Commercial Greenhouse and Nursery Production

Evaluating Container Substrates and Their Components

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One of the most important cultural considerations and investments you can make when you want to produce a successful greenhouse or nursery crop is to select the best substrate components or pre-formulated substrates (also known as growing mixes or media). Today, growers can select from various components, including peat moss, coconut fiber (coir), composted bark, wood, aggregates; and from various substrate additives to produce the substrates that best fit the needs of their crops. Additionally, growers can select from numerous pre-formulated substrates on the market.

This publication provides an overview of the substrate components that are commonly available and used in greenhouse and nursery production. It also examines the general aspects of a pre-formulated substrate.

Desirable Properties

It is vital to understand the importance of a substrate's physical and chemical properties. Knowing these properties will help you design a growing substrate that is consistent, of good quality, and matches your cultural production practices.

Most greenhouse crops have a production period of one to four months; therefore, substrates must support and sustain plant growth from initial transplant into the container until it reaches the final consumer. Ideally, the substrate should maintain a consistent structure and stability with minimal decomposition of the organic constituents. When microorganisms decompose organic matter, it can reduce larger particles to smaller, fine-textured particles, which alters the physical properties of the substrate.

Substrate physical properties include: total porosity, container capacity (water-holding capacity), air space, and bulk density.

- *Total porosity* is the volume of a substrate that is comprised of pores. Within the substrate, this is the volume fraction that provides water and aeration.
- *Container capacity* is the maximum amount of water (capacity) a substrate can hold after irrigation and drainage. Container capacity depends on container size, so the taller the container, the more drainage, and the less water capacity of the substrate.
- *Air space* is the volume of a substrate that is filled with air after it is saturated and allowed to drain. Air space also depends on container size: the taller the container, the more drainage, so the greater the air space.
- *Bulk density* is the ratio of the mass of all the dry solids to the bulk volume of the substrate. It is important to acknowledge that the substrate will shrink after you fill your containers,

because the volume of substrate in the container available for root growth is often minimal. If the substrate volume significantly decreases because of decomposition during crop production, it can be detrimental to the crop.

Chemical Properties

It is essential to understand a substrate's chemical properties — such as the amount of carbon (C) relative to nitrogen (N). Most greenhouse substrates are formulated primarily from organic materials, which are materials that are composed of 50 percent or more of C.

Microorganisms use the carbon from organic materials to grow. Microorganisms require 1 pound of available N for every 25 pounds of available C from organic matter. If the substrate does not meet this 25:1 C:N ratio, decomposition slows down.

If the amount of C exceeds the amount of N from the organic matter and fertilizer applications, microbes use the N intended for the plant in the container. The amount of N microbes take is known as N immobilization. Nitrogen immobilization problems can result in N deficiencies for the crop.

Substrate components such as clay, silt, organic matter, and vermiculite have fixed negative electrical charges that attract and hold positively charged nutrient ions, known as cations. Examples of cations include: ammonium (NH_4^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), iron ($Fe^{++\ +++}$), manganese (Mn), zinc (Zn), and copper (Cu). Substrate components electrically attract and hold positively charged nutrient ions, which allows for nutrient uptake by the plant. When a substrate holds the cations, it also prevents nutrient leaching.

The capacity of a substrate's negative electrical charges to hold positively charged ions is known as *cation exchange capacity* (CEC). For greenhouse substrates, look for a level of at least 6 to 15 me/100 cc (milliequivalents per 100 cubic centimeters). Substrates with higher levels are not common, but are more desirable than substrates with lower levels, which require more and frequent fertilizing.

Substrate components with high CEC include clay, peat moss, coconut fiber (coir), vermiculite, and most composted organic matter. Components with low CEC include sand, perlite, polystyrene beads, rock wool, and non-composted organic materials such as rice and peanut hulls.

Most greenhouse crops grow best in substrates with a pH range of 5.4 to 6.6. When you formulate a substrate, we recommend that you add dolomitic or calcitic limestone to adjust the substrate to the recommended pH range. Alternatively, you can amend gypsum into the substrate to lower the initial pH. Adjusting substrate pH to the recommended range will help make nutrients more available to the plants. You can determine the initial pH of the substrate by utilizing the 2:1 saturated media extract method (SME) or pour through before adjusting substrate pH.

For more information about pH, see *Commercial Greenhouse Production: pH and Electrical Conductivity Measurements in Soilless Substrates* (Purdue Extension publication HO-237-W), available from the Education Store, www.edustore.purdue.edu.

Greenhouse Substrate Components

Traditionally, greenhouse and nursery operations have formulated their substrates on a by-volume basis using peat moss, bark, perlite, or vermiculite. However, rising fuel and transportation costs and peat moss shortages have made alternative substrate components more available and popular. Growers also can now select from more local and regional products.

Sphagnum Peat Moss

Sphagnum peat moss (Figure 1A, page 3), which is partially decomposed sphagnum moss, is harvested from temperate swamps and bogs located predominately in Canada, but also in the United States and Europe.

Peat moss is available in different colors, which indicate their degree of decomposition. White peat and blond peat are referred to as light-colored and have larger particles with limited decomposition. These light-colored peats are more expensive than the more decomposed peats, such as black peat.

That's because the light-colored peats provide excellent aeration plus moderate water-holding capacity and decompose faster than black peats. Black peats are more highly decomposed, so their physical properties vary greatly.

Peat moss has many advantages when used in production, including a high water-holding capacity and high air capacity. Peat moss is naturally acidic with a pH between 3.0 to 4.0. The low pH and low

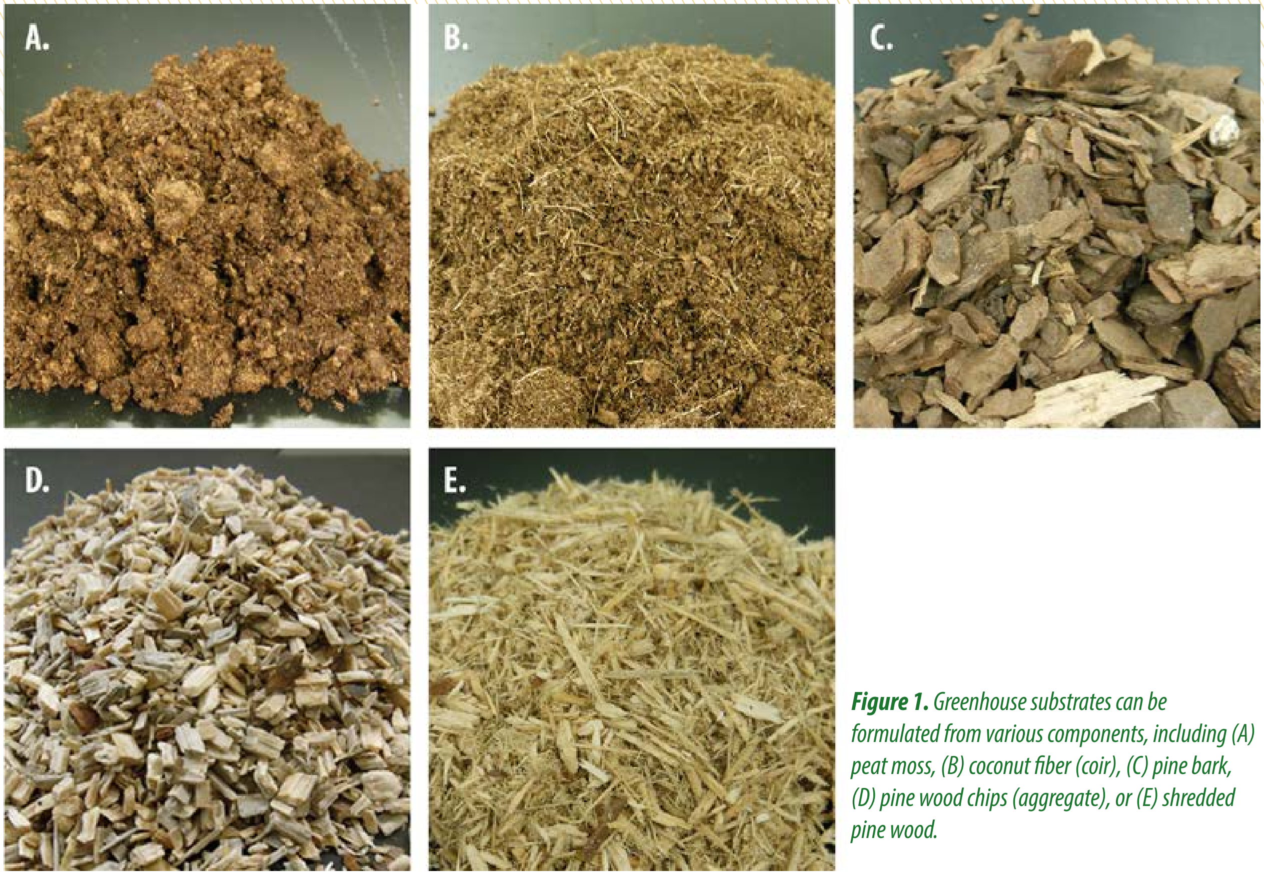

Figure 1. *Greenhouse substrates can be formulated from various components, including (A) peat moss, (B) coconut fiber (coir), (C) pine bark, (D) pine wood chips (aggregate), or (E) shredded pine wood.*

nutrient content of peat allows growers to easily adjust the pH to crop-specific values by including substrate additives (discussed under substrate additives).

Peat is naturally hydrophobic when dry, which means it repels water. Substrates that contain peat must have a wetting agent amended to the substrate to help it absorb and retain water when irrigation events occur. However, if you do not apply water to high-peat mixes, water will begin to evaporate from the surface and shrinkage will occur.

Shrinkage results after water evaporates from the substrate, which decreases the substrate volume. Often, shrinkage results in the substrate "pulling away" from the sides of the container, thus making rewetting even more difficult, because irrigation water channels down the side of the pot instead of being absorbed by the substrate. You must apply water to high-peat substrates before excessive shrinkage occurs so that water does not flow down between the container wall and the substrate.

Overall, peat moss has a low bulk density, a high level of readily available water, variable air-filled porosity at container capacity, and high buffer capacity.

Coconut Coir

Coconut fiber (Figure 1B), also called coir or coconut coir dust, is an agricultural waste product derived from the husks of coconut fruit. It is marketed as an alternative to peat moss and bark.

To produce horticultural grade coir, processors mill and screen the long fibers to less than 2 centimeters in size. Once screened, processors air dry the coir before compressing it by three- to four-fold into bales or blocks.

Fresh coir after air drying and baling is light brown. With age, it turns dark brown to black. Once a growing facility receives bales of coir, they can be easily broken up by hand.

Coir is a suitable substrate component and an alternative to peat moss. University studies have found that bedding plant species grow equivalent to or greater than those produced in peat-based substrates.

Coir's physical properties allow it to absorb liquids and gases, and the fiber or dust structure has a higher surface area, higher water holding capacity, and excellent drainage per unit volume. Unlike peat, coir is hydrophilic, which allows water to evenly disburse over the surfaces of the fibers and deliver it to plant roots.

Coir generally has a higher pH than sphagnum peat moss, so it requires less limestone to adjust substrate pH. However, coir-based substrates require more Ca, sulfur (S), Cu, and Fe; they also require less K. Growers have also reported that coir-based substrates have greater immobilization of soluble N than with peat moss. That means you may need to adjust nutritional regimes on a crop-by-crop basis.

The electrical conductivity (EC) of coir-based substrates can exceed the recommended levels for container-grown plants. That's because if the coir was not properly processed (soaked and rinsed), it may contain excessive levels of nutrients such as K^+, sodium (Na), and chloride (Cl). For most plant producers in the United States, cost will be the deciding factor about whether to use coir fiber or dust.

Composted or Aged Pine Bark

Composted or aged pine bark is a common organic substrate component for container-grown plant production for both greenhouse and nursery industries (Figure 1C). In the greenhouse industry, pine bark in substrates helps extend the use of peat moss more so for structure and aggregation. In the nursery industry, pine bark is the predominant substrate component.

Processors obtain pine bark from harvested pine trees, remove the pine bark, and then hammer mill and screen it to obtain a desirable particle size for growers to use. Once hammer milled, processors often age the pine bark. Growers prefer pine bark with little to no white wood (cambium) content; however, research reports that white wood is not detrimental to crop growth.

Pine Wood

Pine bark and peat moss have often been used in container substrates, but it was not until recently that researchers determined that pine wood can be used as a greenhouse substrate component. It has been demonstrated that substrates that contain wood components are effective for producing a variety of greenhouse and nursery crops. Locally sourced pine bark and wood can help alleviate the costs of transporting sphagnum peat moss.

Commercial noncomposted, wood-based substrates have been available in Europe since the 1990s. Recently, some U.S. substrate manufacturers have introduced substrates containing wood components. These products mostly contain less than 30 percent wood, and are produced from various coniferous tree species that are obtained from forest thinning or from waste from manufacturing.

In the southeastern U.S., loblolly pine (*Pinus taeda*), has been identified as an excellent horticultural substrate component. Other species that could serve the horticultural industry in northern states may include slash pine (*Pinus elliottii*), long leaf pine (*Pinus palustris*), and white pine (*Pinus strobes*).

Processors can chip or grind harvested pine trees with bark, limbs, and needles (whole tree substrate) or without the limbs and needles (pine tree substrate). Next, processors hammer mill it to a desirable particle size, which results in either pine wood chips (Figure 1D) or shredded pine wood (Figure 1E). Processing pine wood chips or ground pine wood through a hammer mill can easily alter their container capacity and air space to make them more desirable substrate components.

The pH of these components can range from 4.5 to 6.0, depending on the time of year that they are harvested. Other chemical properties of substrates that are composed of wood (or large portions of wood) include a lower CEC, a higher C:N ratio, and the tendency to become N deficient as a result of high rates of N immobilization. Therefore, substrates that contain high percentages of wood may require more fertilizer for optimal growth compared to plants grown in peat moss or pine bark-based substrates.

Greenhouse Substrate Aggregates

Perlite

Perlite is a naturally occurring, nonrenewable, inorganic, silicaceous volcanic rock that is produced by mining ore and grinding it to a desirable particle size (Figure 2A, page 5). Once ground, processors heat the crude ore to 1,800 to 3,200°F (982°C, Figure 2B). Heating causes the ore to expand anywhere between four and 20 times its original volume. This results in a lightweight, sterile, white, porous aggregate that has a neutral pH of 6.5 to 7.5 (Figure 2C).

Aggregate sizes vary across the horticulture industry. For example, the perlite particle size for plug mixes is sieved to a smaller aggregate, while mixes used for containers and flats contain larger aggregates.

Figure 2. Perlite is the traditional aggregate incorporated into mixes to provide air space. Processors produce perlite (A) by grinding and (B) heating crude ore to 1,800–3,200°F (982°C). This causes the ore to expand and results in the (C) lightweight, white, porous aggregate.

Parboiled Rice Hulls (PBH)

Rice hulls (Figure 3A) are a byproduct of the U.S. rice milling industry. Fresh rice hulls may be contaminated with whole and broken rice seeds, which could present a weed problem for growers. To prevent rice seedling germination, processors steam (parboil) rice hulls, which should eliminate any viable weed seed.

Large particle sizes of whole parboiled fresh rice hulls can increase the drainage and air-filled pore space in peat-based substrates without causing significant N immobilization. Rice hulls are naturally high in silicon (Si), which decreases degradation. As a result, mixes that contain rice hulls will have a stable structure during production.

Other chemical properties of rice hull products include its EC, ammonium (NH_4^+) and nitrate (NO_3^-) concentrations — they are not excessively high and are within recommended ranges for greenhouse substrate aggregates. However, the pH, and the phosphorus (P) and K concentrations of rice hull

Figure 3. Alternative greenhouse substrate aggregates include (A) parboiled rice hulls; (B) growstones; (C) light expandable clay aggregates (LECA); and (D) expanded polystyrene beads (EPB). Pine wood chips, shredded pine wood, and pumice are not shown. Other substrate components such as (E) vermiculite, can help retain more water and nutrients.

products may exceed the recommended levels for crop production. For that reason, you may need to analyze substrate and foliar nutrition to ensure quality.

Growstones

Growstones (Figure 3B) have been successfully used as a hydroponic substrate. They also have been proposed as an aggregate to adjust the physical properties of peat-based substrates for greenhouse crop production.

Processors produce growstones by combining finely ground waste glass powder with calcium carbonate ($CaCO_3$) and heating it in a kiln. When heated, the glass fuses together, which traps air spaces inside the glass, resulting in a lightweight, porous aggregate that can be ground to the desired particle size.

You can use growstones similarly to perlite and parboiled rice hulls: as an aggregate to increase the air-filled porosity of peat-based substrates. However, growstones can contribute to high pH because of the $CaCO_3$ added during the manufacturing process.

Light Expanded Clay Aggregates

Processors form light expanded clay aggregates (LECA) by firing clay through rotary kilns at high temperatures. During this process, the clay materials begin to expand and produce gases, resulting in porous aggregates (Figure 3C).

There are several LECA products available, including Stalite®, HydRocks®, Livlite®, Gravelite®, Profile™, and Turface™. Both the parent clay material that manufacturers use and the firing temperature they use play a significant role in both the chemical and physical properties of the final aggregate. LECA products have a high bulk density, which limits their use in container substrates. However, LECA has potenial as a replacement to perlite in certain substrate mixes. LECA aggregates provide pore space, but while perlite tends to float to the top of the substrates, LECA does not. Also, LECA does not break down over time and could stabilize substrates with an intended long life. The factors limiting LECA products in substrates for container production include availability, higher cost, and high bulk density.

Expanded Polystyrene Beads

Growers can use expanded polystyrene beads (EPB) in greenhouse and propagation substrates (Figure 3D). You can purchase EPB as waste product of polystyrene processing.

EPB's physical and chemical properties are comparable to perlite, because both are inorganic. EPBs also have a consistent size and shape compared to other aggregates. EPBs do not affect substrate pH, however, the substrate's EC decreases the more EPBs are included in the substrate.

Other factors that growers should consider is that EPBs are an envrionmental concern. EPBs float, so they can accumulate in retaining ponds or containers. Since they are lightweight, they are easily moved by the wind. The positive attributes of EPBs include their low cost, good drainage, and light weight.

Pumice

Pumice is a product of volcanic activity — when magma rapidly cools at atmospheric pressure, it turns into a lightweight, white to light gray, porous rock. The igneous rock mineral composition is aluminosilicate plus potassium and sodium oxides.

For the horticulture industry, pumice is mined, crushed, and graded upon aggregate size. Pumice is ideal for horticulture substrates because it is lightweight, porous, normally sterile (free of pathogens and weed seeds), chemcially inert with a pH of 7.0 to 7.4, and is unaffected by pasterurization.

Vermiculite

Vermiculite ore is a mica-like, silicate mineral that is mined. When heated, the mineral ore plates expand, moving apart into an open, accordion-like structure. Once expanded, processors grade vermiculite based on its particle sizes (extra coarse, coarse, or fine) that provide growers with good aeration and drainage (Figure 3E).

Vermiculite is a desirable substrate component because of its high nutrient (K, Mg, and Ca) content, high water rentention, good aeration, and low bulk density.

Substrate Additives

Limestone

Two types of limestone are commonly available to growers used to adjust the pH of greenhouse substrates: calcitic limestone — calcium carbonate ($CaCO_3$) — and dolomitic limestone — calcium magnesium carbonate [$CaMg(CO_3)$] (Figures 4A and 4B, page 7). Generally, calcitic limestone is more reactive than dolomitic limestone, thus calcitic

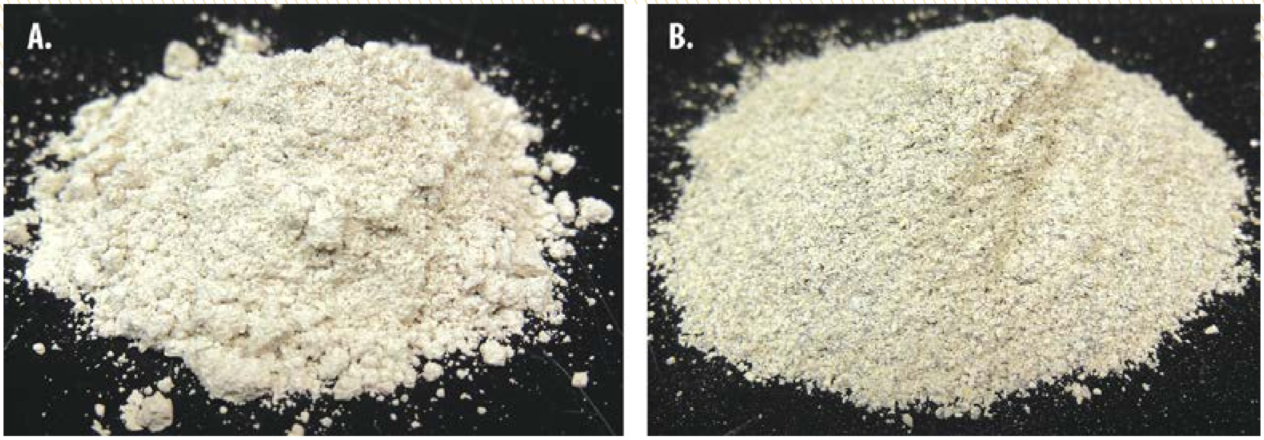

Figure 4. (A) Calcitic limestone ($CaCO_3$) and (B) dolomitic limestone [$CaMg(CO_3)$] are added to substrates to raise (adjust) the substrate pH to the recommended range of 5.4 to 6.6 for most greenhouse crops.

limestone will adjust (raise) substrate pH faster and may raise the substrate pH higher than the same amount of dolomitic limestone.

Horticultural limestones (calcitic or dolomitic) are also avaliable in two common particle size distributions: pulverized (100 mesh — 60 percent of the limestone can pass through a 100-mesh screen) and superfine (200 mesh — 60 percent of the limestone can pass through a 200-mesh screen). These terms are often used interchangebly in the horticulture industry to describe the particle size or mesh size distributions.

In general, superfine (200 mesh, smaller particles) limestone is more reactive in adjusting substrate pH than pulverized (100 mesh, larger particles) limestone. Limestone hardness refers to the soft or hard and smooth mineral structure of limestone crystals. Agricultural and horticultural limestones are considered soft crystals that react quickly with acid. This is more desirable for adjusting substrates formulated with peat moss, pine bark, or coconut coir. Therefore, determining the rate of limestone to incorporate into a substrate to change its pH depends on the substrate components as well as the limestone's properties (type, particle size, and hardness).

Wetting Agents

You should incorporate wetting agents into substrates if you can afford to, or you have means of mixing them into the substrate. The purpose of adding wetting agents to greenhouse mixes is to aid in the process of "wetting" hydrophobic substrate components such as peat moss (Figure 5). Wetting agents also help distribute water evenly throughout the substrate and help rewet substrates when they dry out. Wetting agents are available in liquid and granular forms.

Figure 5. Peat moss is hydrophobic, so wetting agents and other substrate components can help evenly distribute moisture throughout the substrate.

Fertilizer

Starter nutrient charge fertilizers are used to initially supply nutrition to young plants after tranplant. This allows growers to gradually increase the nutritents they provide to young plants without burning the roots, which can cause plant stress or loss.

Other fertilizers you can amend to greenhouse substrates include slow- or controlled-release fertilizers (CRF). The fertilizer prills provide a "slow" or "controlled" amount of fertilizer to be released to the plant during production.

Table 1. Examples of common substrate "recipes" growers can formulate to produce greenhouse and nursery crops.

Crop(s)	Greenhouse Substrate Forumlation		
	Volume Ratio	Substrate Component(s)	Additives[1]
Germination and young plants Annual bedding plants Herbaceous perennials Vegetables Potted flowering crops	2:1	sphagnum peat moss[2]: perlite[3]	limestone wetting agent starter charge fertilizer slow-release fertilizer
	2:1:1	sphagnum peat moss: perlite: vermiculite	
	3:1:1	sphagnum peat moss: perlite: vermiculite	
	2:1:1	sphagnum peat moss: pine bark: vermiculite	
	2:1:2	pine bark: perlite: vermiculite	
Specialty crops (Orchids)	6:1:1	pine bark: perlite: charcoal	
	1:1:1:1	sphagnum peat moss: pine bark: perlite: charcoal	
Herbaceous perennials Nursery / Woody ornamentals	100%	pine bark	

[1] Substrate additives such as limestone, wetting agent, and starter charge or slow-release fertilizers may be incorporated to adjust substrate pH, to help "wet" the substrate, or to provide nutrition to young transplants (seedlings or cuttings) or established plants, respectively.
[2] May be substituted with coconut coir (coir) or shredded wood.
[3] May be substituted with parboiled rice hulls (PBH), pine wood chips (PWC), growstones, light expanded clay aggregates (LECA), or expanded polystyrene beads (EPB).

For more information about fertilizers see *Commercial Greenhouse and Nursery Production: Water-soluble and Controlled-release Fertilization* (Purdue Extension publication HO-251-W), available from the Education Store, www.edustore.purdue.edu.

Formulating Your Own Substrates

Many growers choose to formulate their own substrates. If you decide to formulate your own substrate, it is important to remember the four functions of a substrate. Substrates must:

1. *Support plants*
2. *Provide aeration*
3. *Provide nutrients*
4. *Retain water*

A well-prepared substrate may only contain one to three components (Table 1). However, the information about substrate components in this publication can help you tailor your own substrate to suit your crop and irrigation system(s), and help maintain consistency.

Commercial Greenhouse Substrates

Many growers have access to five or more regional or commercial substrate companies that offer a variety of custom substrates. Substrate manufactures will offer five common categories of substrates including:

1. ***Germination***
   Germination mixes (Figure 6A) are used for sowing seeds. They are composed of (often in

Figure 6. Preformulated commercial greenhouse mixes vary in substrate components and are tailored to the grower's needs. (A) Germination and young plant mixes may contain fine peat, perlite, and vermiculite. (B) Young plant and general peat-based mixes may contain coarse peat, perlite, and vermiculite. (C) Bark-based mixes for perennial and nursery crops may contain peat, bark, perlite, and sand.

equal volumes) superfine peat moss and either fine perlite or vermiculite. Germination substrates tend to cost more than other substrates because it's more expensive to process and create the smaller components. These mixes require greater uniformity and texture of particles to ensure each cell of a plug tray has similar water retention and aeration. Also, the substrate should allow for easy handling for mechincal seed sowing and transplant.

2. ***Young plant***
   Young plant substrates (Figures 6A and 6B) are used to germinate both vegetable and large ornamental plant seeds and for rooting cuttings. These substrates are usually composed of peat moss, perlite, vermiculite, and sometimes coir. When mixed together, these materials provide adequate drainage and aeration. These components are more coarse compared to the components in a germination substrate, but are finer than general peat moss or pine bark substrates.

3. ***General peat moss***
   General peat moss substrates (Figure 6B) are common, and consist of peat moss, perlite, vermiculite, and sometimes coir. These substrates provide adequate water retention and are generally used by "dry growers" to produce bedding plant flats, pots, and hanging baskets.

4. ***General pine bark***
   General pine bark substrates (Figure 6C) are well-aerated and well-drained, so they contain less vermiculite and perlite, two of the most expensive substrate components. These substrates also may contain peat moss to increase water retention, however, 100 percent pine bark substrates can be used for crop production. Growers experience less shrinkage with pine bark substrates than with peat moss-based substrates for long-term crops such as cyclamen and foliage crops.

5. ***Large container substrates***
   Large container substrates are used for container gardens, foliage plants grown in 1 gallon or larger containers, and perennial production. These mixes generally contain 50 to 60 percent coarse bark, which allows excellent drainage of large containers. These substrates normally cost less than other substrates.

Specialty Crop Substrates

Greenhouse growers who produce specialty crops such as orchids, prefer substrates with larger pine bark particles to provide drainage and aeration. Orchid mixes can contain 100 percent pine bark or pine bark amended with sphagnum moss, perlite, or charcoal (Figure 7). Substrates that are used to grow speciality crops are custom mixed to growers' specifications, which means they are generally more expensive and add to the price of the crop.

Figure 7. *Specialty potted flowering crops such as orchids require substrates with larger particles such as composted bark, perlite, and charcoal to improve drainage and aeration.*

Summary

We have discussed and highlighted the desirable chemical and physical properties of substrates, substrate components, and substrate additives. Selecting these materials properly, among other cultural considerations, form the foundation for crop establishment, growth, and development. Based on this information, we hope we have shed some light on the options you should consider when selecting and ordering substrate components or pre-formulated mixes.

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