CHAPTER 7-1
GARDENING: HORTICULTURAL USES

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Figure 1. ***Sphagnum*** species such as this ***S. russowii*** are commonly used in horticulture as bedding material. Photo by Michael Lüth.

Horticultural Uses

I was surprised that in my search for moss uses in horticulture I stumbled on a patent for culturing "moss seedlings" (Hiraoka 1995). The patent was to culture mosses that could henceforth be transplanted and grown in a nursery. Hiraoka presented this as a means of reducing the necessity of collecting wild mosses and creating undesirable forest conditions due to drying soils and erosion. This consideration should serve as a warning for all who desire to use bryophytes for any commercial purpose, and even on a small personal scale, collection can produce local damage.

"People have probably used organic materials as an aid for plant culture since the eve of human history, but documentation is scarce" (Raviv *et al*. 1986). Use of organic materials, including mosses, may not have started that early, but if monkeys can discover the advantage of mosses for getting water to drink, why not? At the beginning of the 18th Century, we find reference to using peat moss as an amendment for clay soils, whereas animal dung was used for sandy soils (Raviv *et al*. 1986). Since then, the need to keep plants alive during transfer made bryophytes a desirable medium because of their ability to retain moisture.

It is surprising how difficult it is today to find literature on the use of bryophytes in plant cultivation, despite the widespread sale of peat mosses for gardening, potting, air layering, and other uses. Rather, the use of mosses, especially peat moss, seems to be assumed and publications concentrate on finding substitutions for it (*e.g.* Tripepi *et al*. 1996) or creating the right mix of moss and amendments (*e.g.* Chong & Lumis 2000; Shujun *et al*. 2004).

Horticulture is the largest market for moss products in Asia (Tan 2003), and probably in most North American countries (Muir *et al*. 2006). In horticulture, mosses find a niche unparalleled in any other living bryophyte industry (Nelson & Carpenter 1965; Tan 2003). In some parts of

the world, they are routinely mined (Clarke 2008). Bryophytes, especially peat mosses (Figure 1), have played a major role in horticulture for centuries (Perin 1962; Arzeni 1963; Adderley 1964, 1965). Although their use as part of the landscape in gardens has traditionally been mostly an Asian practice, they have commonly been used as soil additives and bedding for greenhouse crops, potted ornamental plants, and seedling beds (Cox & Westing 1963; Sjors 1980). They are stuffed into wire frames to make totem poles to support climbing plants (at the Mossers Lee Plant), topiary (Figure 2), moss-filled wreaths, or baskets (Thomason 1994), or for covering the soil in floral arrangements. One company advertises a birch bark pedestal topped by a moss globe.

Figure 2. A swan topiary exhibited in a pedestrian area of Minneapolis, Minnesota, USA. Photo courtesy of David Long.

Overuse of mosses is concerning in several countries. Thus, some horticulturists seek substitutes. The use of rice hulls may provide a more renewable alternative to ***Sphagnum*** (Figure 1) peat for horticulture usage (Sambo *et al*. 2008). Peat has more total pore space and a lower air-filled pore space compared to rice hulls, coinciding with a higher water-holding capacity and the highest water content at container capacity. Nevertheless, peat had a lower available water content than the rice hulls, while releasing its water more slowly.

Shipping and Protecting

Sphagnum (Figure 1) is almost indispensable for shipping live plants, keeping them moist, yet free from mold. In countries where peat is abundant, the damp peat is burned to produce a smoke screen against frost, hence protecting the plants (Thieret 1954). This is one of its uses in Asian countries as well (Tan 2003).

Soil Conditioning

The Shuswap Indians of North America use ***Aulacomnium*** (Figure 3) and ***Dicranum*** (Figure 4) mixed with dirt to make plants healthier (Palmer 1975). As a soil conditioner, coarse-textured mosses increase water storage capacity; fine-textured mosses provide air spaces (Ishikawa 1974; Bernier 1992; Bernier *et al*. 1995). Although supporting experiments seem to be lacking, we assume that mosses improve the nutrient condition of outdoor soils by holding nutrients, especially from dust and rainfall, then releasing them slowly over a much longer period than normal nutrient residency near the soil surface (Stewart 1977; Rieley *et al.* 1979; Scafone unpubl. data).

Figure 3. ***Aulacomnium palustre***. Species of ***Dicranum*** used by the Shuswap Indians of North America to condition the soil for plant growth. Photo by Michael Lüth, with permission.

Figure 4. ***Dicranum scoparium***. Species of ***Dicranum*** used by the Shuswap Indians of North America to condition the soil for plant growth. Photo by Janice Glime.

Their ability to sequester nutrients varies with species and type of nutrient. For most taxa, they do not compete for soil nutrients like phosphorus, but can accumulate from rainfall the potassium, magnesium, and calcium (Timmer 1970). When the mosses later dehydrate, their membranes are damaged, making them leaky. When they rehydrate, nutrients can be dissolved and washed into the soil. It takes a few hours to a day to repair the damaged membranes, giving the roots beneath a chance to retrieve the nutrients that are slowly being washed down from the dusty, leaky mosses. This is dependent also on the force of the rain, with light rains more likely to remain on the mosses long enough for them to absorb the nutrients. This seems to be especially important for potassium, the most soluble and most easily leached nutrient. (See Nutrient chapter in Volume 1 for details.)

Peat, in particular, offers a number of properties important to the growth of plants. To be suitable for most root growth, the peat needs to have about equal proportions of air and water retention. The Peat Research Institute determined that the inclusion of shrubs and cotton grass

from the field site could make the peat inconsistent and alter the water-holding capacity and aeration needed for good plant growth. Therefore, they recommended that the proportion of subshrub residues not exceed 3% wet weight, that the proportion of cotton grass and sedge residues not exceed 6%, and that the proportion of ***Sphagnum*** (Figure 1) residues be at least 90% (Puustjarvi 1982).

In remote places, including national parks, remote villages, and other places where sewage systems are not in place, peat may be mixed with human waste to form compost (Wikipedia 2017). The extra aeration provided by the spaces among the peat plants helps the process of breaking down the sewage. Nevertheless, human pathogens can be a problem, with the greatest of these being *Ascaris* eggs (a nematode parasite; Figure 5-Figure 6) (Hill 2013). A long time or high temperatures are needed to destroy these pathogens. Berger (2011) claims that the compost should be free of live pathogens after at least two weeks at 55ºC or one week at 60ºC.

Figure 5. ***Ascaris*** larva hatched on microscope slide, a genus of parasitic worms of concern in human feces. Photo by SuSanA Secretariat, through Creative Commons.

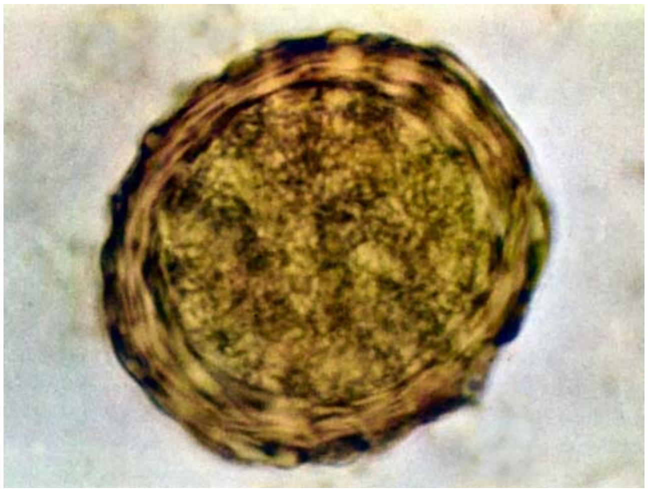

Figure 6. ***Ascaris lumbricoides*** fertilized egg. Presence of these in human feces is of concern when the feces are mixed with peat as a plant growth medium. Photo by Graham Colm, through Creative Commons

In England, the Wye College, University of London, and Southern Water have cooperated to develop a compost that takes advantage of sewage, mixed with peat mosses, providing a valuable soil conditioner and slow-release fertilizer that can be used for container-grown plants (Lopez-Real *et al.* 1989).

One use for the nasty-smelling fish offal takes advantage of the absorptive properties of ***Sphagnum*** (Figure 1) to create a superior compost (Martin & Chintalapati 1990), a real boon for getting rid of fish waste. And, when mixed with fish processing wastes, peat mosses are superior to sawdust and wood shavings in conserving nitrogen, but are a bit more expensive (Liao *et al.* 1995).

Martin (1992) considered that it should be an easy and inexpensive process to use fish by-products (fish offal) with ***Sphagnum*** (Figure 1) peat as a substrate to grow microorganisms for submerged fermentation. Martin conducted experiments on growing fungi and yeast as potential sources of microbial biomass protein for feeding animals. These products, which the fish were willing to include in their diet, served successfully as proteinaceous food for feeding farmed fish.

One of the microorganisms tested was the acid-tolerant fungus ***Scytalidium acidophilum*** (Figure 7) (Martin & Chintalapati 1989). Martin and Chintalapati found that the culture did not produce any better concentration of the fungus dry weight than when they used a diluted ***Sphagnum*** (Figure 1) peat hydrolysate as the substrate source. Martin and Chintalapati (1990) considered that the higher production of nutrients such as nitrogen in the fish offal mixed with peat made this a "promising" source of protein produced by ***Scytalidium acidophilum***.

Figure 7. ***Scytalidium*** sp. ***Scytalidium acidophilum*** is a promising source of protein when grown in fish offal with peat. Photo by Gerardo Garcia-Aguirre, Virginia Vanzinni-Zago, Hugo Quiroz-Mercado, through Creative Commons.

Johnson *et al.* (1992) similarly worked with people from the Wisconsin Sea Grant Inst to find a suitable use for fish by-products to provide a useful compost. They found that the wide range of values for the C:N ratios and other properties related mostly to the initial C:N ratio and the time the mix of peat and fish by-products had been allowed to cure. The ***Sphagnum*** (Figure 1) peat fish by-product composts, especially those with higher C:N ratios, compared well with commercial fertilized mixes.

As with human waste, destruction of pathogens is important for the fish waste, but Liao and coworkers (Liao 1997; Liao *et al*. 1997) found that the rise in temperature during composting, plus the ammonia and volatile fatty acids produced, were sufficient to destroy the pathogens. Addition of fir (*Abies*) or alder (*Alnus*) chips (Figure 8) caused the compost to stabilize sooner.

Figure 8. Wood chips like those used to stabilize the fish offal/***Sphagnum*** compost and destroy pathogens. Photo through Creative Commons.

The addition of ***Sphagnum fuscum*** (Figure 9) peat to hog manure reduced the volatile loss of ammonia, a primary source of nitrogen, by 75%, mainly due to lowered *p*H, making it a more suitable fertilizer (Al-Kanani *et al*. 1992a). It offers the added advantage of preventing release of offensive odors caused by 1,2-ethanediamine, methyl hydrazine, N-methyl methanamine, 3-methyl 2-butanamine, ethanethioic acid, and methanethiol (Al-Kanani *et al*. 1992b).

Figure 9. ***Sphagnum fuscum*** combined with hog manure makes a suitable fertilizer high in nitrogen. Photo by Michael Lüth, with permission.

Rao and Burns (1990) found yet another way of providing nitrogen in the culture of oil-seed rape. They provide **Cyanobacteria** (nitrogen fixers; Figure 10) and bryophytes in the growing medium. Bryophytes are well known for their ability to harbor **Cyanobacteria**.

Miller (1981) found that bryophytes can even increase the buffering capacity of the soil, surprisingly even against the abrupt changes resulting from fertilizer. And as a mulch, the slow decomposition of peat mosses makes them much more long-lasting than leaf litter and compost.

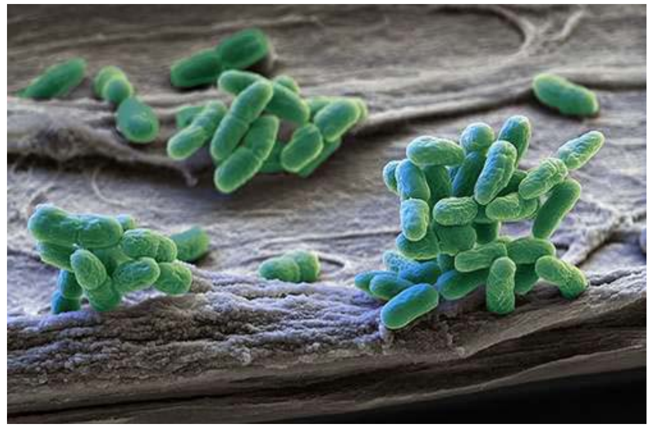

Figure 10. SEM image of ***Synechocystis*** (***Cyanobacteria***) on substrate. Photo from BASF, through Creative Commons.

Mosses such as ***Sphagnum*** (Figure 1) retain moisture and prevent weed growth, while at the same time discouraging damping-off fungi (Miller & Miller 1979).

Culturing

Some mosses, for example the epiphytic ***Octoblepharum albidum*** (Figure 11), are especially suitable for growing hard-to-grow epiphytic ferns (Arzeni 1963). In the Philippines, ***Leucophanes octoblepharioides*** (see Figure 12) and other members of the family are used by gardeners and plant growers instead of peat moss in potting new plants (Ben C. Tan, pers. comm.). ***Leucobryum*** (Figure 13) is a suitable medium for inducing good root sprouts on orchid cuttings, sold at U.S. $0.50 per kilo (in 1963), increased to US $1 in 1986 (Tan 2003). The most popular moss medium for growing orchids, most of which are likewise epiphytes, is ***Sphagnum*** (Figure 1), but mosses like ***Homalothecium arenarium*** (Figure 14), ***Hypnum imponens*** (Figure 15-Figure 16), ***Leucobryum*** spp. (Figure 13), ***Rhytidiopsis robusta*** (Figure 17), and ***Thuidium delicatulum*** (Figure 18) are also useful (Perin 1962; Adderley 1964, 1965). Chen and Chang (2000a, b) had almost 100% survival success when growing the orchid *Oncidium* (Figure 19) from callus explants on ***Sphagnum*** peat. Whereas most of their culture media produced abnormal shoots, both embryo-and shoot-bud-derived regenerants developed into healthy plantlets when potted in ***Sphagnum*** and acclimatized in the greenhouse.

Figure 11. ***Octoblepharum albidum***, a moss suitable for growing hard-to-grow epiphytic ferns. Photo by Niels Klazenga, with permission.

Figure 12. ***Leucophanes*** sp. ***Leucophanes octoblepharioides*** is used instead of peat moss in the Philippines for planting new plants. Photo by Niels Klazenga, with permission.

Figure 13. This epiphytic species of ***Leucobryum*** demonstrates its suitability for supporting root growth by hosting an epiphytic fern. Photo by Janice Glime.

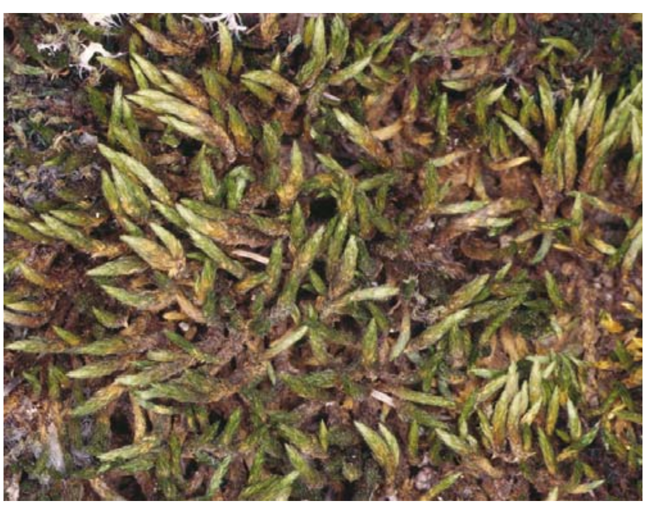

Figure 14. ***Homalothecium aureum*** may be used as a substitute for peat in potting young plants. Photo by Jan-Peter Frahm, with permission.

Figure 15. ***Hypnum imponens*** growing in a sheet on a log. Photo by Janice Glime.

Figure 16. ***Hypnum imponens***, a moss that may be used as a substitute for peat in potting young plants. Photo by Janice Glime.

Figure 17. ***Rhytidiopsis robusta***, a moss that may be used as a substitute for peat in potting young plants. Photo by Blanka Shaw, with permission.

Figure 18. ***Thuidium delicatulum***, a moss that may be used as a substitute for peat in potting young plants. Photo by Janice Glime.

Figure 19. New ***Oncidium*** hybrid pseudobulb that must form a mycorrhizal connection. Photo by Consuelo Tugnoli, through Creative Commons.

But one consideration is that orchids are **mycorrhizal** (see Figure 20). That means they require an appropriate fungal partner in order to successfully form plants from seeds or cuttings. Kreier (2003) reasoned that a fungus that was mycorrhizal to bryophytes might be a good place to find a proper associate for the orchids. Several members of the liverwort family **Aneuraceae** (Figure 21) are mycorrhizal in association with the fungal genus ***Tulasnella*** (Figure 21-Figure 22). Kreier reasoned that if the orchids have the same mycorrhizal fungi, then it should be possible to use those liverwort associations to inoculate the orchids with mycorrhizae from the liverworts. Oberwinkler *et al*. (2017) reported ***Tulasnella*** species are worldwide and likewise are associated with orchids on a global scale. The possibilities look good.

Figure 20. Mycorrhizal root tips of an ***Amanita*** mushroom, partnering with a tree. Photo by Ellen Larsson, R. Henrik Nilsson, Erik Kristiansson, Martin Ryberg, and Karl-Henrik Larsson, through Creative Commons.

Figure 21. ***Cryptothallus*** (white; in **Aneuraceae**) and ***Pinus pinaster-Tulasnella*** ectomycorrhizae. Photo courtesy of Martin Bidartondo.

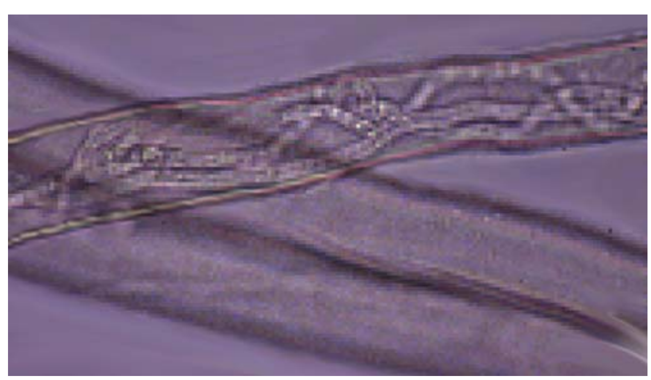

Figure 22. ***Cryptothallus*** rhizoids colonized by ***Tulasnella*** hyphae in a microcosm. Photo courtesy of Martin Bidartondo.

Air Layering

Horticulturists may have learned some lessons from nature. Mosses in nature provide suitable media for air layering of plants like the heath shrub *Calluna* (Figure 23) (Scandrett & Gimingham 1991; MacDonald *et al*. 1995) and even some tropical trees. MacDonald and coworkers (1995) demonstrated that layering was actually associated with the absence or low abundance of the mosses ***Hypnum cupressiforme*** (Figure 24) and ***H. jutlandicum*** (Figure 25) and *Cladonia* lichens (*e.g.* Figure 26). On the other hand, there seems to be a weak connection with layering in ***Sphagnum*** spp. (Figure 1), ***Leucobryum glaucum*** (Figure 27), and pleurocarpous mosses other than ***Hypnum***.

Figure 23. *Calluna vulgaris*, a species that undergoes air layering in mosses in nature. Photo by Willow, through Creative Commons.

Figure 24. ***Hypnum cupressiforme***, a moss that is negatively associated with air layering of *Calluna* in nature. Photo by Michael Lüth, with permission.

Figure 25. ***Hypnum jutlandicum***, a moss that is negatively associated with air layering of *Calluna* in nature. Photo by Janice Glime.

Figure 26. ***Cladonia fimbriata***, a moss that is negatively associated with air layering of *Calluna* in nature. Photo by Paul Cannon, through Creative Commons.

Figure 27. ***Leucobryum glaucum***, a moss that can contribute to air layering of *Calluna*. Photo by Janice Glime.

Despite these somewhat weak connections for ***Calluna*** (Figure 23), mosses, especially ***Sphagnum*** (Figure 1), are used almost exclusively for air layering as a means of propagation of plants. The moss is wrapped (Figure 28) around the area where roots (Figure 29) are to be encouraged, often held in place with cloth mesh, wire, or dark plastic (Figure 30). The moss provides a continuous supply of moisture and encourages the development of adventitious roots while discouraging fungi. Once the roots have formed, the stem can be cut below that point and the explant grown into a new individual (Figure 31). Pant (1989) reports similar use for grafting fruit trees.

Figure 28. Wrapping the tree with ***Sphagnum*** for air layering to make a bonsai. Photo from Bonsai Eejit, through Creative Commons.

Figure 29. Removal of part of the air layer, exposing roots and new branches of a bonsai. Photo from Bonsai Eejit, through Creative Commons.

Figure 30. Bonsai showing air layering with ***Sphagnum***. Photo from Bonsai Eejit, through Creative Commons.

Figure 31. Air layer of oak using moss to make bonsai. Photo from Bonsai Eejit, through Creative Commons.

In addition to its ability to promote root sprouts in orchid cuttings, ***Sphagnum*** (Figure 1) is suitable for air layering of a number of kinds of plants, including trees for bonsai (Tan 2003). The moisture and antimicrobial properties are beneficial in the development of new shoots and roots.

It appears that preparing a tree for bonsai often involves air layering with mosses (Morrow 2001; Hasegawa 2002; Relf 2009). In their book on bonsai, Yoshimura and Halford (1957) provide instructions for making a bonsai. Mosses, usually ***Sphagnum*** (Figure 1), are wrapped around the stem, including a location with young buds, and covered with a material like plastic to retain the moisture. If the plastic is transparent, you can see when the new roots and branches have formed. The lower part of the old stem is then cut off and the layering removed. The bonsai is ready for planting.

Figure 33. Potted *Fuchsias*, a genus whose growth is encouraged by potting with mosses in the mix. Photo by pxhere, through Creative Commons.

Pot Culture

Mosses can also encourage growth of potted plants. Pant (1989) reports that *Begonia* (Figure 32) and *Fuchsia* (Figure 33) bud and flower more profusely in pots where mosses are used to separate the humus-rich top soil from the bottom soil. Members of the Ericaceae, in particular, benefit from the acid of peat mosses. But in Japan, ***Hypnum plumaeforme*** (Figure 34), ***Leucobryum bowringii*** (Figure 35), ***L. neilgherrense***, and occasionally ***L. scabrum*** (Figure 36) fragments are used, mixed with sand or soil, to cultivate *Rhododendron* (Figure 37) shrubs (Ando 1957). Could it be that these mosses also acidify the soil?

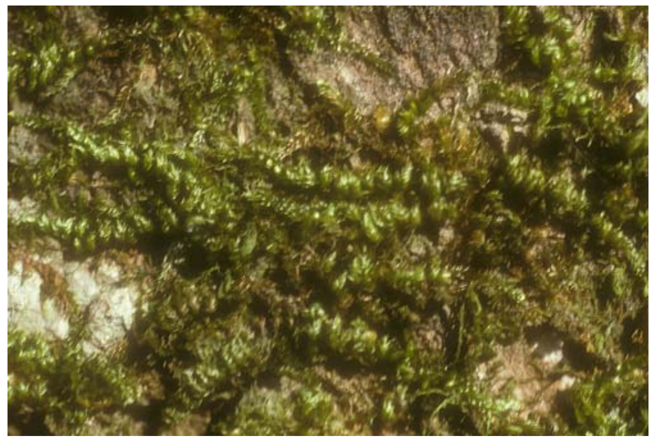

Figure 34. ***Hypnum plumaeforme***, a species used in Japan with sand or soil to cultivate *Rhododendron* shrubs. Photo by Janice Glime.

Figure 32. Potted begonias, a genus whose growth is encouraged by potting with mosses in the mix. Photo by Pixabay, through Creative Commons.

Figure 35. ***Leucobryum bowringii***, a species used in Japan with sand or soil to cultivate *Rhododendron* shrubs. Photo through Creative Commons.

Figure 36. ***Leucobryum scabrum***, a species used in Japan with sand or soil to cultivate *Rhododendron* shrubs. Photo Taiwan Encyclopedia of Life, through Creative Commons.

Figure 37. *Rhododendron*, a genus that benefits from having mosses in the potting mix. Photo by Pete Bobb, through Creative Commons.

The forestry industry likewise finds peat invaluable for culturing young seedlings (see also Reforestation below). Heiskanen and Rikala (2000) found ***Sphagnum*** (Figure 1) peat to be superior to fine sand or peat with perlite, the latter resulting in more weakened seedlings as a consequence of the lower water retention of the medium. However, peat is not always readily available. Israeli researchers found that composted cattle manure mixed with grape marc were good substitutes for peat in that country where peat must be imported; the substitutes were likewise effective at suppressing plant pathogens (Chen *et al*. 1992).

In other cases, the pots themselves (Figure 38) are made of mosses. These are good for starting seedlings and can be planted without removing the plants. Roots will eventually penetrate the pot and grow into the soil.

Figure 38. 3-Inch Jiffy pot of peat moss fibers from Second Sun Garden Supply. Photo from Second Sun Garden Supply, modified by Janice Glime.

Potting Medium

In parts of Asia, horticultural mosses include ***Vesicularia*** (Figure 39), ***Bazzania*** (Figure 40), ***Heteroscyphus*** (Figure 41), and ***Pallavicinia*** (Figure 42) (Tan 2003). Orchid growers in particular use ***Leucobryum*** (Figure 35-Figure 36, Figure 43) and ***Sphagnum*** (Figure 1, Figure 44), especially for their ability to store large amounts of water in their **hyaline cells** (Figure 43-Figure 44).

Figure 39. ***Vesicularia vesicularis*** var. ***vesicularis***. The genus ***Vesicularia*** is among the horticultural mosses in Japan. Photo by Michael Lüth, with permission.

Figure 40. ***Bazzania trilobata***, a leafy liverwort. The genus ***Bazzania*** is among the horticultural bryophytes used in Japan. Photo by Ondřej Zicha (Discover Life), through Creative Commons.

Figure 41. ***Heteroscyphus fissistipus***, a leafy liverwort. The genus ***Heteroscyphus*** is among the horticultural bryophytes used in Japan. Photo by David Francis, through Creative Commons.

Figure 42. ***Pallavicinia lyellii***, a thallose liverwort. The genus ***Pallavicinia*** is among the horticultural bryophytes used in Japan. Photo by Des Callaghan, with permission.

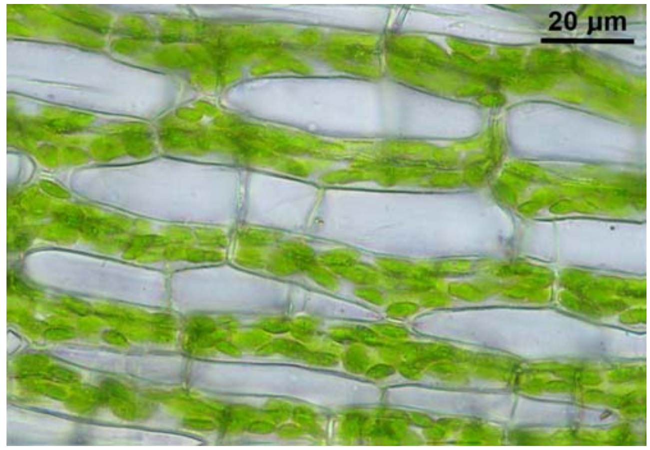

Figure 43. ***Leucobryum glaucum*** leaf cells showing alternating hyaline and photosynthetic cells. Photo by Ralf Wagner <www.drralf-waner.de>, with permission.

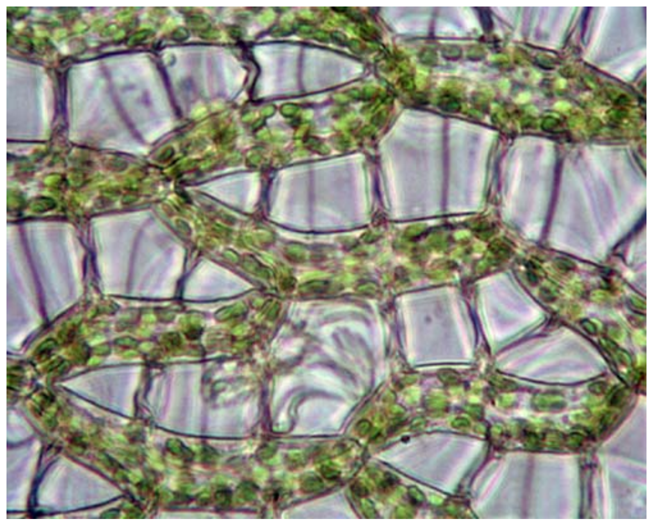

Figure 44. ***Sphagnum palustre*** photosynthetic (green) and hyaline cells. Note that the hyaline cells are not short cells, but are elongate cells with bars across them. Photo by Malcolm Storey through Creative Commons.

Sphagnum (Figure 1) and ***Leucobryum*** (Figure 35-Figure 36) seem to be particularly preferred as a potting medium for orchids (Tan 2003). Tan reported the use of ***Leucobryum*** as a substitute for peat moss to grow orchid cuttings in Asia. The mosses, especially ***Sphagnum***, were good as a potting medium for a variety of seeds.

But in North America, diversity of mosses as a potting medium seems to be absent. I searched with Google for "potting medium moss" and stopped after the 20th hit. All 20 of the mosses were named as peat moss or ***Sphagnum*** (Figure 1).

Dangers of Peat Culturing

There are drawbacks to using mosses in culturing of some plants. We have seen that ***Sphagnum*** (Figure 1) can be dangerous because of its cohabiting fungus that causes **sporotrichosis** (Chapter 1 of this volume). In containers of conifer seedlings, they can choke young seedlings, compete for nutrients, and repel water (Haglund *et al*. 1981). But they can also pose serious dangers. But causing fires? As Michael Richardson shared with Bryonet on 20 June 2013,

peat, including shrubs and other debris along with the mosses, is good potting material, but it can be flammable under the wrong circumstances. The oxygen available in the pot can permit decay to occur, causing heat that is amplified if the pot is in the sun. An article in the *Northumberland News* reported a house fire in June 2013 that was attributed to a pot with peat mosses on a second floor balcony. The deputy chief of the fire department said that the dry peat can easily ignite and can, after being in direct sunlight long enough, ignite by itself. This was not his first experience with flower beds on fire. His advice is to use non-combustible flower pots (not plastic), such as concrete or metal.

Covering Pot Soil

Sheet mosses are frequently used to cover the soil in pots housing flowering plants (Nelson & Carpenter 1965). This is especially true when they are sold by florists. Species of ***Leucobryum*** (not a sheet moss; Figure 35-Figure 36) can be used for this purpose, providing a pale green color contrast to the green of most tracheophyte leaves. In some cases, the strong anti-microbial properties of bryophytes might reduce invasions of bacteria and fungi.

Mat-forming mosses are typically sold as sheet mosses (Figure 45) (Peck *et al*. 2001). These are pleurocarpous mosses that grow horizontally, often on logs. Collectors strip the logs, and sometimes low branches, of their mats. In the eastern USA, one of the mosses used is ***Thuidium*** (Figure 46).

Figure 45. A package of sheet moss being sold in a gardening shop in Ohio, USA. Photo by Janice Glime.

Figure 46. ***Thuidium*** sheet moss, sold at a gardening shop in Ohio, USA. Photo by Janice Glime.

Culturing Mushrooms and Other Fungi

Sphagnum (Figure 1) peat is the substrate of choice as casing medium for cultivating the common grocery store mushroom, *Agaricus bisporus* (Figure 47) (Eicker & van Greuning 1989; Reddy & Patrick 1990; Jarial *et al*. 2005). (Casing is the process in which a non-nutritious layer, in this case peat, is applied over the colonized substrate so that the mycelium has access to more moisture, thereby increasing the size and number of growths.) Sungrow had a multi-million-dollar contract from Campbell (of Campbell soup fame) to improve mushroom culturing using a ***Sphagnum*** mix (Vitt, pers. comm.; Miller 1981). However, in places such as South Africa, where there is no peat, substitutes are necessary. The need for peat substitutes led Eicker and van Greuning (1989) to test other substrata and compare, but peat still gave the highest yields compared to eight other materials, with only weathered, spent compost offering similar results. Other types of mushrooms are grown in peat as well, such as *Pleurotus ostreatus* (Figure 48) (Manu-Tawiah & Martin 1986).

Figure 47. *Agaricus bisporus*, a species commonly grown in ***Sphagnum***. Photo by I. G. Safonov, through Creative Commons.

Figure 48. ***Pleurotus ostreatus*** on a mossy tree trunk. This species can be cultivated in peat. Photo from Charl de Mille-Isles.

In an attempt to make further improvements in mushroom success, Beyer (1997) sought ways to reduce the effect of accumulated substances on late mushroom crops. Surprisingly, he found that the addition of ***Hypnum*** (Figure 15-Figure 16, Figure 24-Figure 25) peat to the compost improved later break yield, but the addition of ***Sphagnum*** (Figure 1) did not. One of the concerns is that the peat becomes infested with nematodes (Figure 49) and may carry *Pseudomonas tolaasii* (see Figure 50), the cause of bacterial blotch, both of which cause serious diseases to the mushrooms (Nikandrow *et al*. 1982).

Figure 49. Soil nematode, a common pest in ***Sphagnum*** that may carry the bacterium ***Pseudomonas tolaasii***. Photo by Christina Menta, through Creative Commons.

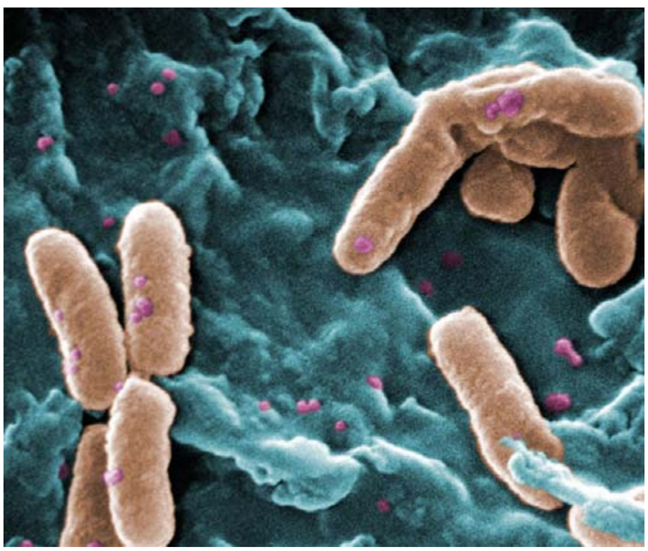

Figure 50. *Pseudomonas*, a bacterium carried by soil nematodes. Photo by Janice Carr, through public domain.

Martin and Bailey (1983) succeeded in using peat as a fermentation medium in which acclimated fungi could be grown. They were more successful with the common mushroom *Agaricus campestris* (Figure 51) than with the morel *Morchella esculenta* (Figure 52) (Martin 1982). Martin and Bailey considered that growth inhibitors might be present in peat. Using sulfuric acid hydrolysates with autoclaved peat released a liquid that, when supplemented with nutrients, would enhance growth and crude protein content of these two edible fungi. Nutrient-supplemented peat hydrolysates enhance growth and crude protein content of fungal biomass.

Figure 51. ***Agaricus campestris***, a species that grows well in a peat fermentation medium. Photo by Andreas Kunze, through Creative Commons.

Figure 52. *Morchella esculenta*, the common morel, can be cultured in a bed of peat. Photo by Janice Glime.

A mixture of ***Sphagnum*** (Figure 1) with fish offal promises to be a suitable substrate for culturing the acid-tolerant fungus *Scytalidium acidophilum* (see Figure 7), which is considered to be a promising source of microbial protein (Martin & Chintalapati 1990). However, not all fungal cultures seem to benefit from peat mixtures. In one commercial operation, the yield of mushrooms improved when the peat was omitted from the cultivation medium (Smith 1983).

Reforestation

The genus ***Tulasnella*** (Figure 21-Figure 22) is a mycorrhizal partner with several members of the thallose liverwort family **Aneuraceae** (Figure 21). If this fungus is likewise a partner with trees, then it should be possible to use those liverworts to help the trees to become established (Kreier 2003). In fact, ***Cryptothallus*** (Figure 21), a member of the **Aneuraceae**, shares its fungal partner with at least some members of the birch (*Betula*; Figure 53) and pine (*Pinus*; Figure 54) genera. Kreier found that both liverworts ***Riccardia palmata*** (Figure 55) and ***R. latifrons*** (Figure 56) grew on rotten wood and were well infected by

mycorrhizal fungi. Kreier also figured it would be relatively easy to disperse these liverworts on the forest floor, and that they would spread easily, preparing the soil with mycorrhizae that could partner with the trees. At that time, the fungi had been grown in culture but not the field. However, the discovery of rhizoidal bridges in tropical ***Aneura*** (**Aneuraceae;** Figure 57) provided a hopeful twist. In 2017, Oberwinkler *et al*. noted that ***Tulasnella*** species are worldwide in distribution and that they may occur in many forest ecosystems in association with wood. And we have already noted that they form mycorrhizal associations with orchids.

Figure 53. *Betula pendula*. Some members of the genus *Betula* share their fungal partner with the thallose liverwort ***Cryptothallus***. Photo by Percita, through Creative Commons.

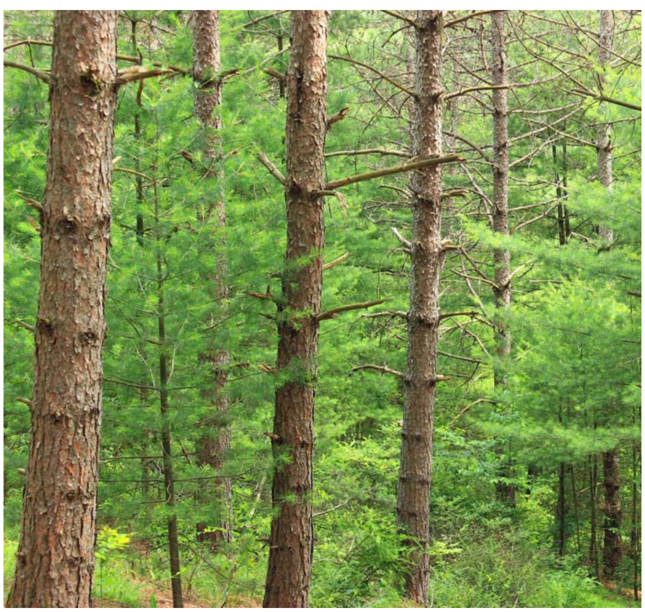

Figure 54. *Pinus strobus*. Some members of the genus *Pinus* share their fungal partner with the thallose liverwort ***Cryptothallus***. Photo through Creative Commons.

Figure 55. ***Riccardia palmata***, a species that grows on rotten wood and is infected by mycorrhizal fungi. Photo by Bernd Haynold, through Creative Commons.

Figure 56. ***Riccardia latifrons***, a species that grows on rotten wood and is infected by mycorrhizal fungi. Photo by Bernd Haynold, through Creative Commons.

Figure 57. ***Aneura pinguis***, a species that might be associated with ***Tulasnella*** on wood. Photo by Li Zhang, with permission.

Container Gardens

Mosses are commonly used in container gardens with **bonsai** (dwarfed ornamental tree; Figure 58) and **bonkei** (tray landscape; Figure 59), where they help to stabilize the soil and retain moisture for the shallow roots.

Figure 58. Bonsai at Dawes Arboretum, Ohio, USA, showing dwarfed tree and mosses at base. Photo by Janice Glime.

Figure 59. Outdoor bonkei in a Japanese private garden. *Selaginella*, a relative of club mosses and not a true moss, is used to represent a tree, with mosses growing on the rocks that form the basin for a small "lake." Photo by Janice Glime.

Designers select the species of mosses to serve particular functions in the container landscapes. Large, upright mosses such as ***Atrichum*** (Figure 60), ***Climacium*** (Figure 61), ***Dicranum*** (Figure 4), ***Polytrichum*** (Figure 62), and ***Rhodobryum*** (Figure 63) simulate forests. ***Bryum argenteum*** (Figure 64) has a silvery, compact look that can simulate grasslands, and ***Leucobryum*** (Figure 27) usually has the role of a mountain. For snow-capped mountains, ***Racomitrium canescens*** (Figure 65) provides a frosted look. ***Physcomitrium*** (Figure 66-Figure 67), often a volunteer in greenhouse flower pots, is so miniature as to appear like a moss, or maybe a grass, in a landscape of ***Leucobryum*** mountains. ***Barbula unguiculata*** (Figure 68), ***Funaria hygrometrica*** (Figure 69), and ***Weissia controversa*** (Figure 70) can contribute to needs of intermediate size. In Mexico, some mosses are even used for fake bonsai: ***Campylopus*** (Figure 71), ***Dendropogonella rufescens***, ***Hypnum*** (Figure 15-Figure 16, Figure 24-Figure 25, Figure 34), and ***Thuidium*** (Figure 18) (C. Delgadillo, pers. comm.). In the Pacific Northwest of North America, ***Leptobryum pyriforme*** (Figure 72), known as Kyoto moss, is sold for bonsai trays (J. Christy, pers. comm.). I would expect ***Climacium*** and ***Polytrichum*** to serve well as trees in miniature landscapes as well.

Figure 60. ***Atrichum angustatum***, in a genus used to simulate forests in tray gardens. Photo by Keith Bowman, with permission.

Figure 61. ***Climacium dendroides***, simulating trees in a dish garden. Photo by Keith Bowman, with permission.

Figure 62. ***Polytrichum juniperinum***, in a genus used to simulate forests in tray gardens. Photo by Janice Glime.

Figure 63. ***Rhodobryum roseum***, in a genus used to simulate forests in tray gardens. Photo by Michael Lüth, with permission.

Figure 64. ***Bryum argenteum***, a species used to simulate grasslands or mountains in tray gardens. Photo by Tushar Wankhede, with permission.

Figure 65. ***Racomitrium canescens***, a moss that is used to simulate snow on mountains. Photo by Michael Lüth, with permission.

Figure 66. ***Physcomitrium pyriforme*** in a dish garden. Photo by Michael Lüth, with permission.

Figure 67. ***Physcomitrium pyriforme*** with capsules, a common volunteer in flower pots. Photo by Janice Glime.

Figure 68. ***Barbula unguiculata***, a moss of intermediate size to fill in as grass or other intermediate needs. Photo by Michael Lüth, with permission.

Figure 69. ***Funaria hygrometrica***, a moss of intermediate size to fill in as grass or other intermediate needs. Photo by Michael Lüth, with permission.

Figure 70. ***Weissia controversa***, a moss of intermediate size to fill in as grass or other intermediate needs. Photo by Michael Lüth, with permission.

Figure 71. ***Campylopus introflexus***; the genus ***Campylopus*** is used in Mexico for fake bonsai. Photo by Michael Lüth, with permission.

Figure 72. ***Leptobryum pyriforme***, a species that is used in the Pacific Northwest, USA, in bonsai trays. Photo by Michael Lüth, with permission.

Bonkei

Miniature tray landscapes [bonkei or **saikei** (art of creating tray landscapes that combine miniature living trees with soil, rocks, water, and related vegetation); Figure 73-Figure 76] in Japan use mosses to provide appropriate texture and color with little danger of damage due to drying (Kawamoto 1980; Oishi 1981). Such trays can delight the bed-ridden. Gerritson (1928) arranged sixteen species of mosses in various stages of maturity to provide a changing landscape for a hospitalized friend: "Each day the mosses had changed appearance; so each day added a new joy. The nurses came from time to time to see and admire. Other patients shared its freshness and beauty. Visitors, too were invited to see the charm of a 'platter of mosses.'"

Figure 73. Bonkei with its miniature landscape containing mosses to simulate mountains. Photo courtesy of Hironori Deguchi.

Figure 74. Bonkei with mosses simulating trees with a rocky crag. Photo courtesy of Hironori Deguchi.

Figure 75. Bonkei simulating a volcano and surrounding mountains and forests. Photo courtesy of Hironori Deguchi.

Figure 76. *Selaginella* (a club moss relative) and moss bonsai, Kyushu, Japan. Photo by Janice Glime.

For making these miniature landscapes, Schenk (1997) recommends the usual potting mix of humus, including peat moss, ground-up tree bark, or rotted sawdust. He cautions that sand, vermiculite, or perlite can be used, but that they must be kept moist because they tend to have larger spaces and dry quickly near the surface, leaving the moss with no source of moisture.

Even in this seemingly harmless occupation, one must use caution against allergens. Tray gardens and other forms of bonsai and dish gardens may use ***Sphagnum*** (Figure 1) peat as a medium or even as the plants of interest (Figure 77). This moss is well known for its ability to harbor the fungus that causes sporotrichosis (Dong *et al*. 1995).

Figure 77. ***Sphagnum*** moss pot in Japan, a potential source of allergens. Photo courtesy of Hironori Deguchi.

Dish Gardens

Dish gardens (Figure 78) are a scaled down version of bonkei. The size may not be scaled down, but they typically do not represent a landscape and may have only one bryophyte species (Figure 78), sometimes as ground cover for flowering plants like spring bulbs (Figure 79).

Figure 78. Dish garden of moss. Photo courtesy of J. Paul Moore.

Figure 79. Dish garden for spring bulbs in cafe in Helsingborg, Sweden. Photo courtesy of Irene Bisang.

Figure 80. A cross between a bonsai arrangement and a dish garden. Photo courtesy of Lars Hedenas and Irene Bisang.

Annie Martin, a prize-winning gardener and landscaper (Figure 81), runs classes for both adults and children in which she teaches them how to make dish gardens and terraria (Figure 82-Figure 83).

Figure 81. The award-winning creator (Annie Martin) of dish gardens, terrariums, and moss gardens is shown here framed by her own artistic bryophyte creation. Photo courtesy of Annie Martin.

Figure 82. Children creating their first dish garden, under the tutelage of Annie Martin, MountainMoss. Photo courtesy of Annie Martin.

Figure 83. The proud owner of a new dish garden that she created. Photo courtesy of Annie Martin.

Similar to the dish gardens, moss rocks (Figure 84-Figure 85) have become popular in some places. These typically have a species of moss growing in a depression or on the surface of a rock.

Figure 84. ***Dicranodontium denudatum*** stone pots in shop in Hakone, Japan. These are a variation on the dish garden, but the mosses are grown on the surface or in a depression of a natural rock and typically have only one moss species. Photo courtesy of Hironori Deguchi.

Figure 85. Moss-Rocks-logo at Moss and Stone Gardens, Pennsylvania, USA, showing a more formal American version. Photo with permission from David Smith.

Bonsai

The term **bonsai** (Figure 86) refers to a dwarfed ornamental tree or shrub grown in a pot and prevented from reaching its normal size. Inoue (1972) pointed out that moss bonsai and moss bonkei (tray landscapes) are popular in Japan by both amateurs and professional horticulturists. But even bonsai trees are potted in wide pots and the soil is typically covered with mosses (Figure 86-Figure 89).

Figure 86. Bonsai at Dawes Arboretum, Ohio, USA, showing the dwarfed tree and mosses at its base. Photo by Janice Glime.

Figure 87. This bonsai arrangement incorporates features of bonkei with rocks and mosses giving it the look of a miniature forest. Photo by Janice Glime.

Figure 88. Bonsai at Dawes Arboretum, Ohio, USA. This bonsai uses a deciduous tree, and bryophytes can warn its owner to water it before the leaves begin to drop or become crispy. Photo by Janice Glime.

Figure 89. Bonsai using the fern ***Osmunda lancea***. Courtesy of Hironori Deguchi.

The mosses can contribute to the success of the bonsai. When the mosses appear dry, you can be sure your bonsai needs water (Figure 90-Figure 91). However, mosses are not always the friends of the bonsai. The continuous moisture of the mosses can inhibit root growth and promote sudden fungal attacks. The experts advise removing the mosses each autumn to reduce fungal damage (Bland 1971).

Figure 90. Bonsai in Dawes Arboretum, Ohio, USA. Mosses on the roots are a good indicator when the soil is becoming dry and the tree needs water. Photo by Janice Glime.

Figure 91. Bonsai on wood, increasing the need for bryophytes to maintain root moisture and warn when it is time to water it. Photo courtesy of Annie Martin, MountainMoss.

In India, bonsai is included in horticultural texts. Dhanda (1984) suggests that the bonsai may be finished off with a layer of moss on top (Figure 92). Yoshimura and Halford (1957) likewise consider the mosses growing around the bonsai to be important. The mosses provide several advantages. They add aesthetic appeal, creating a more natural looking landscape. And they make watering easier, permitting a raised base on the tree while catching the water and protecting the furniture.

Figure 92. Bonsai at Dawes Arboretum, Ohio, USA, illustrating mosses covering the pot and signalling when the tree roots need more water. Photo by Janice Glime.

In Malaysia, bonsai makers typically use the acrocarpous mosses ***Bryum*** (Figure 93) and ***Philonotis*** (Figure 94), and sometimes the pleurocarpous mosses ***Isopterygium/Pseudotaxiphyllum*** (Figure 95) and ***Vesicularia*** (Figure 39) and the thallose liverwort ***Riccia*** (Figure 96) (Tan 2003). In Singapore, the moss ***Ochrobryum kurzianum*** is imported from Thailand for ornamental use in bonsai arrangements. In Japan, ***Leucobryum*** (Figure 27) is common in bonsai landscape design.

Figure 93. ***Bryum capillare*** with capsules, in a genus used in bonsai in Malaysia. Photo by Michael Lüth with permission.

Figure 94. ***Philonotis fontana***, in a genus used in bonsai in Malaysia. Photo by Michael Lüth, with permission.

Figure 95. ***Pseudotaxiphyllum elegans***, in a genus used in bonsai in Malaysia. Photo by J. C. Schou, with permission.

Figure 96. ***Riccia sorocarpa***, in a genus used in bonsai in Malaysia. Photo by <www.aphotofauna.com>, with permission.

Hanging Baskets

Mosses are often used in the construction of hanging baskets for flowers (Smith 1996). In California, USA, meter-long "strips" 8-10 cm wide are used to make hundreds of baskets per week!

In Asia, species of ***Sphagnum*** (Figure 1) are used to line hanging baskets (Tan 2003). Its ability to hold water and its antimicrobial activity make this a good substrate for the roots of flowering plants.

A wire frame is used to give the basket support, with mosses wound among the wires or laid within to provide the structure. Not only do they make an attractive, natural-looking basket, but they reduce the need for frequent watering (Lohr & Pearson-Mims 2001). Species of ***Hypnum*** (Figure 15-Figure 16, Figure 24-Figure 25, Figure 34) and ***Sphagnum*** (Figure 1) are commonly used for this purpose.

The long, stiff stems of ***Polytrichum*** (Figure 62) permitted the early Romans to weave it into baskets (Bland 1971), but these most likely did not have a horticultural purpose.

Terraria

The **terrarium**, a drier plant version of the aquarium, is often arranged like an enclosed garden (Figure 97), a miniature garden like the container gardens. Because of its small size, bryophytes are often used to give the look of mountains (Figure 98); dry brooks made of pebbles ramble between clumps of various hues of green. But bryophytes are not easy to grow in such conditions. If the container is fully open (Figure 98, Figure 99), mosses soon dry out and become crispy. If it is sealed (Figure 97, Figure 100-Figure 103), as many terraria are, fungi can easily grow. The best choice is to leave the top partially open to permit air circulation.

Figure 97. Closed terrarium from MountainMoss, showing miniature garden. Photo courtesy of Annie Martin.

Figure 98. Open terrarium from MountainMoss. Note the mound of ***Leucobryum*** which is sometimes used to simulate mountains. Photo courtesy of Annie Martin.

Figure 99. Open terrarium with moss. Photo courtesy of J. Paul Moore, with permission.

Figure 100. In some covered terraria, small holes with plugs, similar to the green ones seen here, can be opened and even kept open to maintain at least some air movement and reduce condensation. Photo courtesy of Annie Martin of MountainMoss.

Figure 101. Tiered terrarium from MountainMoss. Photo courtesy of Annie Martin.

Figure 102. Terrarium with lid. Note the tiny figure that turns the tall mosses into "trees." Photo by Erin, through Creative Commons.

Figure 103. Tall moss terrarium that not only permits taller plants like ferns, but also provides more air space, reducing fungal takeover. Photo by Ken Gergle, through David Spain.

It seems appropriate to cite the first terrarium, known as the **Wardian case** (Figure 104), invented by Nathaniel Bagshaw Ward (1791-1868) (Hershey 1996). He had fallen in love with plants on a trip to Jamaica and despite ultimately pursuing a profession as a physician, he pursued plants through his attempts at gardening. But, sadly, his attempts at a moss and fern garden failed, due severe air pollution in the outskirts of London. It was this failure that led him to invent the Wardian case, or terrarium. He had placed a "chrysalis" (actually a moth pupa) in a bottle and observed it daily. Then, to his surprise, a "seedling" fern and a grass appeared. He considered the conditions and noted the need for "a moist atmosphere free from soot or other extraneous particles; light; heat; moisture; periods of rest; and change of air." He moved the bottle to the outside of a northern window and there the plants thrived for four years with no additional attention!

Figure 104. Wardian Case, similar to the first terrarium by Nathaniel Bagshaw Ward. Image through public domain.

Choice of mosses depends in part on how moist you intend to keep it and in part on the effect you want to achieve. ***Polytrichum*** (Figure 62) can survive in a somewhat dry terrarium but will easily be covered with mold when it is too damp. Likewise, ***Leucobryum*** (Figure 27) likes it airy with good circulation. ***Ceratodon purpureus*** (Figure 105) is sometimes successful, again requiring at least some air circulation. Schenk (1997) states, "I must tell the whole truth by identifying the great enemy of terrarium gardening with native woodlanders, for there is one: mold." He admonishes that most terraria have a short life due to this problem. My own experience certainly agrees.

Figure 105. ***Ceratodon purpureus***, a species used in bonsai in Malaysia. Photo by Michael Lüth, with permission.

Funaria hygrometrica (Figure 69) can be encouraged in more moist conditions, but it still needs circulation. With a little luck it will even produce capsules. We successfully maintained ***F. hygrometrica*** in an uncovered aquarium in our university greenhouse. These lasted for several years, but we avoided getting tap water on them and only used misting from distilled water or tap water that had been allowed to sit to allow the chlorine to escape.

Schenk (1997) suggests that a container the size of an aquarium (Figure 106) is best, smaller ones being more subject to mold. Air space is of the essence, and it needs to circulate. He considers a potting mix to be suitable, whereas it does not tend to work well in open-air gardens. On the other hand, if the bryophytes have their own deep brown portions (Figure 107), no substrate is necessary. Charcoal may be added to the substrate to absorb excessive acidity and gases produced by decay. Little water is needed as it will recycle (Figure 108) within the nearly sealed container. Adding flowering plants can add color (Figure 109). Mosses that are collected wet generally do not need additional water and may even need to be dried by leaving the terrarium open wide for a day or two. Slightly dry mosses can be moistened with 30-35 ml (2-3 tablespoons) of water; totally dry ones may require up to 70 ml (1/4 cup) (Schenk 1997).

Figure 106. Kitchen terrarium in an aquarium. Photo by Janice Glime.

Figure 107. ***Campylopus flexuosus*** with brown base, needing no substrate. Photo by Michael Lüth, with permission.

Figure 108. Condensation on wall of kitchen terrarium, endangering a mold outbreak. Photo by Janice Glime.

Figure 109. Mix of a variety of plants with color (red-leafed *Begonias*, pale *Tillandsias*) and rocks in kitchen terrarium built in an aquarium. Photo by Janice Glime.

Maintenance for the first few days after planting is essential to avoid an immediate mold attack. Schenk (1997) advises that if a heavy dew (Figure 108, Figure 110) appears on the walls of the container, open it and dry the walls. This should be repeated daily until morning brings only a light condensation on the upper half of the walls of the container. When you discover, probably in a few weeks, that there is no longer any morning dew, it is time to add water, but not much.

Figure 110. Terrarium with moss, showing severe condensation that must be removed by drying the walls or keeping the container open until it is gone. Photo by J. Paul Moore, with permission.

After all this care, Schenk (1997) warns that the terrarium will most likely last only three weeks! (I have had better success than that with larger aquaria.) That can be extended by providing fluorescent lights to avoid the etiolated growth so noticeable in low light. Nevertheless, a mold garden is most likely to ensue within this short time,

and great care and luck are needed to find the right wetting and drying cycle.

Within those first few weeks, a moss garden terrarium can be full of surprises, with mushrooms appearing, capsules extending, and the somewhat rapid but unnatural elongation of the moss stems in low light.

One of the contributors to the demise of the moss terrarium indoors is the warm temperatures night and day indoors. If there is a cool location for the terrarium, it might survive a longer display, and surely in the refrigerator it would last, but would be of little use, not to mention suffering from lack of light.

One last caution I would insert is that lichens are to be avoided if one wishes to maintain a moss terrarium for any length of time. In the moist conditions of confinement, they will soon spread their fungi broadly and overtake the moss, albeit no longer as lichens, but nevertheless encroaching rapidly upon the surfaces of green. If lichens are to be enjoyed in this terrarium, it must by all means be kept open and the mosses provided with water occasionally as needed, perhaps with dry periods, but not too frequently.

I was relieved to read this moss gardener's treatment of the terrarium. If such an expert as Schenk was able to maintain such a terrarium garden for only three weeks, I felt elated that I, too, had succeeded on occasion to maintain one for so long! In short, if you wish to maintain a terrarium of bryophytes for a lengthy period of time, my best advice to you is Good Luck!

Echoing the comments above, David Wagner (Bryonet 23 June 2013) suggested that the problem with terraria is that they are usually closed containers. He has observed mosses doing well for several years in an open water table where water flowed across the water table. This depends on water that is low in dissolved minerals and may require a filtering system on tap water. One danger in closed terraria, especially small ones, is that the enclosed humidity and lack of air movement encourages the growth of fungi and soon they take over.

Alison Downing (Bryonet 23 June 2013) reported success in growing bryophytes for display by using fish tanks for the mesic species. She attributed the success to using water from a garden pond, citing high levels of chlorine in tap water as a possible source of bryophyte collapse. Nevertheless, these bryophytes in the aquaria also have a limited life.

Ben Tan (Bryonet 23 June 2013) found that bryophytes transplanted to a closed terrarium usually survived from 6-18 months. Even on moss walls, the bryophytes needed complete replacement every two years to maintain aesthetic appeal. This is with no fertilizer, watered with tap water, in a fully air-conditioned room. Even ***Bryum*** (Figure 93) and ***Hyophila*** (Figure 111) last only about one year in a self-contained environment indoors with proper light and high humidity.

Alison Dibble (Bryonet June 2013) reports better success. She grows bryophytes on the windowsill all winter in small bonsai dishes. Others are in clear plastic boxes or a clear glass container with a loose-fitting lid. If the container is open, Dibble soaks the mosses in the sink once a week. In the summer she puts them outside under the overhang of a north-facing boulder and lets nature do the watering, but if there is a dry spell she waters them. Using this method, she has kept one bottle of mosses, including ***Sphagnum*** (Figure 1), for more than three years. And even in a terrarium there is competition. Her ***Saelania glaucescens*** (Figure 112) had been growing well for five years, but ***Mnium*** (Figure 113) began to overtake it.

Figure 111, ***Hyophila involuta***, in a genus that lasts about one year in a terrarium. Photo by Michael Lüth, with permission.

Figure 112. ***Saelania glaucescens***, a moss that has survived a terrarium for five years, but that is being overtaken by ***Mnium***. Photo by Janice Glime.

Figure 113. ***Mnium marginatum*** overgrowing other mosses, a problem it can cause in a terrarium. Photo by Jan-Peter Frahm, with permission.

Appropriate moisture levels are clearly a problem. Yoest (2011) suggests that if mosses and flowering plants or other tracheophytes are to co-exist, one must periodically remove the covering to water the tracheophytes. Keep the cover off for a day or two to allow excess water to escape. When you return the lid, check for condensation and vent the container until you achieve the right balance. In a dish garden or terrarium, proper drainage is needed, so putting pebbles on the bottom can help. Contrary to what most people might expect, the humidity level must be kept low. This condition can often be achieved by using a cover with a small opening at the top.

As an alternative, David Spain (in Yoest 2011) suggests removing the cover in the daytime and covering it at night. He has created a terrarium with a tall cover over a dish, using this routine. The terrarium has the fern ebony spleenwort (*Asplenium platyneuron*; Figure 114) and the mosses ***Dicranum scoparium*** (Figure 4), ***Leucobryum glaucum*** (Figure 27), ***Hypnum imponens*** (Figure 15-Figure 16), and ***Campylopus introflexus*** (Figure 71). (Be careful with the latter – it is an invasive species, so don't just throw it outside when you no longer want it.) Another of Spain's favorites is the moss ***Climacium americanum*** (Figure 115). Spain concludes that "mosses do not make ideal terrarium plants."

Figure 114. ***Asplenium platyneuron***, a fern that survives in a terrarium that is opened daily and closed at night. Photo by F. B. Matos, through Creative Commons.

Figure 115. ***Climacium americanum*** with capsules in moss garden, a species that looks good in a terrarium. Photo by Janice Glime.

I have a large (40-gallon) terrarium with begonias, ferns, *Tillandsia*, and a few mosses (Figure 106). Like Spain and Yoest, when I water it, I leave the cover partially open for a few days until the excess water evaporates. Then I cover it and it will last about six months before it needs to be watered again. I have limited success with the mosses because they seem to produce weak stems and to become infected with fungi. Extra aeration helps to avoid fungi, but then more frequent watering is needed, at least for the tracheophytes.

Bryophytes as Pests

Sadly, bryophytes can even be considered to be pests in gardens and flower pots (*e.g.* Newby *et al.* 2007). Greenhouse managers are often dismayed at having the invasion of ***Marchantia polymorpha*** (Figure 116) in many of their flower pots. But it is their method of watering that distributes this liverwort everywhere. The heavy force of water from a hose propels the gemmae out of their cups and onto bare soil nearby. These liverworts often arrive in the greenhouse initially as free-loading passengers in flower pots of new flowers or ferns, either as plants or as gemmae. And the greenhouse satisfies their growing needs.

Figure 116. ***Marchantia polymorpha*** with gemmae cups. Gemmae are splashed about in greenhouses when plants are watered. Photo by David T. Holyoak, with permission.

Another species known throughout most of North America only in greenhouses is the thallose liverwort ***Lunularia cruciata*** (Figure 117). Like species of ***Marchantia*** (Figure 116), it produces gemma in cups, in this case crescent-shaped cups, and these likewise are easily dispersed by typical greenhouse watering methods.

Figure 117. ***Lunularia cruciata*** with gemmae cups and gemmae that are distributed with rain or watering in a greenhouse. Photo by Des Callaghan, with permission.

Other volunteers that I have observed include ***Bryum*** spp. (Figure 64, Figure 93), ***Leptobryum pyriforme*** (Figure 72), and ***Ceratodon purpureus*** (Figure 105). These are all mosses, with the latter two frequently producing numerous capsules and thus most likely spreading by spores. ***Bryum argenteum*** (Figure 64) has detachable terminal buds that will grow new plants. It is likely that it benefits in the same way as the gemmae of the two liverwort species.

A final caution is appropriate. Some bryophytes are invasive, although much less so than their flowering plant counterparts. Nevertheless, they can disrupt ecosystems, changing the success of seed germination, affecting the invertebrates that live there, and changing the hydrology. In addition to the ones that like to travel among flower pots, the most invasive and widespread of these are ***Campylopus introflexus*** (Figure 71), ***Eurhynchium praelongum*** (Figure 118), ***Lunularia cruciata*** (Figure 117), ***Orthodontium lineare*** (Figure 119), ***Pseudoscleropodium purum*** (Figure 120), and ***Lophocolea semiteres*** (Figure 121) (Essl *et al.* 2013; Mateo *et al.* 2015). Some of these have spread due to their use as packing material, especially for shipping plants in the horticultural industry.

Figure 118. ***Eurhynchium praelongum***, a widespread moss species that often travels in flower pots. Photo by Janice Glime.

Figure 119. ***Orthodontium lineare***, a widespread moss species that often travels in flower pots. Photo by Michael Lüth, with permission.

Figure 120. ***Pseudoscleropodium purum***, a widespread moss species that often travels in flower pots and also is used for packing. Photo by Phil Bendle, with permission.

Figure 121. ***Lophocolea semiteres***, a widespread leafy liverwort species that often travels in flower pots. Photo by David Long, with permission.

Summary

Peat mosses have been widely used in horticulture as soil additives, and for bedding, as well as forming the foundation for topiary, wreaths, and hanging baskets. Their ability to add moisture makes them ideal as a shipping medium for plants.

Peat mosses are used as soil conditioners, providing a holding medium for nutrients, releasing them slowly following drying. They provide good compost, especially when mixed with such waste products as fish offal or sewage. Some peat mosses provide additional fixed nitrogen through their **Cyanobacteria** flora. Their antibiotic properties discourage damping-off fungal growth while maintaining moisture. These same properties make them good for air layering. All of these properties make peat mosses good culture media and potting mixes, but other relatively dense mosses work well also.

Peat mosses have been used in forestry to culture young seedlings and in the food industry to culture mushrooms and morels.

Small mosses work well in container gardens such as bonsai and bonkei, where various species are used to simulate different aspects of miniature landscapes. Terraria are more difficult, with mold being a frequent problem. Aeration is important, as is the choice of mosses.

Some species are pests in greenhouses, sometimes being dispersed as gemmae. The watering techniques make gemmae and other detachable parts airborne.

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