only one nursery.

Vermiculite. Vermiculite is an aluminum-iron-magnesium silicate mineral, mined in the United States and Africa, that consists of a series of thin, parallel plates. After the raw vermiculite mineral is mined, it is subjected to intense heat (up to 1,000 °C, or 1,832 °F),a which expands the vermiculite particles to 15 or 20 times their original volume and gives them an accordion-like structure (Bunt 1988) (fig. 2.2.1 1).

Vermiculite has many unique properties that make it useful for horticultural purposes (table 2.2.1): it is lightweight and its plate-like structure generates a very high surface to volume ratio, producing a high water-holding capacity. The plates contain numerous cation binding sites, both externally and internally, which produce a high CEC; this property is unique for inorganic growing medium components, which are typically chemically inert. Bunt (1988) reported that, although vermiculite does not apparently have any anion exchange capacity, it can adsorb phosphate in available forms. Vermiculite contains some potassium and magnesium that are slowly released for plant uptake. Because of the high processing temperatures, vermiculite is completely sterile. The pH of vermiculite is variable, generally ranging around neutral (pH 7.0), too high for most conifer seedlings. This is not a problem, however, because vermiculite is normally mixed with a more acidic organic material such as sphagnum peat moss (Biamonte 1982, Mastalerz 1977).

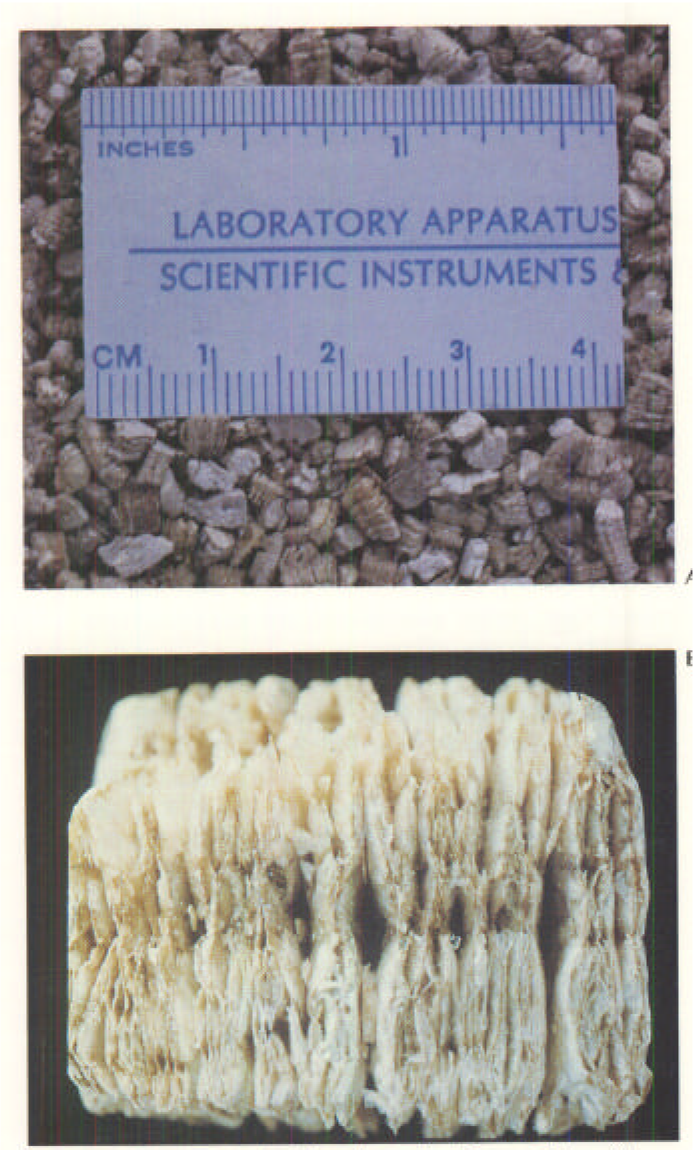


Figure 2.2.11—*Horticultural vermiculite particles (***A***) are accordion-like, because of their expanded structure of parallel plates (***B***), which creates an extensive internal surface area (***B***, courtesy of Biamonte 1982).*

Mastalerz (1977) recommended that only horticultural grades of vermiculite be used for growing media because insulation grades of vermiculite are often treated with water-repellent chemicals. The author, however, has used insulation grade vermiculite without any problems, and Goodwin (1975) also recommended its use in container tree seedling growing media. Tinus and McDonald (1979) stated that vermiculite sold for poultry litter or attic insulation is not only acceptable but cheaper. "Block fill" vermiculite has been treated with water repellents, however, and should not be used. Obviously, growers should test vermiculite or any other growing medium component before using it on a large scale.

Vermiculite is produced in four grades, based on particle size, which determines the relative proportion of aeration and water-holding porosity (table 2.2.12). Grades 2 and 3 are most commonly used in growing media; grade 2 is preferred when more aeration porosity is desired, whereas grade 3 produces more water-holding porosity. It should be emphasized that a vermiculite grade usually contains a range of particle sizes, depending on the size of sieves used by the manufacturer. Several nurseries in the northwestern United States have compared conifer seedling growth in growing media containing either grade 2 or 3 vermiculite and have found better growth with grade 2. Tinus and McDonald (1979) recommended grade 1 for containers of 164 cm; (10 cubic inches) or larger, and grade 2 for smaller containers. Vermiculite particles are structurally unstable in a moist medium and will compress over time (Ward and others 1987). For this reason, vermiculite should not be used alone or with sand but should be mixed with perlite or peat, which provide resistance to compaction (Bunt 1988).

Perlite. Perlite is an alumino-silicate mineral of volcanic origin that is mined in several countries, including the United States and New Zealand. After mining, the raw mineral is crushed and exposed to temperatures as high as 1,000 °C (1,832 °F), producing White, lightweight particles (fig. 2.2.12).

Perlite possesses many useful characteristics that make it desirable for growing media (table 2.2.1). One of these unique properties is its closed-cell structure: water adheres only to the surface of the perlite particles and therefore growing media containing perlite are well-drained and lightweight. Perlite is also rigid and does not compress easily, which promotes good porosity. Compared to other inorganic components, such as sand and grit, perlite increases the aeration porosity of peat-based growing media (Ward and others 1987). Because of the high temperatures at which it is processed, perlite is completely sterile. Perlite is essentially infertile-it contains almost no plant nutrients (table 2.2.13)-and has a minimal CEC (Bunt 1988, Moore 1988). The pH of perlite ranges around neutral (table 2.2.1), but this is not significant because it is usually mixed with acidic sphagnum peat moss (Nelson 1978).

Table 2.2.12—*Physical characteristics of various grades of vermiculite*

Grade	Bulk density (kg/m³)	U.S. sieve size	Range of particle sizes (mm)	Aeration porosity (%)	Water retention (% weight)	Water retention (% volume)
1	64.1–112.1	3/8–16	1.2–10.0	44.3	297	30.7
2*	64.1–128.2	4–30	0.6–4.7	40.4	412	39.0
3*	80.1–144.2	8–100	0.1–2.4	29.9	530	52.4
4	96.1–176.2	16–100	0.1–1.2	24.5	499	54.4

* Standard horticultural grades.
Source: *adapted from Biamonte (1982).*

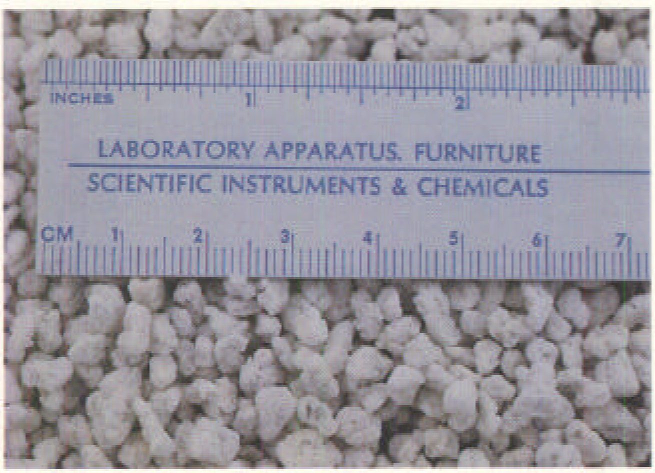


Figure 2.2.12—*Because of its closed-cell structure that repels water, perlite is often added to growing media to increase the aeration porosity and drainage.*

According to the Container Nursery Survey, perlite is a minor component of growing media in forest tree nurseries, usually constituting from 10 to 30% of the mix. Perlite is usually added to organic components, such as peat moss, to increase aeration porosity, which is particularly important in the smaller volume containers used in container tree nurseries. Perlite grades are not standardized, but grades 6, 8, or "propagation grade" are normally used in growing media (table 2.2.13). Perlite grades are also not uniform and contain a range of particle sizes, depending on the sieve sizes used during manufacturing.

Table 2.2.13—*Elemental composition and horticultural grades of perlite*

Element	Average composition (%)
Oxygen	47.5
Silicon	33.8
Aluminum	7.2
Potassium	3.5
Sodium	3.4
Iron	0.6
Calcium	0.6
Magnesium	0.2
Trace elements	0.2
Bound water	3.0
Total	100.0

Grade*	Average particle size (mm)	Commercial labeling
No. 6	3.35	Horticultural grade—coarse
No. 8	1.70	Horticultural grade—fine
Propagation	3.20	Propagation grade

* There are no standard perlite grades, so each manufacturer has its own rating system.
Source: *Perlite Institute (1983).*

Perlite has a couple of operational drawbacks. Horticultural grades of perlite can contain considerable amounts (4% by weight) of very fine particle sizes (Maronek and others 1986) that cause eye and lung irritation during mixing if the perlite is not pre-moistened. Because of its closed-cell structure, perlite has a tendency to float to the top of the medium during irrigation (Mastalerz 1977); this is normally not a problem with the small proportions used in container tree seedling growing media. Gates (1986) reported that perlite particles tended to bind to the walls of Styrofoam block containers, which may damage root plugs when the seedlings are extracted.

Other inorganic materials. Other inorganic materials that have been used in growing media in horticultural nurseries include sand, pumice (fig. 2.2.13), scoria, cinders, calcined (heat-expanded) clays, rock wool, polystyrene flakes, and foam particles. The use of any of these materials will depend on cost and availability, but it is doubtful if any will supplant vermiculite and perlite as the primary inorganic components in North American container tree nurseries.

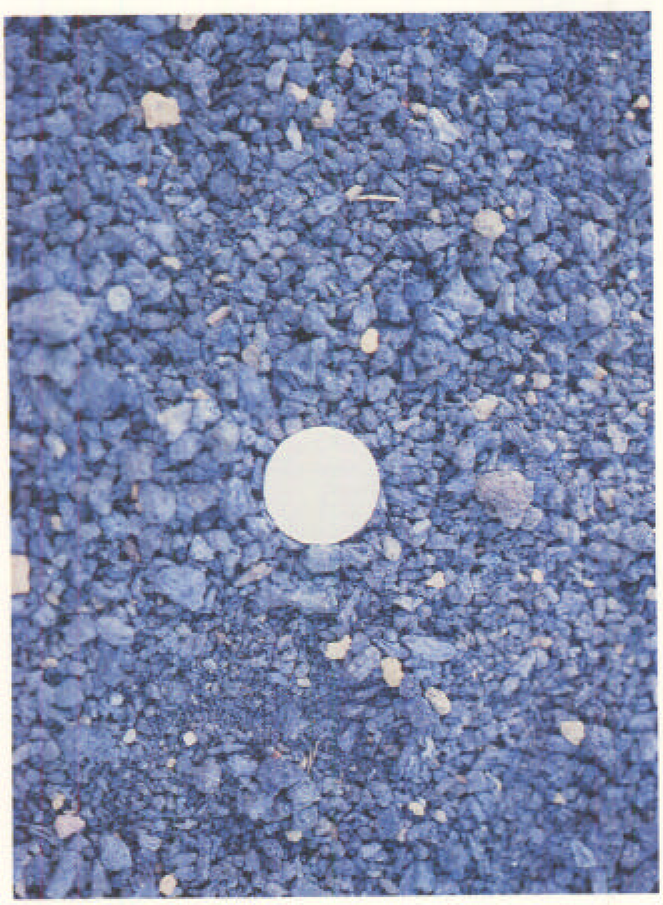


Figure 2.2.13—*Volcanic pumice is another native material that is being used as the inorganic component in growing media; it has physical properties similar to perlite.*

Sand was one of the most common materials used in many of the original horticultural growing media recipes. It is one of the most readily available materials that can be used for growing media and is relatively inexpensive. Size recommendations vary considerably: Whitcomb (1988) recommended a uniform particle size of 2 to 3 mm (0.06 to 0.12 inch), whereas Matkin and Chandler (1957) specified a fine sand with a diameter of 0.05 to 0.5 mm (0.002 to 0.02 inch). Swanson (1989) recommended that 60% of the sand particles be between 0.25 and 1.00 mm (0.01 to 0.04 inch), with less than 3% smaller than 0.1 mm (0.004 inch) or larger than 2 mm (0.08 inch). Although sands are often used to increase porosity, small sand particles can lodge in existing pore spaces and reduce aeration and drainage (Ward and others 1987). Sand does add stability to freestanding containers. Some sands are also contaminated with calcium carbonate, which can raise pH and cause nutrient availability problems (Bunt 1988). Although pH is not always a good indication of $CaCO_3$ content (Ward and others 1987), growers can test sands by adding a drop of dilute acid or even strong vinegar; a fizzing reaction indicates the presence of $CaCO_3$

2.2.5 Selecting a Growing Medium

2.2.5.1 Interactions between growing media and cultural practices

Because of the diverse characteristics of the various growing media components, a container nursery manager can formulate a growing medium with almost any desired property. The physical, chemical, and biological properties of each growing medium are different, however, and are also affected by cultural practices used in the nursery, particularly irrigation, fertilization, and type of container. The timing of the growing season should also be considered. Scagel and Davis (1988) concluded that growers must adjust their cultural practices because of physical and chemical variability between different media. Carlson (1983) evaluated five different brands of Canadian sphagnum peat moss and found that each brand required slight modifications of cultural practices to produce optimum growth of spruce and pine seedlings.

***Irrigation and fertilization practices*.** The water-holding and nutrient-supplying properties of a growing medium are a function of the different growing medium components and their interrelationships . Hoyle (1982) studied the effect of irrigation technique, type of fertilizer, and type of growing medium on the growth of yellow birch seedlings. Using two different peat moss-based growing media, he grew yellow birch seedlings under two irrigation systems and three fertilizer treatments. Seedling growth varied significantly between the two growing media, depending on which irrigation and fertilization treatment was applied (fig. 2.2.14). The container tree nursery manager must tailor irrigation and fertilization regimes to fit the characteristics of the growing medium and will have to alter these cultural practices if the medium is changed. Colombo and Smith (1988) grew two species of conifer seedlings in growing media containing peat moss from local or commercial sources over a range of different fertilization rates (fig. 2.2.15). Although the growth responses differed between the tree species, the largest seedlings were those grown in the commercial peat moss-vermiculite medium; the authors attributed this enhanced growth to better aeration and drainage. Irrigation practices had to be adjusted by the end of the growing season because of changes in the water-holding capacity of a peat-perlite growing medium (Langerud and Sandvik 1988). Scagel (1989) concluded that many growing media problems can be attributed to poor irrigation practices, rather than to the media.

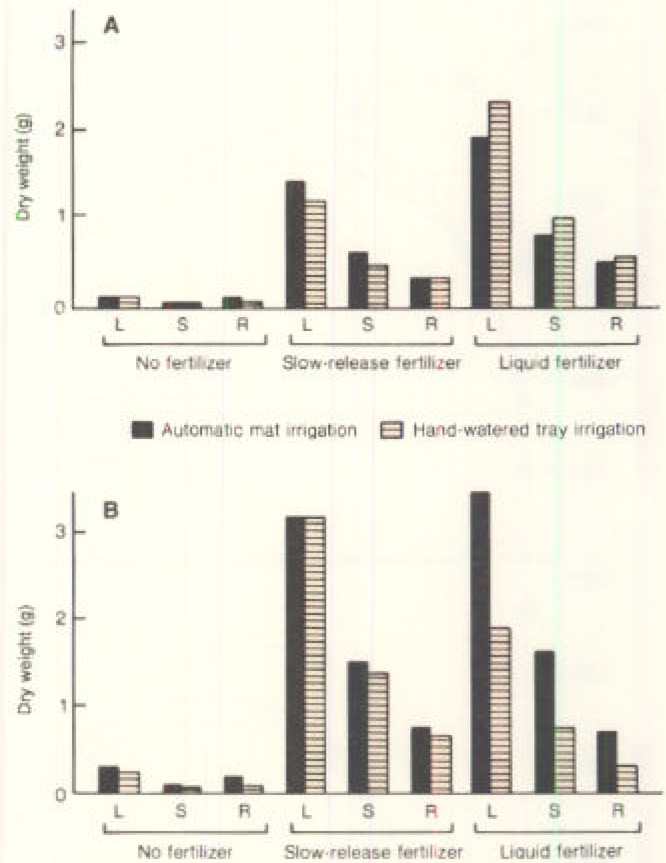


Figure 2.2.14—*The growth of yellow birch seedlings (L=leaves, S=stems, R=roots) was affected by the interrelationships of the growing medium, the type of irrigation system, and the type of fertilizer (adapted from Hoyle 1982).* ***A****, peat-perlite;* ***B****, peat-vermiculite.*

Type of container. Because of the perched water table that is inherent in container culture, the type of container will affect the performance of the growing medium. Short containers have a higher proportion of their volume in the saturated condition and will therefore require a growing medium with a greater aeration porosity than a taller container. Containers with porous sidewalls, like paperpots, have different water and nutrient relationships than impermeable containers and will therefore require a growing medium with more aeration porosity and a different irrigation regime than containers with solid walls. (See chapter 2, volume four of this manual for further discussion on water management in containers.)

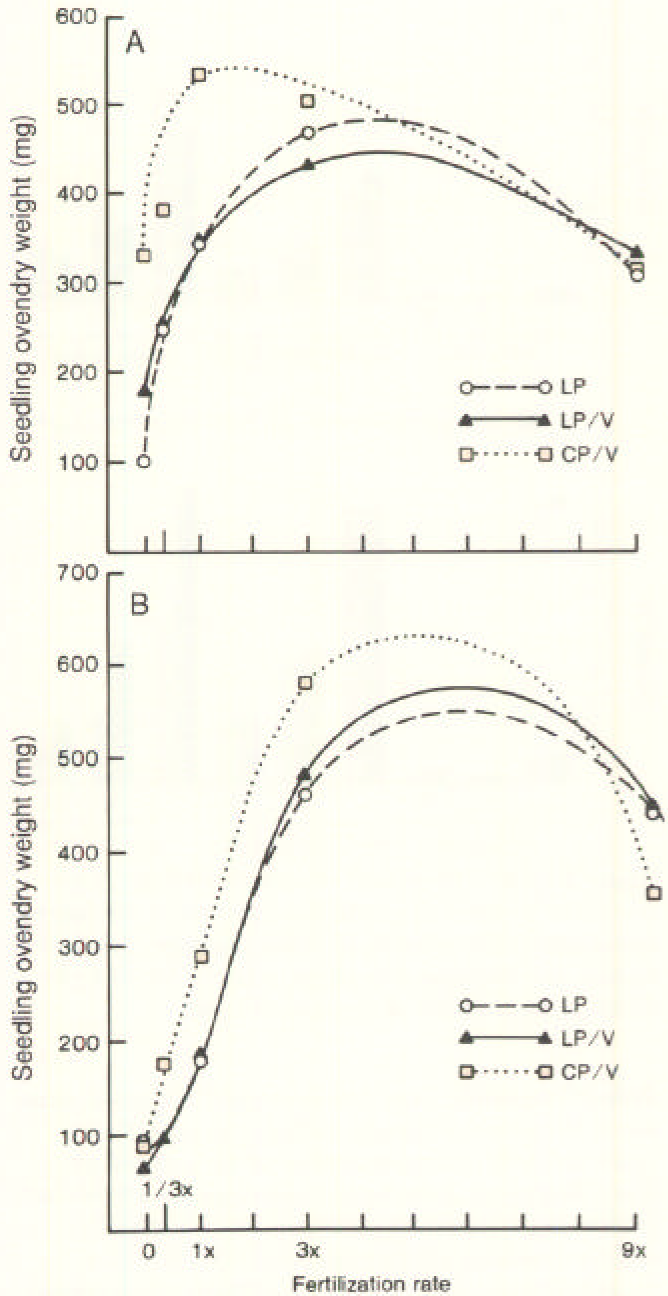


Figure 2.2.15—*Both black spruce* **(A)** *and jack pine* **(B)** *grew better in a commercial peat moss–vermiculite growing medium (CP/V) than in media composed of local peat moss (LP) or local peat moss and vermiculite (LP/V) when fertilized at one-third (1/3x), normal (x), and three times (3x) normal rates; the highest fertilization rate (9x) reduced growth in all media (adapted from Colombo and Smith 1988).*

Growing season. Many container tree nurseries produce more than one crop of tree seedlings per ear and the type of growing medium may need to be formulated differently for different cropping cycles Harlass (1984) reported that growing media with high water-holding capacities should not be used during the low light periods of fall or winter because the low, evapotranspiration rates during these periods can lead to water-logged conditions. A more porous growing medium is best for fall and winter crops, whereas growing medium with a higher water-holding cap city is better for spring and summer crops.

2.2.5.2 Practical considerations

Container tree nursery managers are faced with many different considerations when selecting a growing medium that will match their cultural regimes. The cultural and operational characteristics that were discussed in section 2.2.3 (table 2.2.14) must be evaluated and compared so that the resultant growing medium will have the desired properties. On a practical basis, however, two factors are the most relevant hen selecting growing media: cost and availability of tie medium, and seedling performance.

Cost and availability. Regardless of the properties of specific growing medium components, a nursery manager must be able to find and afford the materials before they can be used. Cost is a relative factor, however, and managers should consider all aspects of the situation. Most materials used for growing me is are not inherently expensive; the cost of a specific growing medium component is more likely related to transportation costs, which are a function of characteristics such as weight and volume. Bulk ordering of large quantities of growing medium or components can greatly redo a unit cost (fig. 2.2.16). Materials such as sand are readily available and cheap but are so heavy that shipping and handling costs are often prohibitive. Other growing medium components, such as vermiculite, have a large relative volume that also increases transportation costs. Some component materials are unique to one particular area of the country and so nursery managers should first consider local materials before importing growing medium components fromsoiree other location. rowers have developed many innovative uses for organic waste materials, which can be substituted for peat moss in growing media (Mastalerz 1977). Container tree nursery

Table 2.2.14—*Quality ratings for some standard growing medium components using cultural and operational characteristics*

	Growing medium components				
	Inorganic			Organic	
Growing medium characteristics	Sand or pumice	Vermiculite	Perlite	Peat moss	Sawdust or bark
Cultural					
Slightly acid pH	V	0	0	+	V
High cation exchange capacity	–	+	–	+	+
Low base fertility	+	+	+	V	+
Large pores for aeration and drainage	+	V	+	V	V
Small pores for water-holding capacity	–	V	–	+	+
Pest-free	V	+	+	V	V
Operational					
Bulk density	+	–	–	–	–
Availability	+	V	V	V	+
Cost	+	V	V	V	+
Uniformity/reproducibility	V	+	+	V	V
Durability/storability	+	+	+	+	V
Changes in volume	+	+	+	V	V
Mixing/filling	+	+	+	V	V
Rewetting ability	+	+	+	–	–
Plug formation	–	+	–	+	V

Rating: + = positive effect, – = negative effect, 0 = no effect, V = variable effect.

Figure 2.2.16—*Most popular growing media components can be ordered in bulk quantities, such as these bales of compressed peat moss; proper storage is essential to avoid contamination.*

managers in some Pacific Islands are investigating native materials for growing media, such as volcanic pumice and the fibrous bark of tree ferns, because any imported material is prohibitively expensive.

The decision to purchase a ready-made commercial growing medium or to mix one's own from individual components **(custom mixing)** is primarily a question of the costs of materials and availability of mixing equipment. Bags of peat moss and vermiculite can usually be purchased more cheaply than a corresponding volume of commercial medium. Sanderson (1983) reported that prepackaged growing media could cost four times as much as custom-mixed media, and Goodwin (1975) estimated that a custom peat-vermiculite medium could be prepared for one-third as much as a commercial growing medium. The real economic consideration is the cost of labor and equipment to do the mixing; because labor and equipment costs vary between nurseries, there can be no standard comparison of costs, and nursery managers must do their own calculations.

Whitcomb (1988) stated that custom mixing batches of growing media can involve significant labor costs. Kusey (1989) listed several different hidden costs that must be considered when comparing commercial and custom-mixed growing media.

Again, because the growing medium is just one in a series of interrelated cultural factors that affect plant growth in a nursery, the prudent grower must consider the overall picture before making a decision about the economics of one particular practice. The combination of cultural practices that produces the best-quality seedling in the shortest period of time and at an acceptable cost will be the most economical in the final evaluation. Kusey (1989) concluded that minor differences in growing medium quality can be reflected ultimately in significant losses in seedling quality.

***Seedling performance*.** Because of the complex relationships between growing media and cultural practices, growers should conduct operational trials of different growing media under their own cultural regimes. Obviously, each nursery cannot afford the time or space to conduct a complicated series of experiments on all the different types of growing media so, initially, managers should rely on recommendations from the literature or from other nurseries.

Small operational trials using different growing media should be attempted on each species of seedling and growing cycle. Nurseries that have implemented such trials have often discovered considerable differences in seedling performance (fig. 2.2.913).

In the final analysis, the best growing medium for a particular nursery will be a compromise of all the various factors in table 2.2.14, and will be custom fitted to the cultural regime of the specific nursery.

2.2.5.3 Commercial growing media

There are many commercial brands of growing media on the market. Harlass (1984) listed 54 brands of growing media, Judd (1983) reviewed the components of 32 brands, and Sanderson (1983) discussed the components and fertilizer properties of 23 different commercially available products. Some of these products are specially formulated for one specific horticultural crop whereas others are more generic in nature. A few companies offer a growing medium specifically designed for tree seedlings (fig. 2.2.17); whether these

Figure 2.2.17—*There are many different brands of commercial growing media, some of which are formulated for specific crops, including tree seedlings.*

specialized media are better than generic types can only be determined by operational testing at individual nurseries. The Container Nursery Survey revealed that only 35% of the container nurseries in the United States and Canada purchase commercial brands of growing media.

When evaluating different brands of commercial growing media, only sphagnum-based media should be considered for growing forest tree seedlings. Lackey and Alm (1982) evaluated five different types of growing media including two commercially prepared brands contained sphagnum peat moss. The red pine seedlings that were raised in each growing medium were measured for a variety of growth parameters, and also rated for plug formation and seedling quality. The commercial media were consistently better: the Forestry Mix® was superior for all growth factors, whereas the Jiffy Mix® was only significantly better than the custom media in stem height. The plug quality rating and seedling quality indices were uniformly better for the seedlings grown in sphagnum-based commercial growing media (table 2.2.15).

2.2.5.4 Custom-mixed growing media

Based on the Container Nursery Survey, 65% of the forest tree nurseries in the United States and Canada mix their own growing media; five different materials are being used: sphagnum peat moss, sawdust, vermiculite, perlite, and sand. Peat-vermiculite blends were by far the most popular (78%), pure peat media were second

Table 2.2.15—*Performance of red pine seedlings grown in different types of growing media*

Composition of growing media	Stem caliper (mm)	Stem height (cm)	Stem weight (g)	Root weight (g)	Shoot–root ratio	Plug quality rating	Seedling quality index
Custom mixes (using generic peat moss)							
1:1 Peat moss–vermiculite	1.5 ab	8.0 a	0.86 a	0.18 a	4.95 a	2.1	0.10
2:1 Peat moss–vermiculite	1.4 b	7.9 a	0.83 a	0.16 a	5.39 a	1.9	0.09
3:1 Peat moss–vermiculite	1.4 b	7.8 a	0.80 a	0.17 a	4.76 a	2.1	0.09
Commercial mixes (using sphagnum peat moss)							
Forestry® Mix	1.9 c	9.7 b	1.22 b	0.36 b	3.51 b	3.9	0.19
Jiffy® mix	1.6 a	8.9 c	0.92 a	0.19 a	4.85 a	3.9	0.11

Values in columns followed by a common letter are significantly different at P = 0.05.
Source: *adapted from Lackey and Alm (1982).*

in popularity (11%), followed by peat-vermiculite-perlite (6%) and peat-perlite (2%). The ratio of sphagnum peat moss to vermiculite in the growing media ranged from 1 :1 to 3:1, with the 1 :1 ratio being the most popular.

For custom-mixed growing media, the author recommends a mixture of coarse-textured sphagnum peat moss and vermiculite. Barnett and Brissette (1986) reviewed the literature and concurred that sphagnum peat moss-vermiculite mixes consistently produce the best quality seedlings. Sphagnum peat moss is the only type of peat moss that is recommended, although other types of peat moss are less expensive. The vermiculite should be grade 2 or 3, the former used for a more porous, well-drained medium and the latter for more water-holding capacity. A small proportion of perlite (10 to 30%) can also be added to increase the aeration porosity of the mix.

2.2.5.5 Comparison of commercial and custom-mixed growing media

Control over quality. Most commercial suppliers have established standards so that the quality of different batches of growing media will remain constant, but nursery managers must rely on the integrity and reputation of the commercial producer. Kusey (1989) advocated the use of commercial media because producers have rigorous quality control programs, and some even have their own testing and research facilities. In custom mixing, however, container tree nursery managers have direct control over the properties of their growing media because the quality of each component can be specifically evaluated.

Ability to "fine-tune" media. Although there is a wide selection of types and brands of commercial growing media available, growers have reported problems in obtaining prepackaged media with specialized properties. Obviously, it is uneconomical for large commercial producers to alter their components and mixing operations to meet small requests. Some local firms have begun to produce custom-mixed growing media, however, and will work with growers to meet their individual needs (fig. 2.2.17). On the other hand, because the nursery manager has control over the proportions and properties of the various components, small batches of custom-mixed growing media can be developed with specific chemical and physical properties, such as pH or aeration porosity, to meet the biological requirements of a particular crop.

Time and labor. Commercial media can be ordered in advance in large quantities, saving time and labor during the container filling operation. Small container tree nurseries, which often cannot afford to invest in mixing equipment or hire the extra personnel to do the mixing, usually find commercial media the most economical and convenient. Although custom-mixing can be done in advance, most nurseries mix their media as part of the container filling process. The extra labor and cost of the specialized mixing equipment must be considered in the total cost of the media.

Incorporation of fertilizers and other amendments. Many brands of commercial growing media contain limestone to raise the pH of the mix to some optimum value, and others contain a starter charge of nutrients to promote early seedling growth. Surfactants, or wetting agents, are often added to commercial growing media to improve their wettability. The fertilizers, wetting agents, and limestone added to commercial growing media may not be desirable and, in fact, may even be detrimental to tree seedling growth; many brands are formulated for crops other than tree seedlings (see section 2.2.6.3 for more detail).

Uniform mixing. Producers of commercial growing media have the proper equipment and knowledge to produce a well-mixed growing medium. Nursery managers, however, may find it difficult to obtain uniform mixing and even distribution of fertilizers and other incorporated materials with some of the equipment used for custom-mixing. Inexperienced personnel tend to over mix batches of media; over mixing breaks down the physical structure of growing medium particles, leading to compaction problems later in the growing season (see sections 2.2.6.4 and 2.2.7).

2.2.6 Procedures and Considerations for Custom Mixing Growing Media

The mixing process is one of the most important steps in the formulation of custom growing media; the best quality components are of no use if the growing medium is improperly mixed. Whitcomb (1988) emphasized that improper mixing is one of the major causes of variation in container plant quality. The proper operating procedures are just as important as purchasing the right type of mixing equipment. Kusey (1989) stressed that mixing should be performed by diligent, experienced workers who will faithfully monitor the quality of the growing media. Incorporation of fertilizers and supplements must be considered, as well as ways of treating growing media for soil-borne pests. Growing media compaction deserves special consideration because it has been shown to be one of the most serious, yet difficult to diagnose, problems in container nursery culture.

2.2.6.1 Equipment and procedures

Small batch mixing. Smaller nurseries often cannot afford to invest in specialized mixing equipment and prefer to prepare small batches of growing medium by hand. Nelson (1978) states that batches of up to 0.25 m^3 (5 or 6 cubic feet) can be mixed on any clean, hard surface by workers with hand shovels.

To mix components, pile them on top of one another and broadcast any amendments over the pile. Then work around the edge of the pile with a large scoop shovel, taking one shovel full of material at a time and turning it over onto the top of the pile. As this material is added to the top, it tumbles down all sides of the pile and is mixed. Make sure that the center of the pile is mixed by gradually moving the location of the pile to one side during the mixing procedure. Mist the pile with water at frequent intervals during the mixing process to make the medium less hydrophobic. Continue this procedure until samples from the pile appear well mixed.

Mechanized mixing. Nurseries that require larger quantities of custom growing media on a regular basis should purchase a mixer. Several brands of mixers and combination mixers/container fillers are commercially available. Whitcomb (1988) recommended paddle-type mixers in which the drum is stationary and internally mounted paddles blend the components together. Handreck and Black (1984) preferred belt mixers that automatically feed each component onto an adjustable flow conveyor; the mixing occurs when the components fall from the end of the conveyor into a slowly rotating drum or directly into the container mixer/filler. Auger type mixers, grinders, and soil shredders are not recommended because they break down particle structure and destroy porosity (Judd 1984, Bartok 1985). Modified mixing equipment, such as portable cement mixers (fig. 2.2.18A) with a capacity of 0.1 to 0.2 m^3 (3 to 6 cubic feet) or concrete trucks (fig. 2.2.1813) with a capacity of 4 to 8 m^3 (5 to 11 cubic yards), can be converted into growing medium mixers. Single batch mixers can produce from 0.2 to 9.2 m^3 (0.25 to 12 cubic yards) of growing medium per hour compared to continuous mixing systems, which deliver up to 38.2 m^3 (50 cubic yards) per hour (Bartok 1985).

A

B

Figure 2.2.18—*Various types of equipment have been modified for custom-mixing growing media, including small portable cement mixers* (**A**) *and converted concrete trucks* (**B**).

Any mixing equipment can be specially modified with spray nozzles so that the growing medium can be gradually moistened and with aerated steam injectors for pasteurization (Nelson 1978). Sterility should be maintained during the entire mixing process for both the individual components and the final product (Bartok 1985).

2.2.6.2 Incorporation of fertilizers and other materials

A variety of materials are routinely added to growing media during the mixing process; these include fertilizers, lime, surfactants, and mycorrhizal inoculum. Bartok (1985) stated that 0.76 m^3 (1 cubic yard) of well-mixed growing medium for an ornamental container nursery may contain from 0.45 to 0.91 kg (1 to 2 pounds) of macronutrient fertilizer, 2.27 to 9.08 kg (5 to 20 pounds) of limestone, and 56.7 g (2 ounces) of micronutrients. Uniform incorporation of these materials is important because tree seedling roots only have access to a limited volume of growing media in the relatively small containers used in forest tree nurseries. It is particularly difficult to incorporate small volumes of dry material, such as micronutrient fertilizer, into a moistened growing medium. The probability of obtaining equal distribution of each fertilizer amendment, particularly the small amount of micronutrient fertilizer, to each container is low. Gladon (1988) stated that many early season growing problems are due to improper incorporation of growing medium amendments, and Whitcomb (1988) concluded that uneven mixing of incorporated fertilizers is one of the major factors causing uneven growth in container nursery stock.

Incorporated chemical amendments may separate out during subsequent handling if dry fertilizers are mixed into dry growing medium components (Bartok 1985). Prewetting the growing medium components, such as peat moss and vermiculite, with warm water containing a surfactant will allow the fertilizer and the growing medium particles to aggregate during the mixing process and stop this problem.

Limestone. Limestone, traditionally called lime in horticulture, has been added to growing media in ornamental container nurseries to raise the pH and supply calcium for plant nutrition. Actually, agricultural limestone [calcium carbonate ($CaCO_3$) or dolomite ($CaCO_3$ • MgC03)] is used rather than burnt lime (CaO) or slaked lime (CaOH) in horticultural applications (Bunt 1988). Liming is a carryover from the days when soil-based media were common; Williams and others (1988) stated that chemical reactions are different in artificial growing media, however, and therefore liming should be discontinued in modern container nurseries. Liming is still practiced in some forest tree nurseries, such as those in coastal British Columbia, where the irrigation water contains low calcium levels (Gates 1986).

Addition of lime to growing media is not recommended in this manual for several reasons:

- It is operationally difficult to distribute the limestone uniformly during the mixing process (see section 2.2.5.5).

- The naturally acidic pH of most peat-vermiculite media should not have to be greatly increased for most tree seedling crops. Sphagnum peat moss has a pH of 3.5 to 4.0 and vermiculite from 6.0 to 7.6 (table 2.2.1); a mixture of these two components should produce a growing medium reasonably close to the ideal pH range of 5.0 to 6.0. In fact, the initial pH of three typical peat-vermiculite medium had a pH of 4.06 (Scarratt 1986) (Table 2.2.3). It is culturally much easier to raise an initially low pH than lower one that is too alkaline; an acidic growing medium can easily be raised into the ideal pH range through routine irrigation and fertilizer injection. In fact, the pH of container media becomes slightly more alkaline over time due to the effect of bicarbonates in the irrigation water and alkaline fertilizers (Bunt 1988). Gladon (1988) estimated that the pH of a growing medium will rise from one-half to one full unit over the growing season.

- Calcium nutrition can be supplied much more quickly and easily with water-soluble calcium fertilizers (for example, calcium nitrate) than with slowly available limestone or dolomite. Calcium deficiency can be a serious problem with young seedlings because of their restricted root systems, and liquid fertilizer injections would be more effective early in the growing season than incorporated granular fertilizers.

Liming has caused some real problems in operational container tree nurseries. Dangerfield (1978) found that addition of dolomitic limestone to a peat-vermiculite growing medium induced lime chlorosis in Douglas-fir seedlings, and he concluded that the practice of incorporating lime should be discontinued. Even with broadleaf species, which prefer slightly less acidic conditions, liming is hard to justify. Saligna eucalyptus seedlings were stunted and deficient in several micronutrients, most notably copper, following the addition of dolomite to a peat-vermiculite medium (Miyasaka and others 1983). Chrustic and Wright (1983) concluded that there was no advantage to liming a pine bark-based medium if all the mineral nutrients are provided in the proper concentration and balance. (The nutritional aspects of liming are discussed in more detail in chapter 1, volume four of this manual.)

Fertilizers. Incorporation of fertilizers is a common practice for ornamental stock and sometimes for container tree seedlings, particularly when liquid fertilizer injection equipment is not available or seedlings are grown outdoors in areas with heavy rainfall. Incorporation of micronutrients is more common because artificial growing media are seriously deficient in micronutrients. (A complete discussion of the merits of fertilizer incorporation is provided in chapter 1, volume four of this manual.)

Surfactants. These chemical additives, which are also called wetting agents (fig. 2.2.19), break down the surface tension of water and increase the wettability of hydrophobic organic materials such as peat moss and pine bark. Unfortunately, the chemical and physical effects of these substances on growing media is poorly understood, and some may even be detrimental (Ward and others 1987). Whitcomb (1988) warned that not all wetting agents are safe to use: some are phytotoxic to certain woody plants. Barnett and Brissette (1986) reviewed the literature and reported that in some cases the recommended application rates were too high for tree seedlings. One widely used product (Aqua-gro®) reduced germination of four species of southern pine seed when applied at the recommended 0.1 % application rate; reducing the rate to approximately 0.02 to 0.04% provided adequate wetting action without causing phytotoxic effects (Barnett 1977). Pokorny (1979) tested 24 commercial surfactants on pine bark media and found that only 9 were both safe and effective.

Incorporated surfactants may become inactive over time Ward and others (1987) reported that, although initially effective, surfactants may have to be reapplied during the growing season.

Figure 2.2.19—*Surfactants (wetting agents) reduce the surface tension of water and are used to increase the wettability of hydrophobic materials such as peat moss.*

Superabsorbents. Superabsorbents are cross-linked polymers than absorb many times their own weight in water. They have been proposed as additives to increase the water-holding capacity of growing media. Several different products are available, however, and not all are suitable for horticultural applications. One class of superabsorbents (propenoate propeamide copolymers) has been shown to increase water-holding capacity, improve aeration and drainage, and reduce the irrigation requirements of growing media (Erazo *1987).*

Although they have been added to growing media in ornamental nurseries, superabsorbents are not widely used in forest tree nurseries at the present time. Lennox and Lumis (1987) investigated the use of hydrophilic gels in growing media and found that one additive (Terra-Sorb®) increased the water-holding capacity by only 5%, which is probably not significant for container tree seedling production. In another study, Terra-Sorb was found to increase the water-holding capacity of the growing medium and delayed wilting in tomato seedlings (Adams and Lockaby 1987). Superabsorbents may not fill a need in most container nurseries at the present time because of regular irrigation scheduling, but their use may be justified in some applications, especially if water use is restricted.

Mycorrhizal inoculum. One method of inoculating container tree seedlings with beneficial mycorrhizal fungi is to incorporate a specially prepared fungus inoculum into the growing medium at the time of mixing. (The benefits of mycorrhizae and the detail, of the inoculation procedure are discussed in chapter 2, volume five of this manual.) In the future, other beneficial microorganisms, such as plant-growth-promoting; rhizobacteria, may be inoculated into growing media (Digat 1988).

2.2.6.3 Pasteurization or sterilization

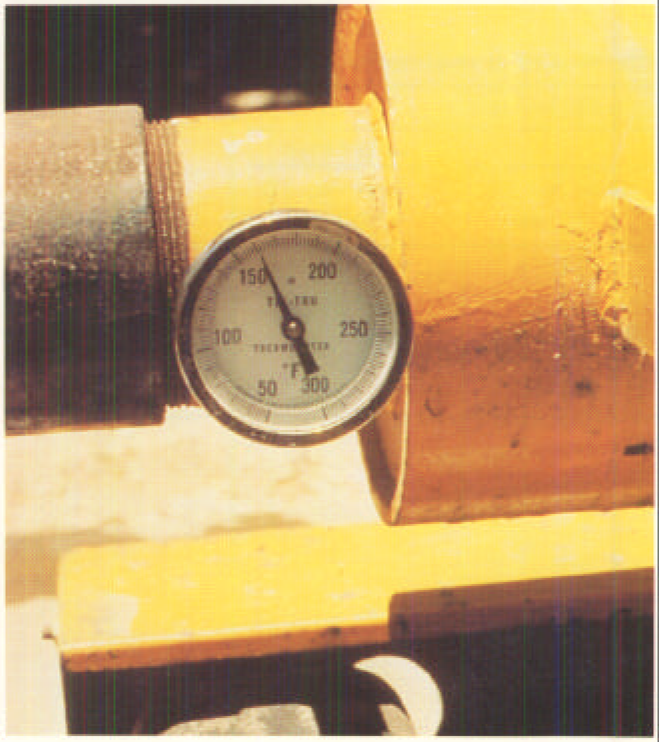
It has been commonly assumed that artificial grow ink; media are free from soil-borne pests, but that assumption has been challenged in recent years. The common inorganic components of growing media, such a,, vermiculite and perlite, are inherently sterile, but peat moss and other organic components are suspect. A recent outbreak of root disease in conifer seedlings in the Pacific Northwest has been traced to a fungal pathogen in peat-vermiculite growing media (Husted 1988). The exact source of the contamination is not always clear. Peat contamination can sometimes be traced to certain bogs, or areas of bogs, or certain stages during the handling or processing of the peat. The actual extent of growing media contamination is not known, but growers should take certain precautions in the interim.

Some brands of commercial growing media do treat their products and advertise that their mixes are essentially sterile (fig. 2.2.20A). Sterilization refers to the complete elimination of all living organisms in the medium whereas pasteurization is not as drastic. Completely sterile growing media may not be particularly desirable because many beneficial microorganisms, including bacteria, actinomycetes, and fungi that are normally found in growing media can actually be antagonistic o pathogens (Wolffhechel 1988). Steam heat (fig. 2.2.20B1 can be used to either pasteurize or sterilize the media, depending on the temperature. Heat pasteurization is generally thought to be preferable if the proper equipment is available (Bunt 1988); the standard recommendation is to heat the growing medium to 60 to 82 °C (140 to 177 °F) for a minimum of 30 minutes (fig.

A

B

Figure 2.2.20—*Some brands of commercial growing media are advertised as being "sterile" (**A**); steam pasteurization (**B**) is beneficial because the relatively low treatment temperature (**C**) can eliminate most soil pests without the loss of beneficial microorganisms.*



c

2.2.20C). Although chemical fumigation completely sterilizes the media, methyl bromide fumigation has proven effective in controlling some soilborne diseases (Garren and others 1989).

Both pasteurization and fumigation are costly and time-consuming and, like all pest control treatments, have their drawbacks (Bunt 1988). The most prudent procedure may be to have samples of peat moss or premixed growing medium tested for pathogens so that seriously contaminated batches can be identified and treated, or rejected. Purchasing specifications can also be written to require testing for pathogens. These preventative measures, like all pest control treatments, should be part of an overall pest management strategy. (See chapter 1, volume five of this manual for more information on soil-borne pathogens and treatment of growing media.)

2.2.6.4 Over mixing and compaction problems

Over mixing can break down the structure of the growing medium particles, which promotes compaction and destroys the aeration porosity of the medium. Fragile materials, such as vermiculite and peat moss, are easily damaged during mixing. Milks and others (1989) found that moistening peat-vermiculite before mixing actually prevented over compaction, although overly wet components are heavy and will compact easier. In a typical batch of peat-vermiculite medium, the individual peat fibers and vermiculite particles should still be visible (fig. 2.2.21), and the medium should feel spongy in texture; a medium that appears fine or powdery has probably been damaged. Some growers prefer fine-textured growing media because it is easy to load into small containers, but such media tend to pack too tightly in the container and reduce porosity. Overly compacted growing media have reduced drainage and aeration, often resulting in root growth problems (see section 2.2.3.1).

Mechanized mixing can be easily overdone if the mixers are run too long or are overfilled, or if the components are too wet (Whitcomb 1988, Handreck and Black 1984). Certain types of mixers are more damaging than others (see section 2.2.6.1). Most mixers will do an adequate job in 3 or 4 minutes if they are filled only about three-quarters full (Whitcomb 1988). Operational trials conducted on the effect of different mixing times on the size of peat moss particles showed that particle size was severely reduced if mixing times exceeded 5 minutes (table 2.2.16).

Figure 2.2.21—*A well-mixed growing medium should have a uniform composition with minimal damage to the size or shape of the original components, in this case sphagnum peat moss and vermiculite.*

Table 2.2.16—*The size of peat moss particles can be substantially reduced by overmixing in a mechanical mixer*

	Percentage of peat particle sizes				
	Smaller than			Larger than	
Mixing time (min)	Sieve No. 20 (0.85 mm)	Sieve No. 16 (1.18 mm)	Sieve No. 10 (2.00 mm)	Sieve No. 10 (2.00 mm)	Totals
5	59.4	11.3	11.7	17.6	100.0
10	63.8	11.0	8.0	16.6	100.0
15	70.2	10.5	7.9	11.4	100.0
20	73.5	8.2	7.0	11.3	100.0
25	76.4	8.3	6.6	8.7	100.0

Source: McDonald (1989).

2.2.7 The Importance of Proper Growing Medium Compaction

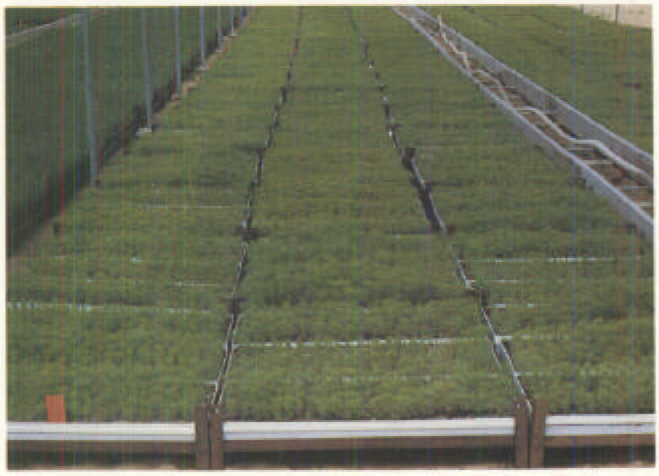
Filling the containers with the growing medium is a critical process. It is important to achieve the proper degree of media compaction, because poorly compacted media can negate the beneficial cultural properties of even the best growing media. Under compaction is rarely a problem and can be easily diagnosed and corrected. Over compaction, however, is fairly common due to over mixed media or to excessive mechanical or manual compression during the container filling process (Bunt 1988).

Over compaction can have several effects on the physical, chemical, and biological properties of a growing medium. Although total porosity is naturally less in compacted media, the more important effect is the reduction or even elimination of the large pores that control aeration and drainage (Bunt 1988). In studies of conifer seedling growth in peat-based growing media that were compressed to various densities, Mitchell and others (1972) found that root activity varied inversely with peat compaction.

The ideal degree of media compaction will vary with the type of medium, type of container, and irrigation practices at each nursery. Matthews (1983) recommended a growing medium density of 0.1 g/cm^3 of usable container volume for Styrofoam block containers. Hocking and Mitchell (1975) studied the effects of growing medium density in extruded peat containers and found that 0.2 g/cm^3 gave the best seedling growth. Container nursery managers should conduct operational trials to determine the proper growing medium density for their own conditions.

Media compaction is difficult to assess in the small containers used in tree nurseries, and there is presently no reliable technique for measuring it. Several direct observations can be helpful in evaluating growing media compaction, however. Because of the resultant increase in bulk density of compacted media, containers that are unusually heavy should be suspect. During the filling process, the medium should not settle excessively when a container is shaken or tapped on the table. The medium in properly filled containers should still feel springy to the touch. Obviously, evaluation of media compaction in containers is an imprecise process that can be improved only through operational experience. Unfortunately, a container nursery manager only becomes aware of a media compaction problem after seedling growth problems become apparent or during extraction, when poorly formed root plugs are apparent.

The deleterious effects of over compaction on tree seedling growth are often subtle and difficult to diagnose because of the myriad effects of compaction on the complex rooting environment in a container. Another factor that complicates diagnosis is variation in the degree of compaction that can occur between different blocks of containers, or even between cells within a block, which produces a mosaic of normal and symptomatic seedlings (fig. 2.2.22A). The symptoms of root injury from over compacted growing media can include foliar chlorosis, leaf drop, root browning, and eventual death. Because it first affects root function, the initial symptoms of over compaction injury can mimic drought stress, over watering, or even mineral nutrient deficiency. Mineral nutrient uptake is impaired when roots are not functioning properly due to an over compacted growing medium; iron chlorosis is just one of the nutritional disorders that can develop (Faber 1982). Roots that become weakened in over compacted media are particularly susceptible to opportunistic root pathogens such as Pythium or Fusarium spp. (fig. 2.2.22B). Langerud (1986) reported a root dieback disease of container seedlings that was attributed to poor porosity of the growing medium.



A

B

Figure 2.2.22—*An overly compacted growing media can cause a reduction in aeration porosity, resulting in a variable seedling growth pattern (* **A** *); root systems become swollen, lack fine roots and mycorrhizae, and often become infected with fungal pathogens such as* Fusarium *spp. (* **B** *).*

2.2.8 Conclusions and Recommendations

The selection of a growing medium is one of the most important decisions in the culture of container tree seedlings. The physical, chemical, and biological characteristics of a growing medium affect not only seedling growth, but also other aspects of nursery operations as well. Container nursery managers, therefore, should carefully consider both biological and operational aspects when evaluating different types of growing media.

Deciding whether to purchase a commercial brand of growing media or to custom-mix will depend on many factors, including availability of components and mixing equipment and the size of the nursery operation. Several good commercial brands of growing media are available but, for complete quality control, container nursery managers should consider custom-mixing their own media.

Whether purchasing a commercial media or custom mixing, the selection of growing medium components is critical. For container tree seedlings produced in North America, a growing medium consisting of sphagnum peat moss and vermiculite is recommended, if these materials are available and reasonable in price. The proportion of peat moss to vermiculite on a volume/volume basis can range from 1 :1 to 3:1. Coarse grade peat moss should be used whenever possible, and the coarser grades of vermiculite are preferred. A small proportion of perlite (10 to 30%) can be substituted for part of the vermiculite if a more well-drained medium is desired. Tree bark, especially composted pine bark, has shown promise as a growing media component in horticultural applications, but more information is needed on this material in forest tree nurseries. Substitution of alternative organic materials for peat moss should be approached cautiously, and only composted organics should be considered.

Chemical amendments to growing media are not usually warranted. Incorporation of limestone or other fertilizer materials into the growing medium is not recommended unless conventional fertilization techniques are unavailable. If possible, pH and mineral nutrient levels should be controlled through injection of acid and liquid fertilizers into the irrigation system. Even though most components are considered sterile, nursery managers should routinely have their growing media tested for pathogenic fungi.

Because the growing medium is just one in a series of interrelated cultural factors that affect plant growth in a nursery, the prudent grower must consider the overall situation before making a decision about the economics of one particular practice. The combination of cultural practices that produces the best-quality seedling in the shortest period of time and at an acceptable cost will be the most economical in the final evaluation. Small-scale operational trials with new types of growing media are always recommended; if trial results appear promising, then the medium can be used on a larger scale.

2.2.9 Literature Cited

Adams, J.C.; Lockaby, B.G. 1987. Commercially produced superabsorbent material increases waterholding capacity of soil medium. Tree Planters' Notes 38(1):24-25.

Baker, K.F. 1985. Development of nursery techniques. International Plant Propagators' Society Combined Proceedings 34:152-164.

Barnett, J.P. 1977. Effects of soil wetting agent concentration on southern pine seed germination. Southern Journal of Applied Forestry 1(3):14-15.

Barnett, J.P.; Brissette, J.C. 1986. Producing southern pine seedlings in containers. Gen. Tech. Rep. SO-59. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 71 p.

Bartok, JW., Jr. 1985. Media mixing systems offer efficiency, variety. Greenhouse Manager 4(8): 108-110, 112-113.

Beardsell, D.V.; Nichols, D.G.; Jones, D.L. 1979. Physical properties of nursery potting-mixtures. Scientia Horticulturae 11:1-8.

Bethke, C.L. 1986. Systematic approach solves grower problems. Greenhouse Manager 4(11):171, 173-174, 177.

Biamonte, R.L. 1982. Domestic vermiculite for horticultural use. Bull. TTB-104. Fogelsville, PA: W.R. Grace and Co., Horticultural Products. 6 p.

Bilderback, T.E. 1982. Container soils and soilless media. In: Nursery Crops Production Manual. Raleigh, NC: North Carolina State University, Agricultural Extension Service. 12 p.

Black, C.H. 1988. Interaction of phosphorus fertilizer form and soil medium on Douglas-fir seedling phosphorus content, growth and photosynthesis. Plant and Soil 106 (2):191-199.

Bluhm, W.L. 1978. Peat, pests, and propagation. International Plant Propagators' Society Combined Proceedings 28:66-70.

Bragg, N.C.; Chambers, B.J. 1988. Interpretation and advisory applications of air-filled porosity (AFP) measurements. Acta Horticulturae 221:35-44.

Bugbee, G.J.; Frink, C.R. 1986. Aeration of potting media and plant growth. Soil Science 141(6): 438-441.

Bunt, A.C. 1988. Media and mixes for container-grown plants. Boston: Unwin Hyman. 309 p.

Carlson, L.W. 1983. Guidelines for rearing containerized conifer seedlings in the Prairie provinces. Info. Rep. NOR-X-214F. Edmonton, AB: Canadian Forestry Service, Northern Forest Research Centre. 64 p.

Chong, C.; Cline, R.A.; Rinker, D.L. 1988. Spent mushroom compost and papermill sludge as soil amendments for containerized nursery crops. Combined Proceedings of the International Plant Propagators' Society 37: 347-353.

Chrustic, G.A.; Wright, R.D. 1983. Influence of liming rate on holly, azalea, and juniper growth in pine bark. Journal of the American Society for Horticultural Science 108(5):791-795.

Colombo, S.J.; Smith, W.A. 1988. Response of containerized black spruce and jack pine seedlings to fertilization rate and growing medium. For. Res. Rep. 1 16. Maple, ON: Ontario Ministry of Natural Resources, Ontario Tree Improvement and Forest Biomass Institute. 15 p.

Dangerfield, J.A. 1978. Influence of lime incorporated in soil mix on growth of Douglas-fir. Canadian Forestry Service Bi-monthly Research Notes 34(1):1-2.

Davidson, H.; Mecklenberg, R. 1981. Nursery management: administration and culture. Englewood Cliffs, NJ: Prentice-Hall, Inc. 450 p.

Digat, B. 1988. The bacterization of horticultural substrates and its effects on plant growth. Acta Horticulturae 221 :279-288.

Erazo, F. 1987. Superabsorbent hydrogels and their benefits in forestry applications. Landis, T.D., tech. coord. Meeting the Challenge of the Nineties: Proceedings, Intermountain Forest Nursery Association. 1987 August 10-14; Oklahoma City, OK. Gen. Tech. Rep. RM-151. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station:] 4-17.

Faber, W.R. 1982. Don't beat it to death. Ohio State Flower Growers Hotline, April 28.

Garren, T.R.; Landis, T.D.; Campbell, S.J. 1989. Methyl bromide fumigation of containers filled with growing media. In: Landis, T.D., tech. coord. Proceedings, Intermountain Forest Nursery Association; 1989 August 14-18; Bismarck, ND. Gen. Tech. Rep. RM-184. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 43-48.

Gates, W. 1986. Personal communication. Victoria, BC: British Columbia Ministry of Forest, Silviculture Branch.

Gessert, G. 1976. Measuring air space and water holding capacity. Ornamentals Northwest 3:59-60.

Gladon, D. 1988. Amendments and media. Container grower: news and notes. Fall 1988. Ames, IA: Iowa State University of Science and Technology, Department of Forestry. 10 p.

Goodwin, O.C. 1975. Greenhouse container seedling production manual. For. Note 19. Raleigh, NC: North Carolina Forest Service. 23 p.

Handreck, K.A.; Black, N.D. 1984. Growing media for ornamental plants and turf. Kensington, NSW, Australia: New South Wales Universit)- Press. 401 p.

Harlass, S. 1984. Uncover answers to media guessing game. Greenhouse Manager 3(5):102-104, 106-107.

Hartman, H.T.; Kester, D.E. 1983. Plant propagation: principles and practices. Englewood Cliffs, NJ: Prentice-Hall, Inc. 727 p.

Havis, J.R.; Hamilton, W.W. 1976. Physical properties of container media. Journal of Arboriculture 2(7):139-140.

Hellum, A.K. 1975. Selecting peat for rearing coniferous container seedlings. Forestry Chronicle 51:200-202.

Hocking, D.; Mitchell, D.L. 1975. The influences of rooting volume-seedling espacement and substratum density on greenhouse growth of lodgepole pine, white spruce, and Douglas-fir grown in extruded peat cylinders. Canadian Journal of Forest Research 5:440-451.

Hoitink, H.A.J. 1980. Composted bark, a lightweight growth medium with fungicidal properties. Plant Disease 64(2):142-147.

Hoyle, M. C. 1982. Economical and simple production of containerized hardwood seedlings. Res. Pap. NE500. Broomall, PA: USDA Forest Service, Northeastern Forest and Range Experiment Station. 12 p.

Husted, L.D. 1988. Douglas-fir dieback. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-1 1 ; Vernon, BC. Gen. Tech. Rep. RM-167. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 161-163.

James, B.L. 1987. Propagation media: what a grower needs to know. Combined Proceedings, International Plant Propagators' Society Meeting 36:396-399.

Johnson, P. 1968. Horticultural and agricultural uses of sawdust and soil amendments. National City, CA: Paul Johnson. 46 p.

Joiner, J.N.; Conover, C.A. 1965. Characteristics affecting desirability of various media components for production of container-grown plants. Proceedings of the Soil and Crop Science Society of Florida 25:320-328.

Judd, R.W., Jr. 1984. Making soilless mixes not without its problems. Greenhouse Manager 3(2):135, 137.

Judd, R.W., Jr. 1983. Soilless mixes for nursery production. Journal of Environmental Horticulture 1(4):106-109.

Kuhns, L.J. 1985. Fertilizing woody ornamentals. University Park, PA: Pennsylvania State University, College of Agriculture. 16 p.

Kusey, W. 1989. Beware of hidden costs in mixing your own media. Greenhouse Manager 8(5):134, 136, 138, 141.

Lackey, M.; Alm, A. 1982. Evaluation of growing media for culturing containerized red pine and white spruce. Tree Planters' Notes 33(1):3-7.

Langerud, B.R. 1986. A simple in situ method for the characterization of porosity in growth media. Plant and Soil 93(3):413-425.

Langerud, B.R.; Sandvik, M. 1988. Physical conditions in peat/perlite mixtures subjected to different irrigation regimes. Acta Horticulturae 221 :363-370.

Lehtovaara, J.; Herranen, M.; Nyronen, T.; Oy, Y.; McDonald, A. 1988. IR-spectroscopy as an analytical method for identification of horticultural peat. Acta Horticulturae 221 :153-160.

Lennox, T.L.; Lumis, G.P. 1987. Evaluation of physical properties of several growing media for use in aerial seeding containers. Canadian Journal of Forest Research 17:165-173.

Lippitt, L. 1989. Personal communication. California Department of Forestry and Fire Protection, L.A. Moran Reforestation Center, Davis, CA.

Lucas, R.E.; Rieke, P.E.; Farnham, R.S. 1965. Peats for soil improvement and soil mixes. Farm Sci. Ser. Ext. Bull. 516. Lansing, MI: Michigan State University, Cooperative Extension Service. 11 p.

Maronek, D.M.; Studebaker, D.; Oberly, B. 1986. Improving media aeration in liner and container production. International Plant Propagators' Society Combined Proceedings 35:591-597.

Mastalerz, J.W. 1977. The greenhouse environment. New York: John Wiley and Sons. 629 p.
Matkin, O.A.; Chandler, P.A. 1957. The U.C.-type soil mixes. In: Baker, Kenneth F., ed. The U.C. system for producing healthy container-grown plants. Ext. Serv. Man. 23. Parramatta, Australia: Australian Nurserymen's Association [First printed by the University of California, Division of Agricultural Sciences, California Agricultural Experiment Station]: 68-85.
Matthews, R. G. 1983. Seedling production for Crown Lands in British Columbia: guidelines for commercial container nurseries. Victoria, BC: British Columbia Ministry of Forests, Silviculture Branch. 45 p.
McDonald, A. 1989. Personal communication. Silviculture Branch, British Columbia Ministry of Forestry, Victoria, BC.
Milbocker, D. 1987. Pine bark shows promise for plugs. Greenhouse Manager 5(11):12.
Milks, R.R.; Fonteno, W.C.; Larson, R.A. 1989. Hydrology of horticultural substrates: III. Predicting air and water content of limited-volume plug cells. Journal of the American Society for Horticultural Science 1 14(1):57-61 .
Mitchell, D.L.; Hocking, D.; Kay, W.C. 1972. Extruded peat cylinders: their physical characteristics as affecting tree seedling growth and greenhouse drought tolerance. Canadian Journal of Forest Research 2:479-486.
Miyasaka, S.C.; Okazaki, E.N.; Bartholomew, D.P. 1983. The effect of lime and micronutrients on Eucalyptus saligna Sm. seedling growth. Res. Ser. 025. Honolulu: University of Hawaii, College of Tropical Agriculture and Human Resources. 11 p.
Moore G. 1988. Perlite: start to finish. International Plant Propagators' Society Combined Proceedings 3 7 :48-5 2.
Nelson, W.R. 1989. Personal communication. Starke Ayres. Pietermaritzburg, South Africa.
Nelson, P.V. 1978. Greenhouse operation and management. Englewood Cliffs, NJ: Prentice-Hall, Inc. 598 p.
Pawuk, W. H. 1981. Potting media affect growth and disease development of container-grown southern pines. Res. Note SO-268. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 4 p.
Peck, K. 1984. Peat moss and peats. Hummert's Quarterly 8(3):1, 4-5.
Perlite Institute. 1983. Typical chemical and physical properties of perlite. Tech. Data sheet 1-1. New York. 2 p.
Poincelot, R. P. 1972. The biochemistry and methodology of composting. Bull. 727. New Haven, CT: Connecticut Agricultural Experiment Station. 38 p.
Pokorny, F.A. 1987. Available water and root development within the micropores of pine bark particles. Journal of Environmental Horticulture 5(2):89-92.
Pokorny, F.A. 1979. Pine bark container media: an overview. International Plant Propagators' Society Combined Proceedings 29:484-495.
Puustjarvi, V. 1975. Peat in horticulture. In: Organic materials as fertilizers. Soils Bull. 27. Rome: FAO: 133-145.
Puustjarvi, V.; Robertson, R.A. 1975. Physical and chemical properties. In: Peat in horticulture. London: Academic Press. 170 p.
Sanderson, K.C. 1983. Growing with artificial media: the advantages, disadvantages. Southern Florist and Nurseryman 96(20):13-14, 16-17.
Scagel, R.K. 1989. Personal communication. Pacific Phytometric Consultants, Surrey, BC.
Scagel, R.K.; Davis, G.A. 1988. Recommendations and alternative growing media for use in containerized nursery production of conifers: some physical and chemical properties of media and amendments. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-1 1 ; Vernon, BC. Gen. Tech. Rep. RM167. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station:60-65.
Scarratt, J.B. 1986. An evaluation of some commercial soluble fertilizers for culture of jack pine container stock. Inf. Rep. O-X-377. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forestry Service. 21 p.
Simpson, D.G. 1985. Growing conifer seedlings in woodwaste-sewage sludge compost. Res. Note 98. Victoria, BC: British Columbia Ministry of Forests. 18 p.
Spomer, L.A. 1975. Availability of water absorbed by hardwood bark soil amendment. Agronomy Journal 67:589-590.
Stewart, N. 1986. Production of bark for composts. International Plant Propagators' Society, Combined Proceedings 35:454-458.
Swanson, B.T. 1989. Critical physical properties of container media. American Nurseryman 169 (11):59-63.

Tinus, R.W. 1974. Characteristics of seedlings with high survival potential. In: Tinus, R.W.; Stein, W.I.; Balmer, W.F., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Pub. 68. Great Plains Agricultural Council: 276-282.
Tinus, R.W.; McDonald, S.F. 1979. How to grow tree seedlings in containers in greenhouses. Gen. Tech. Rep. RM-60. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 256 p.
Van Eerden, E. 1974. Growing season production of western conifers. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Pub. 68. Great Plains Agricultural Council: 93-103.
Ward, J.; Bragg, N.C.; Chambers, B.J. 1987. Peat-based composts: their properties defined and modified to your needs. International Plant Propagators' Society Combined Proceedings 36:288-292.
Whitcomb, C.E. 1988. Plant production in containers. Stillwater, OK: Lacebark Publications. 633 p.
Williams, B.J.; Peterson, J.C.; Utzinger, J.D. 1988. Liming reactions in sphagnum peat-based growing media. Journal of the American Society for Horticultural Science 113(2):210-214.
Wilson, G.C.S. 1985. Effects of additives to peat on the air and water capacity. Acta Horticulturae 172:207-209.
Wolffhechel, H. 1988. The suppressiveness of sphagnum peat to Pythium spp. Acta Horticulturae 221 :217-222.
Worrall, R. 1976. The use of sawdust in potting mixes. International Plant Propagators' Society Combined Proceedings 26:379-381.

Index of Common and Scientific Names

Trees

Others