

Greenhouse Operation and Management  
Paul V. Nelson  
Seventh Edition



PEARSON NEW  
INTERNATIONAL EDITION

# Pearson New International Edition

---

Greenhouse Operation and Management  
Paul V. Nelson  
Seventh Edition

containing soil. Since cut flowers are produced in permanent beds of substrate and the substrate is not shipped with the final product, these factors do not pose a problem. Substrates, whether soil based or soilless, require periodic pasteurization for cut-flower production.

In addition to texture, the CEC of soil is worth considering. Sandy soils of the southeastern United States can have values of 2 me/100 cc and lower. Soils in the great plain of the central United States have values of 40 me/100 cc and higher because of their montmorillonite clay content. Granted, one cannot afford to transport soil any distance. However, large variations in texture and CEC can occur within a single location. It is worth having soil tested prior to selecting the site from which it will be procured.

### Peat Moss and Peats

There are different types of peat. Peat moss that is light tan to brown in color is the least decomposed, and is formed from sphagnum or hypnum moss (mostly the former). It has a nitrogen content of 0.6 to 1.4 percent and decomposes slowly; thus, nitrogen tie-up is not a problem. It has the highest water-holding capacity of all the peats, holding up to 60 percent of its volume in water. Sphagnum peat moss is the most acid of the peats, with a pH level of 3.0 to 4.0, and requires 14 to 35 pounds of finely ground limestone per cubic yard (8 to 20 kg/m<sup>3</sup>) to bring the pH up to the level that is best for most crops. In areas with alkaline water, the lower rate may be suitable. The CEC of sphagnum peat moss is in a desirable range, from 7 to 13 me/100 cc.

The fine structure of the moss can still be seen in peat moss. Large quantities of water are held on the extensive surface area of the moss, while good gas exchange occurs in the large pores between the aggregates (chunks) of peat moss. For this latter reason, peat moss should not be finely ground down to the level of fibers prior to use. Some soilless substrate formulation companies screen their peat moss into three or more size fractions. By looking upon these fractions as distinctively different components and selectively blending them with each other and other materials such as perlite, they can achieve a wide range of physical properties in the resulting mixes.

Hypnum peat moss has a pH level in the range of 5.2 to 5.5. When it is used with vermiculite, no limestone is needed since vermiculite is mildly alkaline. One successful greenhouse pot-crop mixture calls for 50 volume parts hypnum peat moss to 40 parts perlite to 10 parts vermiculite. Little hypnum peat moss is used compared to sphagnum peat moss.

Reed-sedge peat is brown to reddish-brown in color and is formed from swamp plants, including reeds, sedges, marsh grasses, and cattails. It occurs in varying degrees of decomposition but is generally more highly decomposed than peat moss. As a result, more fine particles are present, giving a poorer structure than that of peat moss. Also, the water-holding capacity of reed-sedge peat is lower than that of peat moss. Depending on the source, the pH level of reed-sedge peat can vary from 4.0 to 7.5. The salt level can also vary with the source. Although sphagnum peat moss is preferred for the general range of greenhouse applications, reed-sedge peat can be used in root substrate for pot and bench crops if pH is properly adjusted, high salt sources are avoided, and proper aeration is built into the final mix. There is little technical information available for using reed-sedge peat. Reed-sedge peat is rarely used for greenhouse production.

Peat humus is dark brown to black in color and is the most highly decomposed of the peats. It is usually derived from hypnum peat moss or reed-sedge peat. Original plant remains are not distinguishable, and water-holding capacity is less than that of other peats. The pH level can range from 5.0 to 7.5. Peat humus has a moderately

high nitrogen content, which makes it undesirable in seed-flat substrate or substrate used for salt-sensitive plants. Ammonium nitrogen released from peat humus can build up to levels that are toxic to more sensitive plants such as young seedlings, African violet, azalea, and snapdragon. Ammonium nitrogen is released during microbial decomposition of peat humus because more than 1 pound of nitrogen is present per 30 pounds of carbon. Peat humus is rarely used in the greenhouse.

Sphagnum peat moss remains the premier component of greenhouse substrates. It has superior properties of stability over time, light weight, and high water and nutrient-holding capacities. However, there is rising opposition to its use, particularly in Europe and to a lesser degree in the United States. Opponents question claims that it is a renewable resource since it can require decades and even centuries for a bog to restore itself. There is also concern over disruption of the ecosystem by its removal. There are mandates in the United Kingdom that set forth a scheduled reduction in its use. Already a 40 percent reduction has been achieved in the United Kingdom by substituting alternative components for it and by diluting its content in substrates that contain peat moss. An even stronger force is felt in several countries in Europe where retail outlet chains have required suppliers of potted plants to reduce or eliminate peat moss in response to their customer's wishes. Materials used to achieve these reductions consist of coir coconut fiber, green (plant material) and manure composts, bark, and processed wood.

### Bark

Redwood bark and fir bark have been used on the West Coast of the United States for many years as a component of nursery and greenhouse root substrate. Coarse fir bark provides an excellent substrate for orchids. Pine bark (Figure 5) is extensively used throughout the United States. Hardwood barks have been used to a limited degree in many of the interior states. Pine barks of various species are used in Australia. All are highly satisfactory. Spruce bark is commonly used in the United Kingdom but is softer



**Figure 5**

*Barks of various origins are widely accepted today as a substitute for peat moss. Pine bark is pictured here. Typical processing calls for composting in a pile for three months or longer and then screening into different sizes for various markets. Particles passing through a  $\frac{3}{8}$ -inch mesh screen are used in pot-plant substrate (left); those between  $\frac{3}{8}$  inch and  $\frac{3}{4}$  inch are used for cut-flower substrate amendment (right); and larger particles are used for landscape mulches (center).*

than the others and not quite as satisfactory. Bark is generally inexpensive compared to sphagnum peat moss.

Most bark is purchased by growers after it has been partially composted (aged) and screened. When bark is removed from logs, varying quantities of cambium and young wood are included. These materials decompose faster than bark and accentuate the nitrogen tie-up problem. The wood content tends to be highest in the spring when growth is more active. A period of composting rids the bark of these components and brings it to a stage where the rate of decomposition is slow and steady and nitrogen tie-up is not a problem.

Accounts have been given of fresh hardwood and softwood barks causing growth suppression and injury to plants. Unknown compounds are apparently destroyed during partial composting for a period of 30 days. One explanation is that the toxic material consists of one or more of seven volatile organic acids given off in the initial stages of composting and then quickly destroyed in subsequent stages of composting (Brinton, W., personal communication). These include formic, acetic, propionic, butyric, and valeric acids as well as iso forms of the last two. Terpenes and phenolic compounds have also been suspected. Composting has an additional beneficial effect for bark and sawdust as well. Fresh bark and sawdust do not hold fertilizer nutrients very well because of a low CEC of about 8 me/100 g (about 1.6 me/100 cc). After composting takes place, the CEC rises to a level of 60 me/100 g (about 12 me/100 cc) or higher, which imparts a strong nutrient-retention capacity to the bark and sawdust.

Composting is accomplished in two ways. Nitrogen is mixed in at the rate of 3 pounds of actual nitrogen per cubic yard ( $1.8 \text{ kg/m}^3$ ), and the bark is set in piles in the field. Ammonium nitrate is a good source of nitrogen and is used at the rate of 9 lb/yd<sup>3</sup> ( $5.3 \text{ kg/m}^3$ ), since it contains 33 percent nitrogen. A period of four to six weeks is sufficient to complete the rapid phase of decomposition. In the second system, no nitrogen is used, and a period of three months to a year is required. Both systems result in destruction of inhibitory compounds, degradation of wood, and fragmentation of larger particles into smaller ones. Because bark used for root substrates is not completely composted, it is often referred to as aged bark.

Compost piles must not be over 12 feet (3.7 m) deep because during the process of composting, heat is given off that—if permitted to become too intense—can set the pile on fire. The surface layer should be turned into the pile after one to two weeks of composting to ensure that all the bark has been processed. The heat given off by fermentation is sufficient to pasteurize the bark. Harmful disease organisms, insects, nematodes, and weed seeds are thus eliminated. It is important that subsequent handling be carried out in a way to maintain this cleanliness. The bark should not be piled where crops have been grown or where the runoff from croplands has accumulated. Equipment used for moving bark should be sterilized first if it has been used on crops. If the bark is bagged, clean handling is almost ensured. Larger growers find economy in purchasing bark in bulk (unpackaged).

Prior to sale, bark is screened for various purposes. Particles  $\frac{1}{8}$  inch (3 mm) and smaller are used as soil conditioners in applications such as golf-course greens. Particles  $\frac{3}{8}$  inch (10 mm) and smaller are preferred for greenhouse pot-plant substrates, and those from  $\frac{3}{8}$  to  $\frac{1}{2}$  inch (10 to 19 mm) are used for organic-matter amendment of greenhouse cut-flower substrate. Particles  $\frac{5}{8}$  inch (16 mm) and smaller are most typically used for woody plant nursery production. Larger pieces are used for landscape mulching.

Since the largest part of the cost of bark often lies in the shipping expense—\$1.90 or more per mile for a 60-yd<sup>3</sup> ( $46\text{-m}^3$ ) truckload—it is beneficial to obtain bark from local sources. In general, processed bark will cost from one-fourth to two-thirds

the price of imported sphagnum peat moss. This price advantage is being challenged by an alternative market for bark. New boiler technology makes it possible to burn bark, wood, and other waste products in compliance with Environmental Protection Agency specifications. Bark is much cheaper than oil, coal, or gas as an energy source. Logging companies see an advantage in selling bark for fuel because it can command a higher price than is currently received from root substrate formulators and they don't need to process it prior to sale. Bark comprises 80 percent or more of the volume of components in substrates used by nurseries producing landscape plants in containers outdoors. The floral products industry will need to face considerably higher prices for bark or quickly find an alternative component.

### Coir

A recent, very effective material added to the list of substrate components is coir, which comes from the coconut fruit. Three shells surround the white edible tissue (meat) of the coconut seed. These are the hard inner endocarp, which lies immediately external to the meat; the softer, fibrous middle mesocarp; and the hard, thin outer exocarp. Mature fruits yield coconut meat from the soft inner white tissue. The endocarp is burned in an atmosphere of limited air to yield activated charcoal. The mesocarp–exocarp husks are soaked in water and then shredded to release long fibers. These fibers are used in the manufacture of brushes, automobile-seat and mattress stuffing, filters, twine, and other products. During the process of retrieving the longer construction fibers, a tan-brown material consisting of short fibers along with granular pith material is generated from the mesocarp. This material is often referred to as coir dust. At the point of production, moist coir dust is air dried and screened to remove longer fibers. The resulting product is used as a component in root substrate. It has the consistency of coffee grounds. This coir dust is referred to by different names, including coir pith and sometimes simply coir. It is then compressed into bricks, some the size of standard clay building bricks and others much larger. The bricks are dried for more economical shipment from the various tropical areas in the world where coconuts are grown.

Before use, coir must be rehydrated, either by the supplier or by the grower. This is done by soaking bricks or ground bricks in sufficient water overnight to bring the final mix to approximately 70 percent moisture content by weight. The hydrated bricks yield a ready-to-use material that has a volume between 5 and 10 times that of the dry fiber, depending on the supplier (Figure 6).

The chemical and physical properties of coir are closer to peat moss than any other substrate component. For this reason, coir is used most often as a partial or total substitute for peat moss. Coir holds moderately less water than peat moss but is better aerated. Due to less shrinkage of coir compared to peat moss during crop production, pots of coir and peat moss hold a similar amount of available water. A decided advantage of coir over peat moss is its superior rewetting capacity. When allowed to dry beyond the desired point, peat moss repels water, while coir continues to absorb it. The pH range of coir is from 4.9 to 6.8. This is higher than peat moss, thus mixes with coir require less limestone. Its bulk density at CC in a 6.5-inch (17-cm) pot is about 46 lbs/ft<sup>3</sup> (740 g/L), and its dry bulk density ranges from 3 to 5 lb/ft<sup>3</sup> (48 to 80 g/L). Coir has a CEC of 60 to 130 me/100 g. Assuming an average dry bulk density of 4 lb/ft<sup>3</sup> (64 g/L), this equates to 3.9 to 8.4 me/100 cc. This is moderately lower than peat moss. Coir has a C:N ratio of 80:1. In an alternative material, this could lead to nitrogen tie-up. However, this is not the case for coir. Coir is about two-thirds lignin, which suppresses microbial decomposition. An added advantage of the low decomposition rate is the stability of volume in the pot over crop production time. At this time, the physical and chemical properties of coir can



**Figure 6**

*Various stages of coir during preparation for use in root substrate. Coir is compressed into dry bricks (left) for economy of shipping to consumer countries. Firms in the destination country may sell the bricks directly to growers or may grind the dry bricks and sell the loose, bagged product (center). Growers add water to the bricks or loose coir in sufficient quantity to comprise 70 percent of the final weight and allow the mix to stand overnight for hydration. The resulting hydrated coir can be five to ten times greater in volume than the original bricks (right) and is ready for incorporation into root substrate.*

(Photo courtesy of The Scotts Co., Marysville, OH 43041.)

vary from one source to another. Salt content can be a problem in some sources. A major element contained in these salts is potassium, but sodium and chloride can also be present. Knowledge about the supplier is important.

Coir is sometimes used in mixes along with pine bark as a substitute for the peat moss component. To avoid a heavy bulk density of the resulting mix, a lightweight component such as vermiculite or perlite is advisable when bark is used. A good trial formula for a coir-based mix would be 30 percent coir plus 30 to 40 percent pine bark plus 30 to 40 percent vermiculite. Perlite can be partially substituted for vermiculite, commonly up to 20 percent of the mix, by growers who hold their mixes wetter and need the extra aeration. An excellent, simpler mix consists of 1 coir:2 peat moss (v/v). Cut roses are commonly grown in a substrate of 100 percent coir. The price of coir is competitive with sphagnum peat moss. Highly effective coir-based mixes are on the market for the greenhouse industry.

## Sawdust

Sawdust (aside from redwood sawdust) in many respects is similar to bark. It should be partially composted because in the fresh state its rate of decomposition and nitrogen tie-up is excessive and it may contain toxic substances such as resins, tannins, or turpentine. Even after composting, sawdust decomposes at a faster rate than bark, and because of its wider C:N ratio (1,000:1), a greater amount of nitrogen is tied up in the root substrate. Whereas the problem is insignificant with bark, it must be taken into account in fertilizing a substrate containing composted sawdust.

Abandoned piles of sawdust are often available for the cost of transportation in forested areas. If a pile has existed for a year or more, the sawdust below the surface layer should be well composted. Care should be taken to avoid unleached areas deep in the pile, which are strongly acidic and injurious to plants. These areas did not

receive sufficient oxygen for aerobic composting, thus underwent fermentation. As a result, volatile organic acids were formed and trapped. These problem areas can be identified by the exceptionally dark color of the sawdust and its pungent, acrid odor. This sawdust can be reclaimed by exposing it to the air and to leaching rains for a season, but it still will be more acidic than properly composted sawdust.

Sawdust composted with additional nitrogen for one month, to the stage appropriate for use in root substrates, is itself acidic and requires limestone to neutralize it. In this stage, it is granular and medium-dark brown in color. It continues to decompose during use in the pot or greenhouse bench. Various types of pine and some types of hardwood sawdust require further additions of limestone as time passes. Sawdust, like other plant materials, ends up close to neutral in pH when thoroughly composted; however, this is well beyond the stage at which it is initially used in greenhouse root substrates.

Sawdust, with the exception of redwood sawdust, is rarely used in greenhouse substrates because of its erratic decomposition during crop production. Redwood sawdust is an excellent substrate component because its content of waxes and tannins suppresses decomposition during crop use.

### Whole Tree Chips

The woody nursery industry recently adopted whole pine tree chips as a substrate for woody container plants. While the chips work well without any other component, better results have been obtained when aged pine bark and/or sand is added. Current studies show promise for these chips in greenhouse container substrate when steps are taken to reduce average particle size (Jackson et al., 2010). Loblolly pine (*Pinus taeda*) and white pine (*Pinus strobus*) can be used, with the former functioning a little better. Hardwood chips have not been satisfactory due to more rapid decomposition as a result of their lower lignin content. Freshly harvested pine trees can be used immediately upon chipping. Efficacy is the same whether limbs, needles, and bark are included with the trunk or not. Fresh chips have a pH between 5.8 and 6.2 and do not require limestone. They can be stored prior to use, but with time pH will decline and require limestone. Fresh and stored chips are equally effective. Coarse wood chips have been shown to have a similar shrinkage rate to pine bark during 70 weeks of container production.

Finer substrate texture is required for greenhouse containers than that used for nursery production. This can be attained by mixing the coarser nursery chips (ground in a hammer mill without a screen) with about 25 percent fine wood chips (ground through a  $\frac{3}{16}$ -inch [4.6-mm] screen). One problem with the fine wood chips, compared to coarse wood chips, is their more rapid rate of decomposition and nitrogen tie-up by increased microbial activity. Another problem is the high cost of energy consumed in the long grinding time required to pass wood through the fine screen. Alternatively, coarse wood chips can be mixed with about 25 percent sphagnum peat moss to achieve finer substrate texture (improved water and nutrient-holding capacity) or coarse pine wood chips and aged pine bark can be ground together for the same added benefits. More study is needed for greenhouse application.

### Animal Manure Composts

Noncomposted animal manure is rarely used in greenhouse production today. However, until the middle of the 20th century annual addition of 10 to 15 percent manure by volume, generally rotted (aged) cow manure, was a standard practice in cut-flower beds containing soil-based substrate and was quite frequently used in bedding- and pot-plant substrate. Its use ended when soil pasteurization became popular in the mid-20th century. Pasteurization of manure released toxic levels of ammonia.