Container Soils and Soilless Media

Approximately one-third of the total nursery acreage in North Carolina is devoted to container production and this figure is increasing each year. Growing in containers offers many advantages to the grower such as year-round marketing and the potential to produce many plants in a given area. However, container production also requires daily attention and precise control of many critical production factors. One of the most important factors is the medium or container substrate in which the plants are grown, since the development and maintenance of an extensive functional root system is essential to the growth of a healthy plant. A variety of terms are applied to the materials in which the roots of crops grow. They include growing media, plant substrates, container mix or mixtures and potting composts. The term soil mixture infers that soil is contained in the potting material and will be used only when this is intended. The other terms will be used interchangeably. The term medium is singular for media referring to only one potting mixture.

Container-grown plants are subjected to a unique environment, that of growing in a limited volume of root medium from which water and nutrients must be absorbed. Uniformity in the substrate from one container to another or from one crop or season to the next is essential if a grower is to standardize fertilizer or water application. Great variation in particle size and distribution within a container medium effects the porosity, bulk density (weight per volume) and water and nutrient retention of a medium.

Media Composition

A container medium consists of three parts: (1) solids, (2) gases and (3) liquids (Fig. 1). Approximately one-third to one-half of the total volume of a growing medium is occupied by the solid particle and organic matter. The remaining voids between the particles are known as the pore space and can be occupied by water or by air (Fig. 2). Pores between the solid particles may be large or small. The quantity of pores that are present determines the volume of air and water available to the roots. Total pore space (total porosity) is determined by particle size and compaction of the medium. The size of the pores determines the rate of water movement through the soil mix (drainage) and the quantity of water stored after irrigation and drainage (Fig. 3).

If the growing medium in the container is made up of materials which create very small pores or air spaces, the growing medium retains large quantities of water. On the other hand, if the growing medium is a mixture of materials which have some large pores or air spaces, the container retains much less water.

The liquid phase of a soil mix is composed of water and nutrients in solution. The medium serves as a reservoir for water and nutrients needed for normal plant growth and development. When irrigated, the surface of the medium becomes wet, water fills the pores and moves downward through the pores, particularly the large pores (Fig. 3). The water retained in the small pores contains dissolved nutrients, gases and organic materials and is potentially available to the plant.

The gaseous phase of a soil mix is neither solid nor liquid. Atmospheric air contains approximately 21 percent oxygen but aeration and gaseous exchange from the air to the soil mix may be restricted such that oxygen (0_2) may range between 0 and 21 percent (Pokorny, 1979). Carbon dioxide ($C0_2$) may range well above the .03 percent atmospheric content (Fig. 4).

All living cells including plant roots need oxygen for respiration and give off carbon dioxide. To maintain adequate O_2 and CO_2 levels in the medium, gaseous exchange must occur with the soil atmosphere. High CO_2 levels have even been reported to be detrimental to root growth (Whitcomb, 1979). An 0_2 content of soil atmosphere below 12 percent inhibits new root initiation. Oxygen levels between 5 to 10 percent are too low for established root growth and development, and at levels of 3 percent, roots do not function. Below 3 percent oxygen content, roots die and decompose (Pokorny, 1979).

Container Effect

Container soils have less volume and are shallower than ground beds or field soils. Because of this "container soil effect," an excellent garden or field soil placed in a container will remain saturated following watering and drainage. The result is poor soil aeration and plant growth. The type of container is irrelevant assuming that drainage openings are of adequate size and do not restrict flow after it is released from the soil. The increased water retention is due to a change in the length of the column affected by gravitational pull (Mastalerz, 1977).

Height of Column

The effect of container shallowness can be demonstrated with an ordinary cellulose sponge (Spomer, 1974). The sponge is saturated and placed flat in a pan (Fig. 5). The sponge-like soil is permeated by pores which are full of water when the sponge is saturated. If after the sponge ceases to drip, it is turned on its side, more water drains into the pan (Fig. 6). After it once again ceases to drip, if stood on end, additional water will drain into the pan (Fig. 7). Each time the height of the column is increased, water content decreases.

It follows that the deeper the container medium, the lesser its surface and average water content following watering and drainage.

The water and air content is a function of height for the same soil placed in containers of three different heights. The deepest container is likely too dry and the shallowest container too wet following watering and drainage (Fig. 8).

The effect of placing gravel or coarse materials in the bottom of the container is that of shortening the container and reducing the column length, thus changing the drainage and air-water relationship (Fig. 9).

The diameter of the container has no bearing on drainage. The same growing medium placed in containers of the same depth but of varying diameters will have similar drainage patterns (Fig. 10).

The effects of shallowness can be remedied by incorporating coarse textured amendments into the soil to create large pores which drain despite the perched water table at the bottom of the container.

Measurement of a Medium Air Space and Water Holding Capacity

Table 1 lists water holding capacities, air space and other physical properties of growing media. However, many container mixes or special media a grower might use are not included. Also, due to the effect of container depth, information may not directly pertain to a grower's system. To determine the approximate water holding capacity and drainable pore space of a growing medium, the following procedure can be used (Adapted from G. Gessert, 1976 and Whitcomb, 1979).

The following materials are needed: a measuring cup, masking tape, a pencil or crayon, container in question, a pan and a few containers of water.

Once materials are assembled, proceed as follows:

1. Measure the volume of the container in question. Clean the area around all drain holes and using duct tape shut the holes on the outside of container (Fig. 11). Be sure not to allow folds in the tape which may leak. An alternative method is to place a freezer bag in the container to act as a waterproof liner.

2. Fill the pot with water to the soil lithe or to one- half inch of the brim and mark this point with pencil or crayon. Pour the water from the pot into the measuring cup and record the number of cups or total volume of water held in the pot (Fig. 12).

3. Dry the inside of the pot, but do not remove the tape. Fill the container with the growing medium in question, firm it as though a liner was being planted.

4. Slowly fill the container with a known volume of water until the medium is fully saturated (Fig. 13). When a thin film of free water appears at the medium surface, stop. Add additional water as needed since the growing medium may absorb a sizable quantity. Allow the container to sit for 1 hour or longer. Record the total volume of water added.
This volume represents the total pore space (total porosity) for the growing medium in this particular container. Percent porosity is calculated as follows:

$$\textbf{Percent porosity} = \frac{\textbf{Cups of water required to saturate medium}}{\textbf{Total volume of the pot (cups)}}$$

5. After saturating the medium, suspend the container over the water-tight pan and remove the tape from the drain holes or puncture the freezer bag through the drain holes (Fig. 14). Allow 5 to 10 minutes to drain or until no more water drains from the pot. *Do not* tilt or tip the container as this increases the length of the column (depth) and will give a false reading.

6. Record the volume of water drained from the container. This volume of drained water is equivalent to the air space in the drained medium. Percent air space is calculated by the following formula:

$$\textbf{Percent air space} = \frac{\textbf{Cups of drained water}}{\textbf{Total volume of the pot (cups)}}$$

7. The percent water retention or "water holding capacity" of the medium is the

difference between the amount of water required to saturate the medium and the amount drained. Water holding capacity is calculated as follows:

Water holding capacity = Percent porosity - Percent air space

The percent drainable pore space should be 20 to 30 percent for growing most nursery crops. In general, recently mixed media with values below 20 percent are unsuitable for most container plants. Values above 32 percent represent excessive drainage and a limited supply of water. Propagation media is an exception to this rule. In shallow containers or flats, drainable pore space (percent air space) should be 40 percent or higher (Whitcomb, 1979).

It is advisable to test growing media which has been in use for some time. Compaction and shrinkage of media occurs with normal settling, watering and decomposition of organic matter and plant roots may fill some pore spaces. In general, after 6 months values below 15 percent may cause root suffocation, especially if overwatering occurs from irrigation or rainfall.

Shrinkage of Container Substrates

Three types of shrinkage of media occur:

(1) Shrinkage by expansion and contraction occurs with materials such as peat moss. It expands when wet and contracts or actually pulls away from the sides of a pot when allowed to dry. Culturally, it is important not to let a peat moss substrate dry out or it becomes difficult to rewet. Water added to dry peat moss will be repelled and run between the medium and container rather than be retained in the medium.

(2) Decomposition shrinkage occurs when medium components decay or break down to smaller particles within the container. Organic components such as sawdust, woodchips, hardwood bark, peanut hulls, straw or corn cobs usually require composting before use in container substrates. Pine bark does not decompose appreciably during production. Decomposition shrinkage occurs when additional nitrogen is applied for plant growth in the container medium. Organic components of the medium tie up the nitrogen as microbes break down cellulose contained in the component. A ratio of carbon (C) to nitrogen (N) is used to express the extent to which further decomposition will occur. Fresh hardwood bark has a C/N ratio of 150/1 but after composting will have a C/N ratio of 40/1. An ideal C/N ratio for plant growth is 20/1 but continual fertilization can compensate for further decomposition after composting. In a container, this type of shrinkage actually reduces the volume of medium in the container. Uncomposted components may reduce the volume of a full container at potting to one-half a container of medium 6 months later. Particle size of the medium is also decreased during this type of shrinkage which decreases total porosity, water retention and drainable pore space.

(3) Space-volume shrinkage occurs because large particles interlock with smaller particles and spaces which were originally pore spaces are filled with finer particles. The greater the difference in particle size between two components, the

greater the space-volume shrinkage. For example, 1 cubic foot of pine bark mixed with 1 cubic foot of sand will not equal 2 cubic feet of medium on a volume basis.

Bulk Density

Bulk density is the mass per unit volume of a substrate and is expressed as grams per cubic centimeters (g/cm3), kilograms per cubic meter (kg/m3), pounds per cubic foot (lbs/ft3), pounds per cubic yard (lbs/yd) or by any other weight to volume units. Recent trends have been to design potting mixes with low bulk density to reduce labor and shipping costs. However, bulk densities should not be drastically reduced so that the container medium will not support plants erectly. The addition of sand in various ratios to a light, weight component such as pine bark is commonly used to increase bulk density to increase support and anchorage. Large differences in particle size of two components and space-volume shrinkage will increase bulk density but decrease water and nutrient retention and air space.

Particle Size Distribution, Bulk Density and Pore Space Relationships

Pore space and bulk density are correlated with particle size and the range in particle size. For example, 0 to one-half inch screened composted hardwood bark placed in a 1-gallon (3.8 l) container has a dry bulk density of 33 pounds per cubic foot, water retention of 35 percent volume and drainable pore space of 16 percent (Table 1). The total porosity, a sum of water retention and drainable pore space is 51 per- cent. Builders sand has a bulk density of 104 lbs/ft[a], 27 percent water retention, 9 percent air space and total porosity of 36 percent. In a 1:1 (by volume) combination, all factors are intermediate for the two components. However, if a grower potted some plants in 100 percent hardwood bark and others in 1:1 he would need to manage them differently. In comparison to 100 percent hardwood bark, bulk density is increased in the 1:1 mix and water retention, air space and total porosity are decreased. The sand has apparently filled in some spaces which were pore spaces in the hardwood bark reducing air space and water retention. The 100 percent hardwood bark would require less frequent irrigation. The 1:1 mix should not be used in shallow containers because the medium would remain too wet with too little air space for good plant growth.

Cation Exchange Capacity and Nutrient Retention

The retention of nutrients by a container substrate is normally measured by cation exchange capacity (CEC). Plant nutrients are usually applied to a medium as salts (charged long). Cation exchange capacity is defined as the sum of exchangeable cations or bases that a medium can absorb per unit weight and is expressed as millequivalents per 100 g (meq/100 g) media. The larger this number, the greater its cation exchange capacity. As an example, sphagnum peat moss has a high CEC of 100 to 120 meq/100 g where perlite has a CEC of 1 to 5 meq/100 g. Cations associated with plant nutrition are Ca++, Mg++, NH_4+ and K+. In addition to cations, plants also require negatively charged anions such as nitrate (NO_3-), chloride (Cl-), sulphate ($S0_4$-) and phosphate ($HP0_4$"). A total of 16 elements are considered necessary for plant growth and 13 must be provided to the plant. Many of the minor elements required are provided in media containing soil and the soil should be tested to determine nutrient content.

In soilless media, all nutrients required for plant growth must be provided.

Soilless media are commonly amended with minor elements of which several commercial products are available, dolomitic limestone (dolomite) which provides Ca++ and Mg++ and effects pH, and often superphosphate for root development. Nitrogen, potassium and phosphorus are usually supplied in greater quantities relative to other nutrients since plants require larger amounts of these elements. Dolomite regulates pH in components such as pine bark which become acidic as decomposition proceeds. Dolomite keeps the pH within a range where most elements are available to the plant. However, dolomite cannot be used in hardwood bark media. As a result, calcium and magnesium are often supplied through addition of gypsum ($CaS0_4$) and magnesium sulfate [MgSO, (epsom salts)].

The term pH is the measure of acidity or alkalinity of a potting substrate. It is expressed on a scale of 0 to 14 with 7.0 being neutral, above 7.0 alkaline and below 7.0 acidic and 5.2 to 6.2 considered to be optimum for plant growth. When pH in a potting medium is below 5.0 or above 7.0 the availability of some essential elements may become restricted. The pH of a medium can be adjusted prior to potting but the amount of material required for adjustment depends upon the components in the mix. In general, to increase (or raise) pH 0.1 units add 1 pound of dolomite per cubic yard potting medium (Koths, et al., 1976). For example, to increase pH from 4.2 to 5.2, incorporate 10 pounds of dolomite into each cubic yard of potting mix.

To reduce pH, 1.0 units elemental sulfur can be incorporated at the rate of 1 pound per cubic yard (Evans and Wagner, 1979) or 1 pound per 100 square foot. Aluminum sulfate and iron sulfate can be used at 1 pound per 100 square feet to lower pH 0.2 units (Koths, et al., 1976). The pH of a medium changes very slowly over a period of time and if pH of a potting mix is adjusted before potting, pH problems during production are unusual.

Soluble Salts

Soluble salts refer to all the soluble nutrients or long present in the growing medium (Warncke, 1975). A measure of soluble salts of a medium will give a general indication of the available nutrient status. However, the soluble salts level within a container changes hourly. After drainage has occurred and following irrigation, all the soluble nutrients are dissolved in the water that is present in the container. As water is lost by evaporation or transpiration, the concentration of soluble nutrients increases. If the soluble salts concentration becomes too high, water will be drawn from the plant and injury can occur. Since the nutrients are soluble, the problem can be solved by leaching or irrigating. A low soluble salts level indicates that nutrient levels are too low to support continued growth. A soluble salts reading does not, however, indicate what elements are deficient.

A complete analysis of the growing medium (such as conducted when samples are sent to the state soils lab) is necessary to determine nutrient balance. A grower can, however, measure soluble salts with a solubridge. Such an instrument can help a grower avoid costly mistakes.

Pasteurization and Fumigation

Topsoil may contain disease organisms (bacteria, fungi, viruses), nematodes, insects and weed seeds which need to be eliminated before use as a growing medium. As a result, pasteurization or fumigation is required. Most plant pathogenic organisms can be controlled by heating soil to a temperature of 140°F (60°C) for 30 minutes (Mastalerz, 1977). Weed seeds require higher temperatures and 180°F for 30 minutes is generally considered optimum for elimination of all undesirable organisms. Heat penetration is best with moist soil. Steam provides the best heat treatment for stationary soils, dry heat can be used with soils which are rotary mixed during pasteurization. Several methods of steam pasteurization are available. The Thomas Surface method (Hartman and Kester, 1975) utilizing perforated pipes laid on the soil surface and covered with a steaming tarp can be used to steam pasteurize ground beds, soil containers, soil bins or soil on potting tables. Steam can also be introduced into modified cement mixers to pasteurize soils while mixing. These methods require a steam source or generator. A relatively new technique of steam pasteurization is aerated steam pasteurization where air is mixed with steam through use of an aerated steam generator (Aldrich, et al., 1974). The air provides better penetration into the soil mass and permits temperature regulation to about 160°F, and reduces the danger of manganese toxicity which occurs when soils are overheated. A portable steam aerator is often used with a portable soil wagon. Both the steam aerator and the soil wagon can be purchased through greenhouse and nursery equipment suppliers; however, a steam source or generator is required.

Chemical fumigation can substitute for steam pasteurization (Mastalerz, 1977). Disease organisms are more difficult to kill with chemical fumigants than insects, nematodes and weed seeds. Methyl bromide plus 2 percent chloropicrin (Dowfume MC-2) can be injected under a plastic cover. Best results are achieved with moist soil at 50° to 90°F. Fumigation requires 48 hours and potting mixtures must be aerated for periods up to 10 to 14 days before potting. Methyl bromide plus 2 percent chloropicrin is very toxic and should be applied by a licensed pesticide applicator.

Other potting materials such as peat moss, pine bark and sand can be pasteurized or fumigated but many times are not. Peat moss and barks are not technically sterile since they contain various microorganisms. However, these microbes are usually not pathogenic. Occasionally, grower problems, especially in propagation media are traced to materials which were not pasteurized. Many growers consider sand and other aggregates inert and free of organisms. However, sand can and often does contain weed seed and other pathogens and pasteurization or fumigation may be the best policy. Vermiculite and perlite are heated to very high term- peratures to produce them and so are initially free of pathogenic organisms. Composted materials such as hardwood bark reach temperatures as high as 160°F and are therefore relatively pathogen free. Good sanitation practices are the key to avoiding most pathogenic problems associated with soilless potting mixtures. If clean materials are purchased, covered and stored away from possible contamination such as water runoff or discarded plants from growing areas, disease, insect and weed seed problems will be greatly reduced.

Components for Growing Media

Nursery crops can be grown in virtually any non- toxic substance that provides anchorage, water, oxygen and essential elements. However, some materials are easier to use and manage (Havis and Hamilton, 1976) and generally mixtures of two or more materials are used to provide the desired air space, moisture and nutrient retention and bulk den- sity. Potting components may be somewhat regional in use because of availability. However, components such as peat moss, vermiculite, perlite and now pine bark are widely available to growers regardless of location. Sand and soil, although common to all nur- sery production areas, vary widely in their physical, chemical and biological makeup. Use of fine sand in a potting mixture requires different management than when coarse sand is used. Table 2 lists criteria which should be considered for use of a material in a potting mixture.

Components of a potting mixture are often selected by growers according to their cost as well as their availability and the growers experience with potting material. Although cost is important, it should not be used as the sole consideration as it can drastically effect the survival, growth and quality of plants produced. As an example, pine bark in the southeast has traditionally been cheap and easy to obtain. Mixed with sand in various ratios it was easy to manage and it produced quality plants. Today some shortages and higher prices occur. Many growers now choose to try other materials such as peanut hulls, sawdust and hardwood bark. To use these materials requires different management and possibly additional steps such as composting to grow high quality plants. If short cuts are taken, plant survivability, growth and quality will be sacrificed. Some materials may be too difficulty manage to be used efficiently. Growers should experiment with small blocks of plants when new materials are tried rather than jeopardizing an entire crop. Test blocks will also provide comparisons to present materials and procedures being used. Criteria which should be considered for use of a material in a potting mixture include:

1. Effective in producing good drainage and aeration,
2. Biologically and chemically stable when pasteurized,
3. Low in soluble salts,
4. Readily available in uniform grade,
5. Economical,
6. Capable of retaining moisture and nutrients to meet plant requirements,
7. Light in weight,
8. Easily incorporated into mixture,
9. Acceptable pH (Matkin, et al., 1957).

Soil

Soil is used as a part of a potting medium by some nurserymen. However, topsoil supply, uniformity and quality are difficult to maintain and soil must be pasteurized or fumigated. Pasteurization of some soils at high temperatures creates additional problems such as manganese toxicity and an imbalance between ammonifying and nitrifying bacteria. The high bulk density of a soil medium increases handling labor and cost of shipping plants. The principal advantage of soil in the potting medium is the ease of plant nutrition since minor element deficiencies are not common, and nitrogen and phosphorus exchange is enhanced. Soil also has a high buffering capacity which lessens the hazards of excessive nutrient application. In addition, many nurserymen believe that a soil medium aids in the establishment of container plants in the landscape.

Sand

The particle size of sand is a critical factor in selection for use in a potting medium. Sharp sand or builders sand (5/64 or 2 mm) is preferred (Mastalerz, 1977). Sand is used in a medium only to add bulk density. In Table 1 it can be seen that builders sand weighs 104 lbs/ft^{3}. This weight aids in keeping container plants upright. Sand retains only 27 percent water by volume and only 16 percent water by weight. The air space after drainage is a very low 9 percent and raises the question of use as a propagation medium. When combined with other medium components, sand decreases air space and would be expected to decrease water retention. However, if combined with clay soil, particles interface very closely, eliminating pores so drainage occurs very slowly. This will also occur when great differences exist between particle sizes of components so fine sand should be avoided.

Peat and Peat Moss

The terms peat, peat moss or moss peat refer to several materials that are similar in origin but distinctly different in their botanical composition and physical and chemical properties. Peats are organic materials formed by accumulation of specific plant species which are partially decomposed by aerobic conditions. The type of plant material and its degree of decomposition determine the value for use in growing media. Peat is classified into four distinct types (1) sphagnum moss peat; (2) hypnaceous moss peat; (3) reed and sedge peat; and (4) humus peat or muck (Mastalerz, 1977).

1. Sphagnum moss peat-Principal sources of sphagnum peat moss are Germany, Canada and Ireland. More of the criteria for selecting ingredients for a growing medium are met by sphagnum peat moss than any other material. It is readily available although German peat moss, which is preferred to Canadian or Irish peat moss, is more expensive. Sphagnum peat moss is acid in pH but easily adjusted with dolomite. It is low in soluble salts, long-lasting in a substrate, uniform in composition and effectively improves drainage and aeration. Yet it has high water and nutrient retention. Values in Table 1 show that sphagnum peat moss absorbs 7 times its dry weight in water and has 59 percent by volume water retention and after drainage has 25 percent by volume air space. When combined with bark and sand in equal volumes these characteristics of peat moss enhance water retention and air space characteristics in the mixture. Two grades of sphagnum peat moss are available. Poultry litter grade is coarse and works well for amending ground beds or for incorporating in a backfill for planting landscape plants. Horticultural grade is finer in particle size range and grade and is best for potting media. Dry peat moss is hard to wet and sheds applied water. Therefore, before use, it must be soaked. Many times wetting agents are added to accelerate wetting.
2. Hypnaceous moss- This peat is comparable to sphagnum peat moss in many of its properties. It decomposes more rapidly than sphagnum peat moss but can be used in potting mixtures. Many of these peats are available from northern sections of the United States.
3. Reed and sedge peats- These peats are usually brown to black in color, finer in texture, less acidic and less fibrous than sphagnum peat moss. They also contain some colloidal plant residues, wood, silt and clay particles. Reed and sedge peats

decompose rapidly in a potting mix, and therefore are not recommended for such use.

4. Humus peat or muck- These peats are extensively decomposed, brown or black in color, finely textured and often contain large quantities of mineral particles such as silt and clay. When used in potting substrates they do not enhance drainage or aeration and are considered to be undesirable. A principal source is from poorly drained areas in the southeastern United States.

Perlite

Perlite is heat-expanded volcanic rock. It has low cation exchange capacity and low waterholding capacity (19 percent volume, Table 1). When used in a medium it increases aeration (56 percent by volume) and reduces bulk density (6 lbs/ft3). It will not compact in a mix but has a tendency to float and separate from the other components when watered. Perlite should be considered for use only in propagation media for nursery crops. It is much too light and causes too much of a reduction in bulk density to be used as a container mix component.

Vermiculite

Vermiculite is an aluminum-iron-magnesium silicate (mica). Deposits are found in the Carolinas as well as other areas of the United States and several foreign countries. It is produced by subjecting raw vermiculite to temperatures of 1400°F (745°C). In its expanded form it has a high cation exchange capacity, a pH of about 7.0 and contains large amounts of potassium and magnesium which are available to plants. As seen in Table 1, vermiculite has a low bulk density, approximately 7 lbs/ft^{3,} but is easily compressed when combined with heavy components such as sand or soil. Only horticultural grades should be used although particle sizes are available from very fine for seed germination to coarse particles. Vermiculite, like perlite, should be considered only for propagation media for nursery crops and does not belong in a container potting substrate because of its tendency to compact.

Manure

Manures are not recommended as a potting medium component. They may contain weed seeds and pathogenic organisms and pasteurization is not compatible with their use. The organic matter is high in protein and other nitrogenous compounds which are coverted to ammonia and nitrites (Mastalerz, 1977). This process begins as soon as the manure is produced and continues at a rapid pace. Ammonia toxicity is commonly associated with manure use. The severity of ammonia toxicity is reduced with well-rotted manure but its effects on soil structure are limited and the media deteriorates with long term crops. From the stand point of standardizing growing media, manures are extremely variable. In addition, handling and storage methods have marked effects on the structure of manure. Manures contain approx- imately 0.6 percent nitrogen, 0.15 percent phosphoric acid and 0.48 percent potassium. A ton would supply 12 pounds N, 3 pounds P and 9.5 pounds K, and would amount to approximately $3 of nutrient value. Calcium, magnesium, sulfur and minor elements are also found in manures but these elements are more easily and safely applied in known quantities by commercial products. Plant nutrients applied in the form of manure are no more effective in stimulating plant growth than nutrients applied from chemical fertilizers.

Pine Bark

Pine bark is the most common container mix component for nursery crops in the southeast due to ease of use and availability. Presently, there is some concern that pine bark shortages may occur in the future. The amount of pine bark processed by the sawmill and pulpwood industry will not likely decrease. However, the demand for pine bark and therefore its value are increasing. Large quantities of pine bark are shipped from North Carolina and other southeastern states to northern states for use in nursery and floricultural operations. Container mix components, such as composted hardwood bark and peat moss, utilized in the Northeast and Midwest are now so expensive that pine bark shipped to these areas is comparative in cost and possibly less trouble to use. In addition to the increased demand from the horticultural industry, pine bark can also be used for fuel and provides as much as 9000 BTU/lb (Ince, 1977). The fuel value of bark is approximately $15 per ton or between $3.80 and $7 per cubic yard (calculated from Allison, 1976). Southern nurserymen can therefore expect to pay as much as the fuel value for pine bark in the future.

Debarking and Grinding

Various types of debarkers are now used (Hoitink and Poole, 1979). Ring and drum debarkers remove little wood from logs and generally yield bark with a wood content of less than 10 percent. Rosserhead debarkers used at sawmills remove considerable wood in addition to bark. The percentage of wood in this bark may vary depending on the time of year at which bark **is** removed from logs. Hosmerhead debarkers follow the contour of the log and remove less wood than Rosserhead debarkers and, therefore, are more suitable.

Recently, whole tree chippers have been introduced by the paper industry. Entire trees are chipped in the field and bark is separated from woodchips at the mill by screening. These screenings may contain up to 60 percent wood and are not suitable for use in container media unless they are composted for long periods, perhaps for several years. In addition to causing nitrogen deficiency in plants, an excessive amount of wood in bark decreases and actually negates the suppressive effect of bark compost. Saw- mills that wish to produce bark for container media need to dispose of sawdust and woodchips separately.

Pine Bark--Particle Size

One advantage of using pine bark in a potting medium is its resistance to decomposition. Another advantage is that it can be hammer milled and screened to provide a uniform material that is reproducible. Pokorny and Delaney (1975) have shown that milled pine bark, with 70 to 80 percent of the particles in the range of 1/42 to 3/8 inches in diameter and 20 to 30 percent of the particles smaller than 1/42 inch, is very satisfactory as a potting medium component. If pine bark is too coarse, water retention will not be adequate for plant growth. Conversely, if too many fine particles are present, excess water and poor aeration can result in poor plant growth. For this reason, pine bark used alone as a potting medium is usually screened to one-fourth inch to eliminate large particles. In Table 1, 0 to one- fourth inch pine bark samples had greater bulk den- sity and water retention and less drained pore space than 0 to one-half inch samples.

Pine Bark Composting

Composting is a process comprised of a series of biological processes that decompose cellulose (xylem and cambium fibers) from bark (Poincelot, 1975). In contrast to hardwood bark, composting pine bark has not been shown to be highly beneficial since bark from softwood species of the southeast such as loblolly, slash, white shortleaf and longleaf pine contain small amounts of cellulose (Pokorny, 1979). Nevertheless, nurserymen have preferred to use aged pine bark in contrast to fresh pine bark. This may be due to the particle size distribution because fresh pine bark might have a greater percentage of coarse and fine particles (Pokorny, 1975, 76).

Self and Pounders (1974) reported that many plants grew well when potted in fresh pine bark potting mixes and if pine bark was composed first and potting delayed 60 days, excessive salt accumulation occurred. Pokorny (1979) has conducted laboratory tests which show approximately one- fourth pound nitrogen per cubic yard will provide adequate nitrogen for microorganisms acting upon pine bark unless excessive amounts of wood or sawdust accompany the bark. This quantity would be provided in a normal fertilization program.

Pine Bark pH

Pine bark is acidic and may range from 3.9 to 5.4. A preplant addition of dolomite at a rate of 4 to 15 pounds per cubic yard is necessary to raise the pH to a suitable growing range. Dolomite may require a few weeks to stabilize pH.

Pine Bark--Sources of Nitrogen

Nitrate base fertilizers (calcium nitrate, potassium nitrate) appear to be preferred nitrogen sources for fertilization in comparison to ammonium sources of nitrogen (Pokorny, 1978). When over 50 percent of the nitrogen is supplied as ammonium, plant growth appears to be depressed, possibly due to ammonium tie up in bark particles rather than ammonium toxicity. Slow release fertilizers containing nitrate N have given good growth.

Pine Bark Mixtures

A wide range of potting media have been used with successful results (Bosley, 1967; Joiner and Conover, 1965, 1967; Lunt and Clark, 1959). The key to use of various mixes is learning proper management. Pine bark and sand substrates 3:1, 2:1 and 1:1 (by volume) are commonly used mixtures (Pokorny and Delaney, 1976). With each decrease of pine bark volume to sand, it can be seen from Table 1 that bulk density in- creases and air space after drainage decreases. Peat moss can be added to increase water retention of a pine bark sand mixture.

Dry Pine Bark Wetting Difficulty

Below 35 percent moisture content a wetting agent or surfactant must be used to insure thorough wetting of pine bark (Natarella, Airhart and Pokorny, 1978). Growers often try to increase moisture content in pine bark by placing a sprinkler over the bark pile for several days prior to potting.

Hardwood Bark

Particle Size of Hardwood Bark

Hardwood bark should be hammer milled and screened so that all particles pass through a one-half inch (12.5 ram) screen before composting (Hoitink and Poole, 1979). Koranski and Hamza (1978) report best results with one-fourth screened and composted bark. As a potting component Gartner *et al.*, (1971) found approximately 35 percent of the particle sizes should be smaller than 1/32 inch, 10 percent larger than one-eighth inch and the rest between one-eighth and 1/32 inch to insure good aeration and drainage. This is accomplished by hammer milling and screening before composting.

Composting Hardwood Bark

Hardwood harks from species such as oak, maple, poplar and alder are high in cellulose content and decompose rapidly. This rapid decomposition results in nitrogen depletion in the medium and plant stunting when fresh hardwood bark is used in a potting medium. Additionally, plant growth inhibition may occur due to phenolic compounds present in fresh hardwood hark. These plant growth inhibitors break down with aging or composting, but hardwood bark will not fully decompose without addition of nitrogen and composting.

Procedures for Composting

A procedure which was developed by Klett, Garther and Hughes, (1972) for composting states that 6 pounds of ammonium nitrate, 5 pounds of 0-20-0 superphosphate, 1 pound of elemental sulfur and 1 pound of iron sulfate are needed for each cubic yard of bark utilized. Gartner et al., (1970) suggests that urea and ammonium sources should be avoided. Sulfur and iron sulfate are used for pH control and may not he necessary if water is acidic or ericaceous plants such as azaleas are not being grown. These ingredients should be wet and thoroughly mixed (rotary mixing is best), and then stockpiled in piles of at least 3 cubic yards for a minimum of 60 days. Temperatures in the middle of the pile will reach 140° to 160°F then decline. This temperature can he monitored using a thermometer. When this decline occurs, the pile should be rewet and turned (about 4 to 5 weeks after mixing). The temperatures will again rise and decline and at this time the bark mix should be ready for use. Additional turning could be of advantage.

Consider the elements added during composting to be consumed. All the N-P-K fertilizer necessary to grow the nursery crop must still be added; however, hardwood bark has been reported to contain all the minor elements essential to plant growth. Liquid fertilization, top-dressing or incorporation of fertilizer can he used when growing plants in hardwood bark mixes. Lime cannot he added to hardwood bark mixes. The pH (approximately 5.2 to 5.5) rises as the bark ages to 6.8 to 7.0 due to the calcium content. Magnesium deficiencies have occurred and can be avoided with the addition of 1 pound of $MgSO4$ per cubic yard of mix.

Hoitink and Poole (1979) have reported composting techniques which vary somewhat from Gartner's (1971) procedures. They conclude that ammonium nitrogen is a better source of nitrogen for composting than nitrate nitrogen and concur that phosphate increases the decomposition rate. However, they state that pH correction with elemental sulfur or iron sulphate three-fourths to 1 pound (.3-.5 kg) each per cubic yard should not be added before composting and that $MgS0_4$ can he added before or after composting. To supply adequate nitrogen (3.8 pounds of actual N/per cubic yard [2 kg/m3]) they recommend 4 pounds (2.4 kg/m3) per cubic yard urea and 1 pound (.45 kg) triple superphosphate (0-46-0) per cubic yard (0.3 kg P2Os/ma). Higher rates of ammonia nitrogen seem to increase the length of composting due to high ammonia levels which are toxic to microbial decomposers. Decomposition by this technique should require approximately the same amount of time as Gartner's procedure.

Hoitink and Poole (1979) suggest composting should be done in windrows up to 8 feet in height and 8 feet wide. The windrows must all be turned or air forced through piles with fans. The optimum moisture content of bark during composting using this method is 50 to 65 percent (wet weight basis) contrasting to Gartner's procedure recommending 60 to 80 percent moisture content. In practice, this compares to moistening rather than thoroughly wetting the medium.

Koranski and Hamza (1978) had good success with mixing 5 pounds (2.3 kg) ammonium nitrate, 2 pounds (.91 kg) potassium nitrate, 5 pounds (2.3 kg) superphosphate, 1 pound (.45 kg) magnesium sulfate and 1 pound (.45 kg) iron sulfate each per cubic yard. They concluded microbial activity was more rapid with other forms of nitrogen but a better root system was developed with this process. When composting was prolonged for 6 months to 1 year, greater stabilization was possible and plant growth increased.

Hardwood Bark pH

Lime cannot be added to hardwood bark mixes at composting or before potting without creating an excessively high pH. Freshly harvested bark initially has a pH of approximately 5.2 to 5.5 and the pH increases as the compost ages, often reaching 6.8 to 7.2. This rise in pH is due to 3.5 to 4.0 percent calcium by dry weight in hardwood bark. The pH of compost prepared with urea is higher than that of ammonium nitrate compost but after composting the pH is similar. Acidic sand is beneficial in pH control of bark-sand mixes, but sand should be added after composting.

Suppression of Disease and Nematode Infestation in Composted Hardwood Bark Media

Composting involves self-heating at *high* temperatures up to 160°F (71°C). In effect, this is a form of pasteurization and kills most plant pathogens. Hardwood bark composts also suppress all soil-borne plant pathogens (Hoitink *et al.,* 1974,75,76; Malek and Gartner, 1975).

Hardwood Bark Mixes

A standard hardwood bark mix has been 2 parts ground bark and 1 part coarse sand. From Table 1 it can be seen that one-half inch (12.7 mm) screened composted hardwood bark has higher bulk density and lower water retention, drainable pore space and total pore space than pine bark. With the addition of sand bulk, density increases and the other values decrease. Therefore, if deep containers are used less frequent irrigation is required. Other reports show good results with using 4:1 hardwood bark to sand (Gartner, 1979), 2:1:1 bark:peat: sand (by volume) (Scar- borough, 1976) or hardwood bark alone (Smith, 1978). These mixes reduce the chance of over watering which is likely in a hardwood bark sand medium. Hardwood bark is also difficult to wet if allowed to dry out. After potting, plants should be watered thoroughly 2 to 3 times and if difficult to wet a sur- factant should be used. A regular fertilization program has been shown to be essential during the course of plant production.

Sawdust

Like hardwood bark, plant growth is severely restricted in uncomposted sawdust (Allison and Murphy, 1962; Allison, 1965). This effect is mainly one of a depletion of available nitrogen but walnut and incense cedar sawdust is known to have direct phytotoxic effects. Sawdust has characteristics that make it desirable for use in a growing mix. It has a bulk density slightly less than sphagnum peat moss, has similar water retention but greater air space after drainage than pine bark (Table 1). Large amounts of nitrogen must be added to compensate for nitrogen depletion of sawdust. It is estimated that 2 to 3 per- cent nitrogen by weight is required to compost saw- dust, thus 100 pounds (45 kg) of sawdust would re- quire 2 to 3 pounds (.91 - 1.36 kg) actual nitrogen. Great risk of very high soluble salt levels would occur if this much nitrogen was added while growing a nursery crop. Also hardwood sawdusts decay more rapidly than pine bark sawdust and require about 1 percent by weight more nitrogen to accomplish decomposition (Mastalerz, 1977). Old sawdust has a lower nitrogen requirement than fresh sawdust but full decomposition cannot occur without the addition of nitrogen.

Composting sawdust to achieve full decomposition, however, is also difficult. Aeration of the interior of the pile is necessary for decomposition to continue. Therefore, the sawdust pile would require frequent turning or forced air movement into the pile.

A new process, however, eliminates the need for supplemental nitrogen (Mastalerz, 1977). When sawdust is treated by the fersolin process (Pope and Talbot, Inc., San Francisco, Calif.), it is impregnated with sulfuric acid in the presence of hot gases 2000°F (933°C) to remove cellulose compounds.

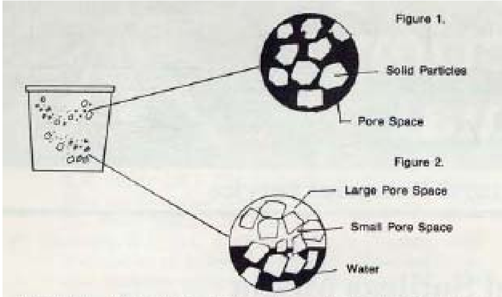

Figure 1. The three parts of a container medium are solids, liquids and gases.
Figure 2. Pore spaces are occupied by water or by air.

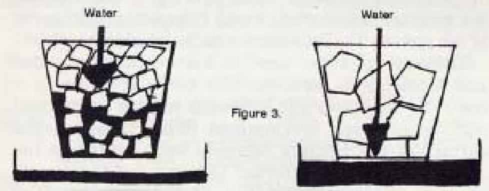

Figure 3. The size of the pores determines the rate of drainage and water storage.

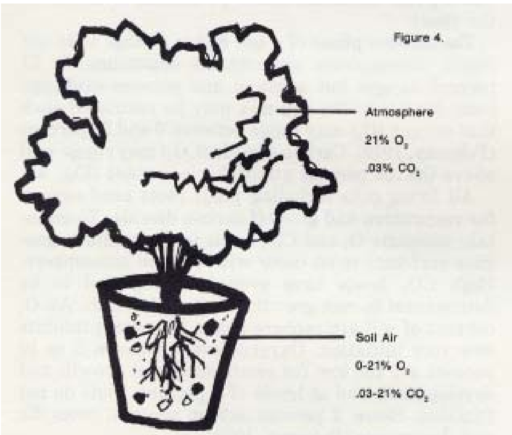

Figure 4. Atmospheric and soil air contents may differ.

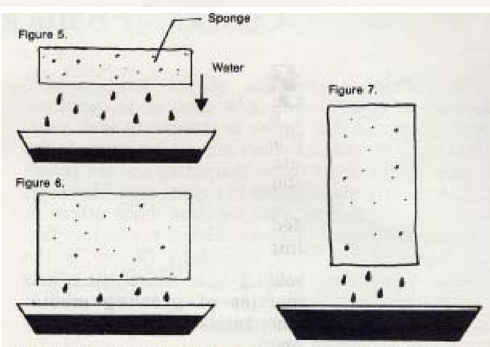

Figure 5. The saturated sponge is placed flat in the pan.
Figure 6. More water drains into the pan if the sponge is turned on its side.
Figure 7. Water content decreases as the height of the column increases.

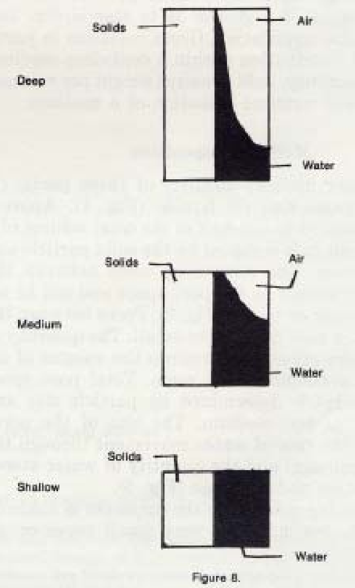

Figure 8. Following watering and drainage, the deepest container is likely too dry and the shallowest container is too wet.

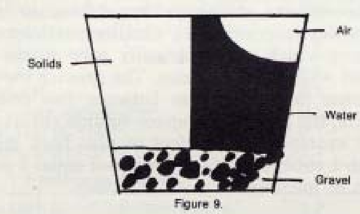

Figure 9. Placing gravel or coarse materials in the bottom of the container changes the drainage and air-water relationship.

Measurement of a Medium Air Space and Water Holding Capacity

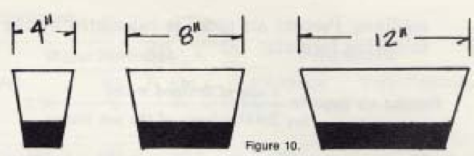

Figure 10. The diameter of the container has no bearing on drainage.

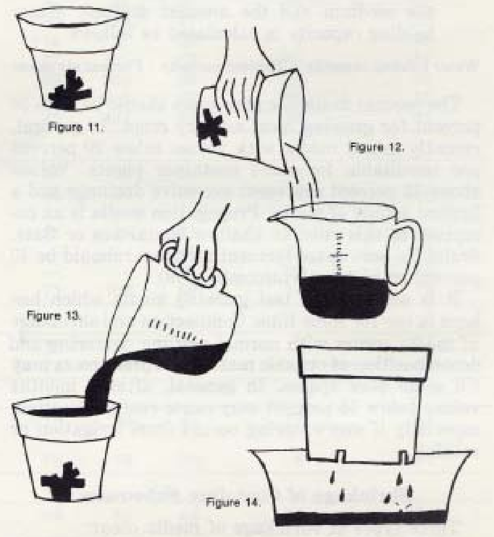

Figure 11. Shut the holes on the outside of the container.
Figure 12. Pour the water from the pot into the measuring cup and record the amount of water.
Figure 13. With the container now filled with growing medium, slowly pour water from the measuring cup into it.
Figure 14. Suspend the container with saturated medium over the water-tight pan and remove the tape.

Table 1. Physical properties of amendments, soils and mixtures.

Material	Density				Water Retention		Pore Space	
	Dry		Wet					
100%	g/cm³	#/ft³	g/cm³	#/ft³	Wt %	Vol %	Air space (after drainage) % vol	Total Porosity % vol
Bark,Fir 0-1/8" (3.18 mm)[z]	0.2	14	0.6	38	165	38	32	70
Bark,Pine 0-1/4" (0-6.30 mm)[x]	0.3	21	0.8	49	132	44	22	66
Bark,Pine 0-1/2" (0-12.7 mm)[x]	0.3	19	0.7	44	134	41	29	70
Bark,Hardwood (0-1/2")[x]	0.5	33	0.8	52	60	35	16	51
Sand,builders[z]	1.7	104	1.9	120	16	27	9	36
Sand,fine[z]	1.4	89	1.8	113	27	39	6	45
Sawdust[z]	0.2	13	0.6	37	185	38	43	81
Peat moss, sphagnum[z]	0.1	7	0.7	43	560	59	25	84
Perlite (3/16-1/4")[z]	0.1	6	0.3	17	213	19	56	75
Vermiculite (0-3/16")[z]	1.1	7	0.6	40	492	53	28	81
1:1 mixtures (by vol)								
Pine bark (0-1/4"):Builders sand[x]	1.0	62	1.3	84	36	39	8	46
Pine bark (0-1/2"):Builders sand[x]	0.9	61	1.3	85	39	39	8	47
Hardwood bark (0-1/2"):Builders sand[x]	1.0	63	1.3	81	28	31	10	41
Fine Pine bark:soil[y]	1.0	—	—	—	—	47	22	69
Fine Pine bark:sand[y]	1.2	72	—	—	—	21	45	66
Sawdust:clay loam[z]	0.6	34	1.1	71	108	58	14	72
1:1:1 mixtures (by vol)								
Peat:Pine bark:sand (0-1/4")[x]	0.7	45	1.1	72	58	44	10	54
Peat:Hardwood bark:sand (0-1/2")[x]	0.7	46	1.1	71	53	42	14	56
2:1 mixtures (by vol)								
Pine bark:Builders sand (0-1/4")[x]	0.8	49	1.1	73	50	44	10	54
Hardwood bark:Builders sand (0-1/2")[x]	0.8	53	1.1	73	38	33	8	41
3:1 mixtures (by vol)								
Pine bark:Builders sand (0-1/4")[x]	0.7	43	1.1	69	62	43	11	54
Hardwood bark:Builders sand (0-1/2")[x]	0.8	50	1.1	63	38	32	9	41

[z]Data from Mastalerz, 1977, The Greenhouse Environment. John Wiley & Sons, Inc.Pages 350-351.
[x]Data from Bilderback and Tilt, 1980 unpublished. Using a 1-gallon container and method adapted from Gessert 1976 and Whitcomb, 1979. More precise data to be developed later.
[y]Data from R.C. Smith & F.A. Pokorny, 1979. Physical characterization of some potting substrates used in container nurseries.

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