Mushroom Cultivation

Organic Grower's School

March 6th, 2019

I. The Fungal Life Cycle

Fungi are a fascinating group of organisms that have inhabited the Earth for hundreds of millions of years and are integral to all ecological processes.

Like animals, fungi consume oxygen and release carbon dioxide. Unlike animals, fungi digest food outside their bodies through decomposition and are able to access food from dead organic matter, rocks and soil.

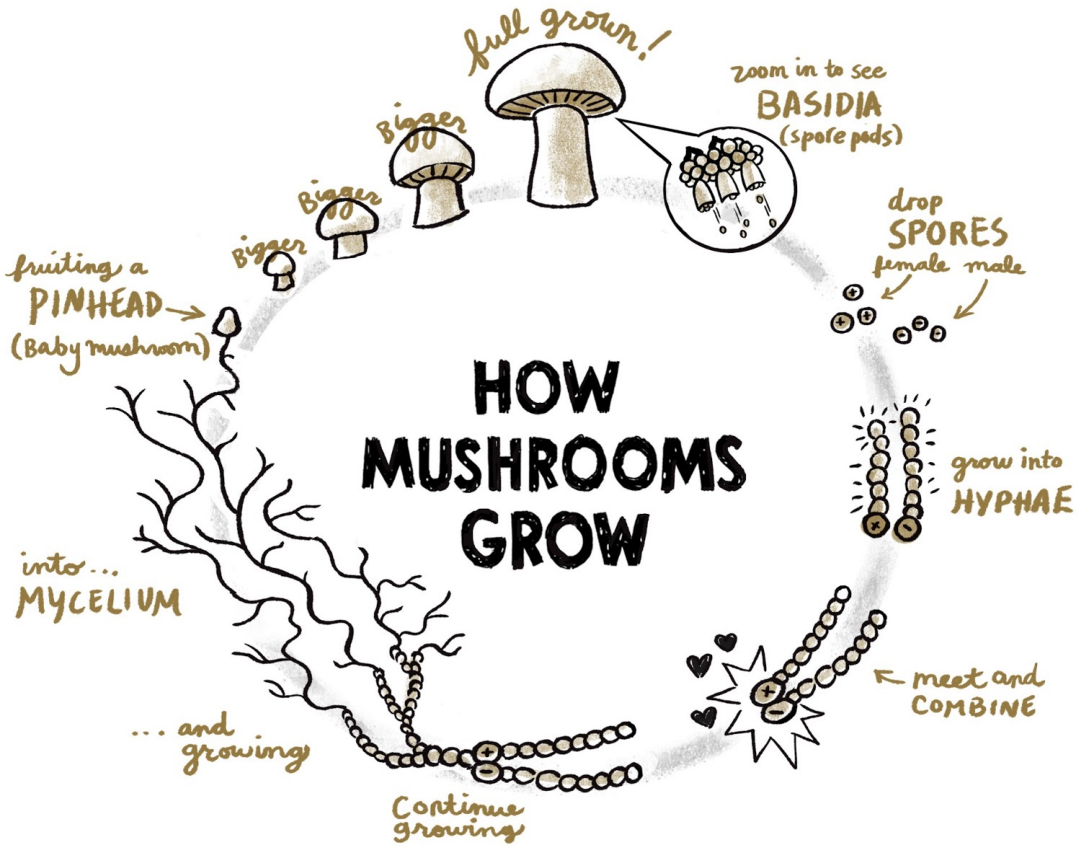

Figure 1. The fungal life cycle
Illustration by Stef Choi: http://stefchoi.blogspot.com/search/label/Illustration

There are three main types of tissue in fungi: mushrooms, mycelium, and spores. Mycelium refers to the threadlike material that is the vegetative body of a fungus, similar to the stems or roots on a plant.

Mushrooms are a reproductive fruiting structure formed by certain types of fungi, similar to an apple on a tree. Mushrooms only form when a fungus is trying to create more of itself, also called propagation, and this usually occurs when the fungus feels it has exhausted its food supply and the environmental conditions are right.

A mushroom is actually just an elaborate structure of densely woven mycelium, so there are really only two types of fungal tissue, mycelium and spores. However, since mushrooms are so remarkable we'll treat them as a different type of tissue.

Spores are the reproductive cells of fungi, similar to sperm and eggs in animals, or pollen and ovaries in a seed forming plant. Spores are produced by mushrooms or from mycelial strands in non-mushroom forming fungi. When spores land on a suitable material, a thread called a hypha begins to grown from the spore until it encounters another genetically compatible hypha, at which time they fuse and become mycelium.

Now that we have covered to main points of the fungal life cycle, let's explore the basics of mushroom cultivation!

II. Basics of Mushroom Cultivation

There are many approaches and methods for mushroom cultivation, and the process of growing mushrooms can be loosely categorized into four phases. Here we will mostly focus on the last two phases of the process, but a brief overview of all the phases will be given. The phases are:

1. Culturing

Culturing is the process of isolating a strain of fungi in order to use it for further propagation. A strain is a genetically distinct individual of a species of fungi, for example, a Shiitake (*Lentinula edodes*) is a species of mushroom, while the strain is the individual mushroom, and its mycelium that you find growing. You can create cultures by taking a piece of tissue from a mushroom and growing it out, or by collecting spores from a mushroom so hyphae can grow out and fuse into new mycelium.

Tissue culturing is a cloning process, meaning that your culture will be genetically identical (i.e. the same organism, or strain) as your starting mushroom. Making cultures with spores will breed new genetically distinct individuals, different from the parent mushroom. The difference between the two can be compared to taking a stem cutting from a plant (cloning), versus using plant seeds (new individual).

Culturing is normally done in a clean lab space or a still air box using petri dishes and sterilized media. For the beginner or low tech cultivator, this is often not feasible. In addition to isolating cultures on petri dishes, strains can also be grown out in sterilized liquid broths containing sugars and other nutrients, this "liquid culture" technique can potentially be performed in non sterile settings.

A low tech cloning method that works for many types of mushrooms is to cut off the base of a mushroom and roll it up in wet cardboard. The wet cardboard should be stored near room temperature in a container that is <u>not</u> airtight. A sandwich baggie with the top partially opened is a good option.

Wait a week or two then check for mycelium growth, which should look like white fibers or mats. When the cardboard is covered in mycelium it can be used to inoculate other materials. It's difficult to grow mushrooms that are nutritious from cardboard because it tends to be high in carbon but not many other nutrients or minerals.

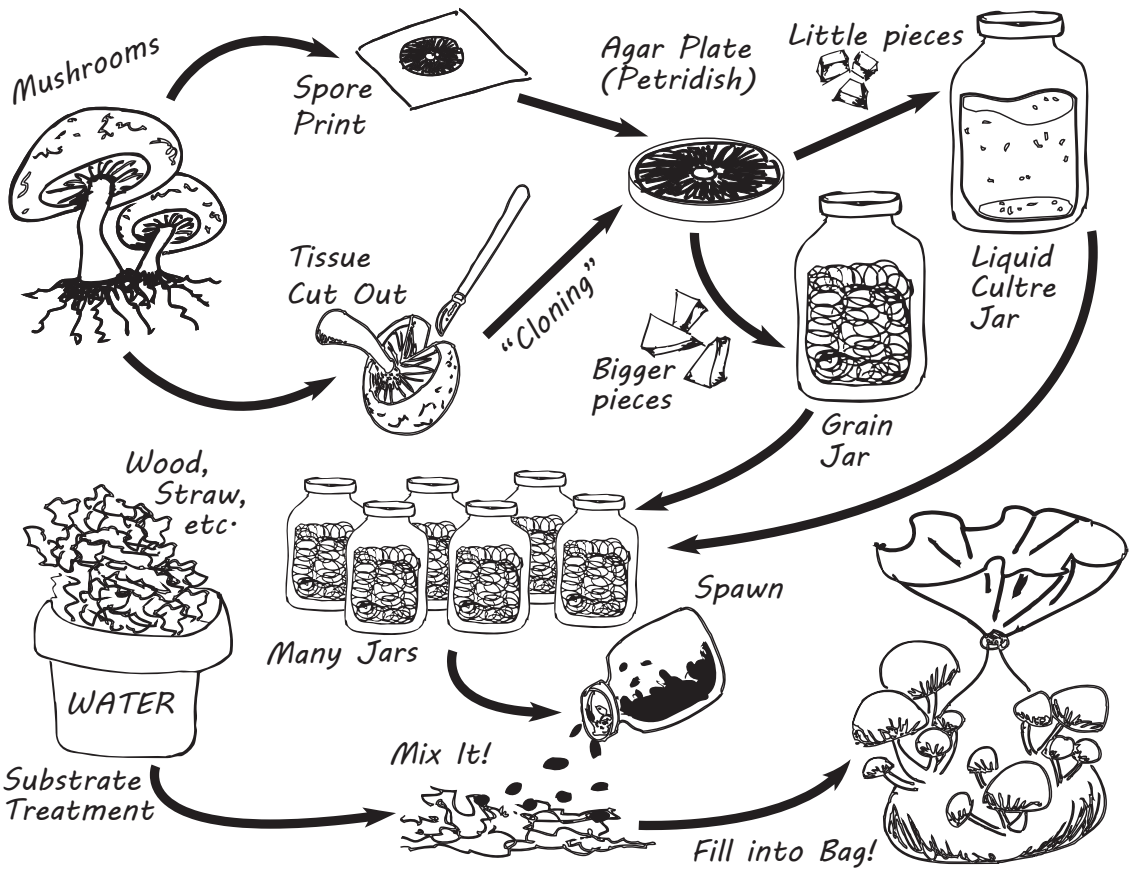

Figure 2. A visual diagram of the mushroom cultivation process.

2. Grain Spawn

After a fungus is isolated in culture it can be placed onto partially cooked grains, allowing the mycelium to grow out and expand itself. Grains are a good next step because they are rich in nutrients and proteins that the mycelium can consume to grow and become more vigorous.

Making grain spawn generally needs be done in a sterile environment, and the grains themselves need to be sterilized in a pressure cooker or an autoclave before inoculating, which requires more equipment and expertise and can be a potentially dangerous process of not done with care and caution.

Newer methods have been developed to inoculate grains using sterilized syringes and liquid cultures, that can potentially be done in a non sterile environment, like your kitchen.

Mushrooms can sometimes be fruited directly off of grains, but this is usually not done because grains are far more expensive than the bulk substrates used in the next step.

3. Bulk Inoculation

This step is a further expansion of the growing mycelium onto larger, cheaper and more readily available materials. For home growers who don't want to set up a lab or work with autoclaves, this is generally the starting step and the mushroom spawn that is acquired from elsewhere.

Commonly used bulk substrates, which depend on the species being cultivated, are straw, field cuttings, sawdust, wood chips and compost. There are many resources for looking up what substrate to

use for a species, it is generally helpful to learn about the fungus you are growing and understand their ecological niche and what food they would eat in the wild, and matching your substrate to that.

Some species are very versatile in what materials they will consume, for example oyster mushrooms (*Pleurotus ostreatus*) will generally be found growing on trees or logs in the wild, but can be grown on straw, grass clippings or coffee grounds.

Depending on the species and substrate you are working with, you may need to pasteurize or sterilize your substrate. There are several common low tech pasteurization methods like using heat, raising the pH or fermenting the substrate.

4. Fruiting

This is the phase where the mycelium initiates the process of forming a mushroom. It begins with mycelium condensing into small nodes on its surface, often referred to as "pinning". The "pin heads" are baby mushrooms that will grow to full size in the right conditions. Fruiting is generally triggered by these factors:

1. Food Depletion

   Mycelium will generally continue to grow, decompose and eat available materials in its surroundings. Mushrooms are formed when the mycelium runs out of food, so it uses its energy reserves to create a spore-releasing mushroom.

2. Light

   Mushroom formation can be triggered by light. The fungus is not consuming light and turning it into energy like plants do, they have pigments that are triggered by certain wavelengths of light to change their behavior and potentially induce fruiting. Many species are triggered by blue visible light. Light can signal to mycelium growing in wood or soil, that there are no longer physical barriers to the mushroom's growth.

3. Humidity

   Most mushrooms require high levels of humidity to fruit, and this is why mushrooms (but not necessarily fungi) are less abundant in dry arid environments. The trigger of humidity can be traced to the fact fungi are mostly made of water (well above 90%) so low ambient humidity can cause mushrooms to dry out and not grow properly.

4. Fresh Air

   Like animals, fungi breathe oxygen and release CO_2. A lack of fresh air can cause long spindly stems in mushrooms, leading to a less meaty and flavorful mushroom. Note that that fungus sense CO_2 levels to do this so it is not low oxygen, but high CO_2 that causes this effect.

5. Temperature

   Different fungi will form mushrooms at different temperatures, which correlate to the season they would fruit in the wild, like plant blossoms, each species fruits during certain times of the year. Temperature tolerance can vary greatly between strains of the same species and some commercial spawn providers have warm and

cold weather strains of species like Shiitake (*L. edodes*). Generally mushrooms will grow slower at the lower temperatures and be more prone to contamination at the higher temperatures.

6. Symbiosis

   This trigger does not apply to all mushrooms, for example most wood decomposers do not need the help of other organisms to fruit, but many soil fungi require the presence of certain microbes in order to fruit. A class of fungi called mycorrhizae can only survive by growing on plant roots, these include chanterelles, amanitas and porcini, all of which are extremely difficult to cultivate. Certain species will not fruit from a sterilized medium, and so things like casing layers are used to add a material that is filled with microorganisms that the fungus can interacts with.

III. Low Tech Cultivation Methods

1. Soil Bed Inoculation

A variety of mushroom species can be grown in the ground, either within a garden or in a specific mushroom patch. You can also add their spawn to garden beds, burying it or placing it under mulch where they benefit soil by accelerating decomposition, improving soil structure, increasing water retention, and protecting plant roots from soil predators like root feeding nematodes. Common species for this technique are Wine Cap Stropharia (*Stropharia rugoso-annulata*) and oysters.

The general procedure for growing mushroom beds is to:

1. Dig a ditch around 12 inches wide, 4-10 inches deep and a few feet long. The dimensions of the ditch should be adjusted to fit the contour of the landscape or impediments in the surrounding area. They can also be bigger or smaller, but it is advisable to make multiple smaller patches than one big one in case there is heavy contamination or other issues.
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2. Ideal sites should be shady and have nearby windbreaks, to prevent the sun and wind from drying the bed out, but should also be in a well drained area to prevent flooding out the fungus.

3. Cover the bottom and sides of your ditch with cardboard that has holes poked in it. Remove plastic tape and staples from the cardboard, which should decompose over time. This cardboard layer gives your spawn a head start before wild fungi from the soil get into the substrate.

4. Add a 1-2 inch layer of substrate to the ditch. Woodchips, sawdust and/or straw are commonly used. Make sure the substrate is relatively fresh and hasn't been decomposed or composted already. The more colored splotches or white strands you see on the substrate, the more organisms are already present on it, decomposing it. This means less food for your fungus and lower mushroom yields.

5. Break up mushroom spawn and add a small layer on top of the mulch substrate (1:10 is a good inoculation ratio, but can be adjusted based on available materials).

6. Repeat steps 4-5 until the substrate in the ditch is level with the ground.

7. Add a final layer of either straw or cardboard to help hold moisture in.

8. Water the bed thoroughly, 5-15 minutes, allowing all the substrate to become soaked. Alternatively, soak the substrate for several hours or overnight before adding it to the bed.

9. For the first month after inoculation, water the beds once a week if there is not rain.

10. Wait 4-8 months, then remember to check the beds after it rains and pick some mushrooms! (Make sure they're what you planted before you eat them!).

2. Hot Water Straw Pastuerization

Pasteurized straw is a great material for growing a variety of fungi on, most notably, Oysters, which are vigorous and versatile decomposers that grow quickly and create high fruiting yields.

Pasteurization is the process of treating a substrate to eliminate potential competitive microorganisms. Three common forms of pasteurizing mushroom substrate involve soaking it in water where it can be either heated, anaerobically fermented, or pH adjusted.

The following instructions are for heat pasteurization:

1. Heat a container of water to around 170 F

2. Place the substrate into the water

3. Measure the internal temperature of the substrate until it reaches 160 F (A compost thermometer is good for this)

4. Keep the substrate between 140 F and 170 F for 60-90 minutes

5. Remove the substrate from the water and allow it to dry and cool down to 90 F

6. Inoculate the substrate by breaking up spawn and mixing it in with the substrate (You should sterilize your hands with rubbing alcohol or hydrogen peroxide before handling the spawn or substrate, wearing nitrile gloves is recommended)

7. Place the spawn/substrate mixture into a container. Good choices are sturdy bags with the top loosely tied or a five gallon bucket with holes drilled in it covered in breathable tape.

8. Wait several weeks or months for the substrate to be colonized (depending on the size of the container). Mycelium tends to grow best at 75 F. If your container is clear you can see when the substrate is colonized because it will be covered in white mycelium.

9. If using a bag, cut a hole or slit in the bag at an area of dense growth, to encourage mushroom growth out of the hole. If using a bucket, remove a few pieces of tape, or just let fruiting bodies grow through the tape and push it aside. (You can spray around the openings with a water mister bottle to encourage fruiting).

Bags or buckets can fruit multiple times, so observe them and see what happens before composting them. Also, if the material you used isn't contaminated, you can use it to inoculate other pasteurized substrate.

3. Cold Water Fermentation

This process can be used instead of hot water pasteurization. It is a simpler and less resource intensive process. The draw back is that it takes longer to perform and creates a very strong odor, similar to swamp water.

The steps for performing cold water fermentation are:

1. Pack your substrate into a Container. Five gallon buckets and 55 gallon barrels are common choices.

2. Fill the container with water until the substrate is fully submerged. You may need to fill the container and let it soak for a minute before filling it more. It also can be helpful to place a rock or heavy object on top of the substrate to keep it submerged.

3. Top off the container with water and place an airtight lid on the top.

4. Let the containers sit for 7-14 days. Be aware that (very smelly) water might leak out of the container during the process so don't leave them in your living space. Fermentation happens faster when it is warmer so adjust your wait time accordingly.

5. Prepare a clean table or surface by wiping the top down with rubbing alcohol and putting your fermented substrate on it to drain. (Once again, wherever the water drains off to will likely smell unpleasant for some time afterwards)

6. Follow steps 6-9 from the hot water pasteurization section.

This is a straightforward, low resource method for growing mushrooms. Just be aware that whatever the fermented water touches (table, driveway, hands, clothes) will smell like swamp water for several days afterwards.

4. Log Inoculation

Logs are a great way to grow mushrooms that do not require sterilization or pasteurization. Make sure to use logs that are fresh and from healthy trees and lack visible signs of mold or bacteria growing on them. Avoid using logs from trees that are sick, already decomposing or have already fallen over, unless they were knocked over by a storm and were healthy before that. When a tree is naturally falling over and losing limbs, this is a sign that it is dying, which means it is already being decomposed and leading to less nutrients and more competitors for your fungus, and lower yields.

Acquiring good logs can be tricky. Keep an ear out for friends and neighbors who are removing trees for aesthetic purposes or network with tree service crews and arrange to pick up, or have their freshly cut logs dropped off.

Keep in mind is that fungi prefer certain types of wood. Oaks are the best for most species, with white oaks being preferable. Generally you want to use hardwoods, maples and poplars can work well but have lower yields and longevity than oaks. Oyster mushrooms (*P. ostreatus*) are very versatile and can fruit off of tulip poplar trees (*Liriodendron tulipifera*), which are highly abundant in this area and are often taken down for landscaping purposes.

Once you find a good source of logs, the best dimensions to maximize fruiting are thought to be 4-8 inches in diameter and 24-48 inches long. Less than 3 inch diameter is generally not worth inoculating because of low yields, greater than 8 inch diameter will work, but wider longs may take much longer, potential several years to be colonized and fruit. It can be convenient to use shorter logs, around 18 inches long, for the sake of making your logs lighter and easier to carry them when you need to move them.

Once you have your logs cut the general procedure is:

1. Drill holes in the log using either a power drill or an angle grinder with drill bit attachment, which is quicker and more efficient. Holes can be drilled in offset lines along the length of the log to form a diamond pattern, aim for holes to be 2-6 inches apart. If the holes are closer, the log will be colonized faster, but its more work to do, and if the holes are too far apart you increase the risk of contaminants getting into the log before it is colonized.

2. Place spawn in the drilled holes. The two forms of spawn for log inoculation are either wooden dowel plugs, which you can hammer into the holes or sawdust spawn, which you plug with you a tool called a sawdust plunger or inoculator that grabs sawdust then ejects into the holes on your log. Using a sawdust inoculator tends to be faster and less expensive than wooden plugs if you have the right equipment. Make sure to drill holes that are the same size diameter as the dowels, or sawdust inoculator you are using.

3. After plugging the holes, melt cheese wax or beeswax in a pot and cover the filled holes with it. This helps hold in moisture, making the mycelium more comfortable while it tries to jump off of the spawn and into the logs. This step in not always necessary, especially if making the logs in a humid environment that gets lots of rain.

4. After all your logs are inoculated, stack them together somewhere that is moist and out of direct sunlight to incubate for 6 months or so, or potentially years if using larger logs. For the first month, if there is no rain, water the logs at least once a week.

5. The way you setup the logs to fruit will depend on the species you're growing. Shiitake and oysters can be fruited by simply leaning the logs against a fence or wall or stacking them up like a cabin. Sometimes, if it has been exceptionally dry, you can dunk the logs in water for 12-24 hours to trigger fruiting, but make sure you don't soak them any longer or the mycelium will drown.

6. Species like Reishi (*Ganoderma spp.*) or Maitake (*Grifola frondosa*) require the logs to be buried before they will fruit. Find a patch of soil that seems relatively moist and dig a ditch then fill the bottom with sand and gravel to improve drainage. Add the logs on top, then bury them in woodchips and soil, the fruiting bodies will then rise of the soil when ready.

A typical mushroom log will fruit anywhere from 2-6 years depending on the species, type of wood and size of the log. For example, Shiitakes will usually fruit 5-6 years on oak, but only 2-3 on maple.

5. Growing Fungi on Paper Products

Decomposer fungi with diverse growth capabilities, like the oyster mushroom, are capable of growing on and eating various paper products including cardboard, mail, notebooks, compostable food containers, newspapers, magazines, and any similar paper products that are made of plant material.

While oyster mycelium can grow well on these materials, it is important to note that paper products are very low in nutrition, so mushrooms fruited off of paper tend to be a relatively poor food source and generally not recommended for eating. However, there are two useful benefits of growing fungi on paper:

1. Myceliated paper can be used as an inoculum, and functions as a vector for mycelium so you can use the paper to inoculate for nutritious substrates like woodchips, straw, etc.

2. Growing fungi on paper "digests" it, making that paper easier to break down in a compost pile or be buried and decomposed back into soil. Turning paper and cardboard back into soil is a greater sustainability technique as recycling paper is far more energy intensive than decomposing it back into soil.

The following method can be used to inoculate just about any type of paper or plant based product as long as it doesn't have a plastic or thick wax coating.

1. Collect paper scraps that might otherwise fill up your trash and recycling bins.

2. Remove tape, staples and other non-paper components.

3. Soak all of the paper items in a bucket or bin of water for at least one hour, up to 24 hours for cardboard.

4. Select a location for a pile outside, somewhere in the shade ideally, and possibly out of the direct view of your neighbors or visitors (unless having a visible piles of paper waste is okay). You can also use a plastic bucket or tote bin with holes drilled in it to digest the paper in.

5. Tear apart the soaked paper into smaller pieces and layer it on the ground or in the container, mixing in mushroom spawn or spent mushroom substrate with the paper.

6. You may also add wood chips or sawdust, which will provide a more nutritious food source to the fungi than just paper, which is low in nutrients.

7. Make sure to layer your materials in a way that allows airflow, too much wet paper stuck together will become anaerobic and not decompose well.

8. Once you have layered all of the paper and mushroom spawn together, cover it in a mulch like leaves, straw or wood chips to help keep the moisture in, or if you are using a container, place a lid on it.

9. Once the fungal mycelium is growing through the pile you can add more soaked paper to the top to keep feeding it. For best results add additional sawdust, wood chips and mushroom spawn.

10. After 1-6 months the pile or bin may become fully colonized.

11. At this point you have several options for what to do with the inoculated paper:

a. Bury the pile in a thick layer of mulch and/or soil, and after a couple of years it should turn back into soil

b. Add the materials of the pile to a compost pile as a biologically active carbon source (brown), the paper will decompose in the compost pile much easier than it would have without fungi growing in it and is a better food source for microbes

c. Use the myceliated fungal paper to inoculate and make other substrate, like a wood chip bed or another paper digester

IV. Closing Thoughts

Growing mushrooms can seem daunting at first because the processes involved are quite different that other food growing processes, and before mushrooms form, there is relatively little observable action. But this is the nature of fungi, any experienced cultivator will tell about a time they thought a batch was no good and gave up on it, only to find massive mushrooms unexpectedly growing later. With time and practice the process can become quite intuitive by relating to the fungi and imagining their needs.

It is good to be aware of some of the common setbacks with growing mushrooms, the most common of which is contamination. Contaminants are usually bacteria or fungi species that get into your substrate or grow on the fungus itself. Contamination can be identified by bright colors, like green, blue, black or orange, and foul odors. With some exceptions, mycelium of edible mushrooms is white, smells good, and is often sweet. If you smell odors that resemble ammonia, urine or are just plain gross, your substrate is probably contaminated and you should compost it to keep it away from other cultivation materials and try to avoid breathing spores.

Orchestrating mycelial growth is a dance of fine tuning intricately linked microscopic processes, but if you can figure out the macroscopic signals, you can become a prolific cultivator without ever stepping in a lab or looking under a microscope. But don't be afraid to try newer and more complex techniques, that is where the fun can really begin.

V. Resources

Contact the Instructor for more info, events and services offered:

Leif Olson
mycoscapes@gmail.com
integratedlandenhancement.com
https://integratedlandenhancement.com/events

Suggested Reading:

Cotter, Tradd – "Organic Mushroom Farming and Mycoremediation"
McCoy, Peter – "Radical Mycology"
Stamets, Paul – "Mycelium Running"
Stamets, Paul – "Growing Gourmet and Medicinal Mushrooms"
Stamets, Paul & Jeff Chilton – "The Mushroom Cultivator"