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EC88-2305 Six Steps to Mushroom Farming

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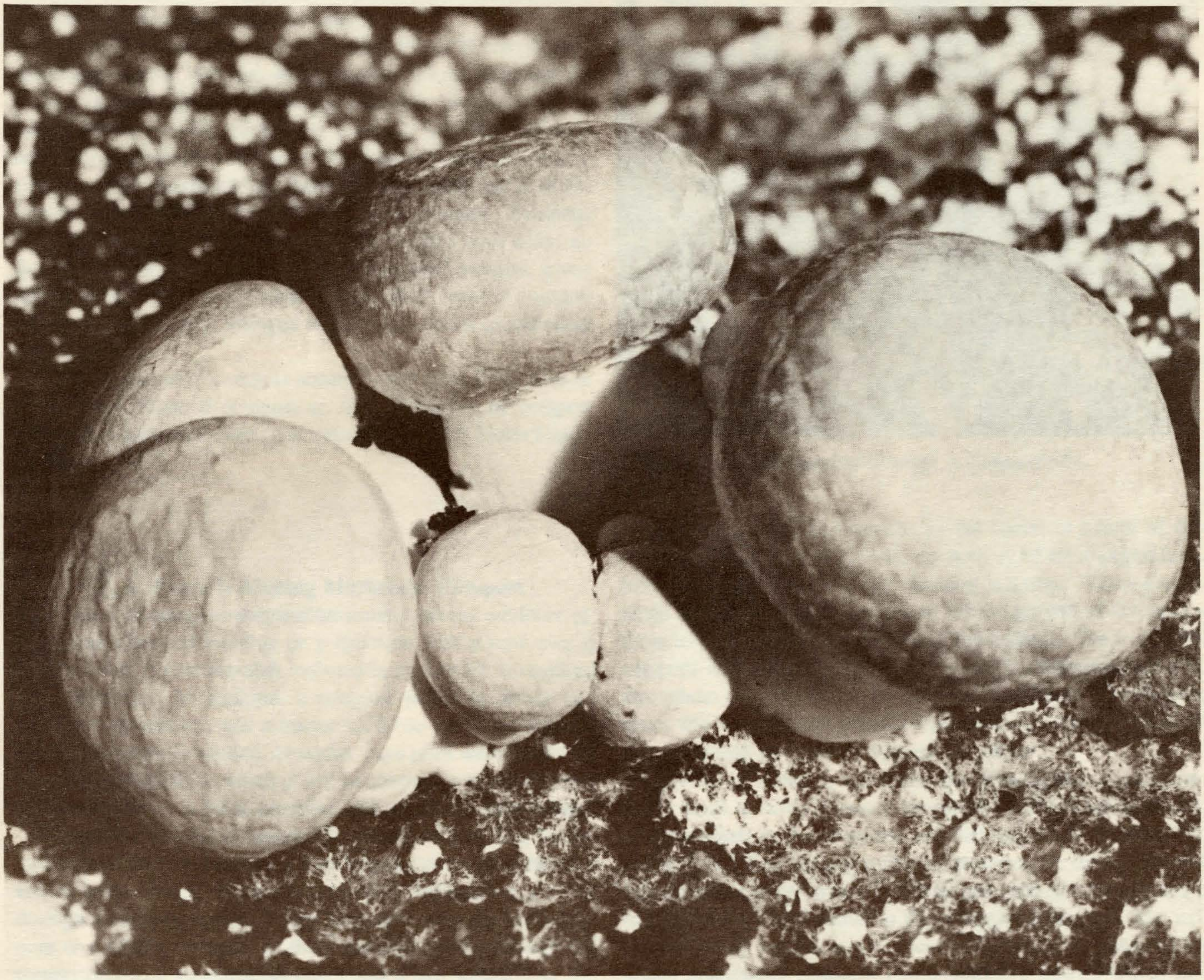
Six Steps to Mushroom Farming



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Mushroom farming consists of six steps, and although the divisions are somewhat arbitrary, these steps identify what is needed to form a mushroom production system.

The six steps are Phase I composting, Phase II composting, spawning, casing, pinning, and cropping. These steps are described in their naturally occurring sequence, emphasizing the salient features within each step. Compost provides nutrients needed for mushrooms to grow. Two types of material are generally used for mushroom compost, the most used and least expensive being wheat straw-bedded horse manure. Synthetic compost is usually made from hay and crushed corn cobs, although the term often refers to any mushroom compost where the prime ingredient is not horse manure. Both types of compost require the addition of nitrogen supplements and a conditioning agent, gypsum.

The preparation of compost occurs in two steps referred to as Phase I and Phase II composting. The discussion of compost preparation and mushroom production begins with Phase I composting.

1. Phase I: Making Mushroom Compost

This phase of compost preparation usually occurs outdoors although an enclosed building or a structure with a roof over it may be used. A concrete slab, referred to as a wharf, is required for composting. In addition, a compost turner to aerate and water the ingredients, and a tractor-loader to move the ingredients to the turner is needed. In earlier days piles were turned by hand using pitchforks, which is still an alternative to mechanized equipment, but it is labor intensive and physically demanding.

Phase I composting is initiated by mixing and wetting the ingredients as they are stacked in a rectangular pile with tight sides and a loose center. Normally, the bulk ingredients are put through a compost turner. Water is sprayed onto the horse manure or synthetic compost as these materials move through the turner. Nitrogen supplements and gypsum are spread over the top of the bulk ingredients and are thoroughly mixed by the turner. Figure 1 is a close-up of a machine "eating" its way through a compost pile. Once the pile is wetted and formed, aerobic fermentation (composting) commences as a result of the growth and reproduction of microorganisms which occur naturally in the bulk ingredients. Heat, ammonia, and carbon dioxide are released as by-products during this process. Compost activators, other than those mentioned, are not needed, although some organic farming books stress the need for an "activator."

Figure 1. Turner moving through a compost pile.

Mushroom compost develops as the chemical nature of the raw ingredients is converted by the activity of microorganisms, heat, and some heat-releasing chemical reactions. These events result in a food source most suited for the growth of the mushroom to the exclusion of other fungi and bacteria. There must be adequate moisture, oxygen, nitrogen, and carbohydrates present throughout the process, or else the process will stop. This is why water and supplements are added periodically, and the compost pile is aerated as it moves through the turner.

Gypsum is added to minimize the greasiness compost normally tends to have. Gypsum increases the flocculation of certain chemicals in the compost, and they adhere to straw or hay rather than filling the pores (holes) between the straws. A side benefit of this phenomenon is that air can permeate the pile more readily, and air is essential to the composting process. The exclusion of air results in an airless (anaerobic) environment in which deleterious chemical compounds are formed which detract from the selectivity of mushroom compost for growing mushrooms. Gypsum is added at the outset of composting at 40 lbs per ton of dry ingredients.

Nitrogen supplements in general use today include brewer's grain, seed meals of soybeans, peanuts, or cotton, and chicken manure, among others. The purpose of these supplements is to increase the nitrogen content to 1.5 percent for horse manure or 1.7 percent for synthetic, both computed on a dry weight basis. Synthetic compost requires the addition of ammonium nitrate or urea at the outset of composting to provide the compost microflora with a readily available form of nitrogen for their growth and reproduction.

Corn cobs are sometimes unavailable or available at a price considered to be excessive. Substitutes for or complements to corn cobs include shredded hardwood bark, cotton seed hulls, neutralized grape pomace, and cocoa bean hulls. Management of a compost pile containing any one of these materials is unique in the requirements for watering and the interval between turnings.

The initial compost pile should be 5 to 6 feet wide, 5 to 6 feet high, and as long as is necessary (Figure 2). A two-sided box can be used to form the pile (rick), although some turners are equipped with a "ricker" so a box isn't needed. The sides of the pile should be firm and dense, yet the center must remain loose throughout Phase I composting. As the straw or hay softens during composting, the materials become less rigid and compaction can easily occur. If the materials become too compact, air cannot move through the pile and an anaerobic environment will develop.

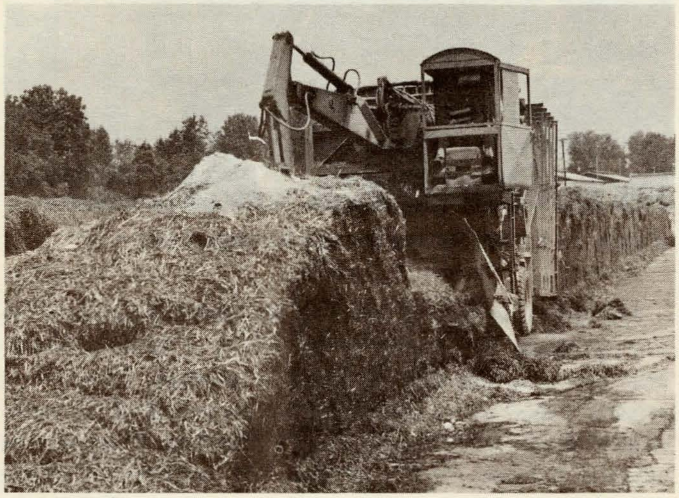

Figure 2. A composting wharf on which ricks of compost can be seen.

Turning and watering are done at approximately 2-day intervals, but not unless the pile is hot (145° to 170°F). Turning provides the opportunity to water, aerate, and mix the ingredients, as well as to relocate the straw or hay from a cooler to a warmer area in the pile, outside versus inside. Supplements are also added when the ricks are turned, but they should be added early in the composting process. The number of turnings and the time between turnings depends on the condition of the starting material and the time necessary for the compost to heat to temperatures above 145°F.

Water addition is critical since too much will exclude oxygen by occupying the pore space, and too little can limit the growth of bacteria and fungi. As a general rule, water is added up to the point of leaching when the pile is formed and at the time of first turning, and thereafter either none or only a little is added for the duration of composting. On the last turning before Phase II composting, water can be applied generously so that when the compost is tightly squeezed, water drips from it. There is a link between water, nutritive value, microbial activity, and temperature, and because it is a chain, when one condition is limiting for one factor, the whole chain will cease to function. Biologists see this phenomenon repeatedly and have termed it the *Law of Limiting Factors*.

Phase I composting lasts from 7 to 14 days, depending on the nature of the material at the start and its characteristics at each turn. There is a strong ammonia odor associated with composting, which is usually complemented by a sweet, moldy smell. When compost temperatures are 155°F and higher, and ammonia is present, chemical changes occur which result in a food rather exclusively used by the mushroom. As a by-product of the chemical changes, heat is released and the compost temperatures increase. Temperatures in the compost can reach 170° to 180°F during the second and third turnings when a desirable level of biological and chemical activity is occurring. At the end of Phase I the compost should: a) have a chocolate brown color; b) have soft, pliable straws; c) have a moisture content of from 68 to 74 percent; and d) have a strong smell of ammonia. When the moisture, temperature, color, and odor described have been reached, Phase I composting is completed.

2. Phase II: Finishing the Compost

There are two major purposes to Phase II composting. Pasteurization is necessary to kill any insects, nematodes, pest fungi, or other pests that may be present in the compost. And second, it is necessary to remove the ammonia which formed during Phase I composting. Ammonia at the end of Phase II in a concentration higher than 0.07 percent is often lethal to mushroom spawn growth, thus it must be removed; generally, a person can smell ammonia when the concentration is above 0.10 percent.

Phase II takes place in one of three places, depending on the type of production system used. For the zoned system of growing, compost is packed into wooden trays, the trays are stacked six to eight high, and are moved into an environmentally controlled Phase II room. Thereafter, the trays are moved to special rooms, each designed to provide the optimum environment for each step of the mushroom growing process. With a bed or shelf system, the compost is placed directly in the beds, which are in a room used for all steps of crop culture. The most recently introduced system, the bulk system, is one in which the compost is placed in a cement-block bin with a perforated floor and no cover on top of the compost; this is a room specifically designed for Phase II composting.

The compost, whether placed in beds, trays, or bulk, should be filled uniformly in depth and density or compression. Compost density should allow for gas exchange, since ammonia and carbon dioxide will be replaced by outside air.

Phase II composting can be viewed as a controlled, temperature-dependent, ecological process using air to maintain the compost in a temperature range best suited for the de-ammonifying organisms to grow and reproduce. The growth of these thermophilic (heat-loving) organisms depends on the availability of usable carbohydrates and nitrogen, some of the nitrogen in the form of ammonia.

Optimum management for Phase II is difficult to define and most commercial growers tend toward one of the two systems in general use today: high temperature or low temperature.

A *high temperature Phase II system* involves an initial pasteurization period during which the compost and the air temperatures are raised to at least 145°F for 6 hours. This can be accomplished by heat generated during the growth of naturally occurring microorganisms, or by injecting steam into the room where the compost has been placed, or both. After pasteurization, the compost is re-conditioned by immediately lowering the temperature to 140°F by flushing the room with fresh air. Thereafter, the compost is allowed to cool gradually at a rate of approximately 2° to 3°F each day until all the ammonia is dissipated. This Phase II system requires approximately 10 to 14 days to complete.

In the *low temperature Phase II system* the compost temperature is initially increased to about 126°F with steam or by the heat released via microbial growth, after which the air temperature is lowered so the compost is in a temperature range of 125° to 130°F. Pasteurization is initiated 24 to 48 hours later by injecting steam into the room, which raises the air and compost temperatures to 140°F. These temperatures are monitored and maintained from 2 to 4 hours, which completes the pasteurization requirement for the compost. After pasteurization, the air temperature is lowered to force the compost temperature back to the 125° to 130°F range. During the 4 to 5 days after pasteurization, the compost temperature may be lowered by about 2°F a day until the ammonia is dissipated.

It is important to remember the purposes of Phase II when trying to determine the proper procedure and sequence to follow. One purpose is to remove unwanted ammonia. To this end the temperature range from 125° to 130°F is most efficient since de-ammonifying organisms grow well in this temperature range. A second purpose of Phase II is to remove any pests present in the compost by use of a pasteurization sequence.

At the end of Phase II the compost temperature must be lowered to approximately 75° to 80°F before spawning (planting) can begin. The nitrogen content of the compost should be 2.0 to 2.4 percent, and the moisture content between 68 and 72 percent. Also, at the end of Phase II it is desirable to have 5 to 7 lbs of dry compost per square foot of bed or tray surface to obtain profitable mushroom yields. It is important to have both the compost and the compost temperatures uniform during the Phase II process since it is desirable to have as homogenous a material as possible.

3. Spawning

Mushroom compost must be inoculated with mushroom spawn (Latin *expandere* = to spread out) if one expects mushrooms to grow. The mushroom itself is the fruit of a plant as tomatoes are of tomato plants. Within the tomato one finds seeds, and these are used to start the next season's crop. Microscopic spores form within a mushroom cap, but their small size precludes handling them like seeds. As the tomato comes from a plant with roots, stems, and leaves, the mushroom arises from thin, thread-like cells called mycelium. Fungus mycelium is the white, thread-like plant often seen on rotting wood or moldy bread. Mycelium can be propagated vegetatively, like separating daffodil bulbs and getting more daffodil plants. Specialized facilities are required to propagate mycelium, so the mushroom mycelium does not get mixed with the mycelium of other fungi. Mycelium propagated vegetatively is known as spawn, and commercial mushroom farmers purchase spawn from any of about a dozen spawn companies.

Spawn makers start the spawn-making process by sterilizing a mixture of rye grain plus water and chalk; wheat, millet, and other small grain may be substituted for rye. Sterilized horse manure formed into blocks was used as the growth medium for spawn up to about 1940, and this was called block or brick spawn, or manure spawn; such spawn is uncommon now. Once sterilized grain has a bit of mycelium added to it, the grain is incubated at 74°F, and the bottle containing the grain and mycelium is shaken 3 times at 4-day intervals over a 14-day period of active mycelial growth. Once the grain is colonized by the mycelium, the product is called spawn. Spawn can be refrigerated for a few months, so spawn is made in advance of a farmer's order for spawn.

In the United States, mushroom growers have a choice of four major mushroom cultivars: a) Smooth white — cap smooth, cap and stalk white; b) Off-white — cap scaly with stalk and cap white; c) Cream — cap smooth to scaly with stalk white and cap white to cream; and d) Brown — cap smooth, cap chocolate brown with a white stalk. Within each of the four major groups, there are various isolates, so a grower may have a choice of up to eight smooth white strains. The isolates vary in flavor, texture, and cultural requirements, but they are all mushrooms. Generally, white and off-white cultivars are grown for the fresh market, while cream and brown cultivars are used for processed foods like soups and sauces, but all isolates are good eating as fresh mushrooms.

Spawn is distributed on the compost and then thoroughly mixed into the compost (Figure 3). For years this was done by

Figure 3. Spawn distributed in the compost.

hand, broadcasting the spawn over the surface of the compost and ruffling it in with a small rake-like tool. In recent years, however, for the bed system, spawn is mixed into the compost by a special spawning machine which mixes the compost and spawn with tines or small finger-like devices. In a tray or batch system, spawn is mixed into the compost as it moves along a conveyor belt or while falling from a conveyor into a tray. The spawning rate is expressed as a unit or quart per so many square feet of bed surface; 1 unit per 10 ft^2 is desirable. The rate is sometimes expressed on the basis of spawn weight versus compost weight; a 2 percent spawning rate is desirable.

Once the spawn has been mixed throughout the compost and the compost worked so the surface is level, the compost temperature is maintained at 75°F and the relative humidity is kept high to minimize drying of the compost surface or the spawn. Under these conditions the spawn will grow — producing a thread-like network of mycelium throughout the compost (Figure 4). The mycelium grows in all directions from a spawn grain, and eventually the mycelium from the different spawn grains fuse together, making a spawned bed of compost one biological entity. The spawn appears as a white to blue-white mass throughout the compost after fusion has occurred. As the spawn grows it generates heat, and if the compost temperature increases to above 80° or 85°F, depending on the cultivar, the heat may kill or damage the mycelium and eliminate the possibility of maximum crop productivity and/or mushroom quality. At temperatures below 74°F, spawn growth is slowed and the time interval between spawning and harvesting is extended.

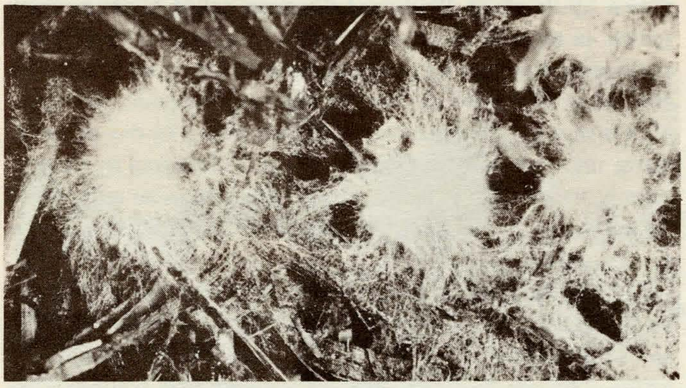

Figure 4. Spawn with mycelium growing out from the grain and into the compost; about 5 days after spawning.

The time needed for spawn to colonize the compost depends on the spawning rate and its distribution, the compost moisture and temperature, and the nature or quality of the compost. A complete spawn run usually requires 14 to 21 days (Figure 5). Once the compost is fully grown with spawn, the next step in production is at hand.

4. Casing

Casing is a top-dressing applied to the spawn-run compost on which the mushrooms eventually form. Clay-loam field soil, a mixture of peat moss with ground limestone, or reclaimed weathered, spent compost can be used as casing. Casing does not need nutrients since casing acts as a water reservoir and a place where rhizomorphs form. Rhizomorphs look like thick strings and form when the very fine mycelium fuses together. Mushroom initials, primordia, or pins form on the rhizomorphs, so without rhizomorphs there will be no mushrooms. Casing should be pasteurized to eliminate any insects and pathogens it may be carrying. Also, it is important that the casing be distributed so the depth is uniform over the surface of the compost. Such uniformity allows the spawn to move into and through the casing at the same rate and, ultimately, for mushrooms to develop at the same time. Casing should be able to hold moisture since moisture is essential for the development of a firm mushroom.

Figure 5. Spawn has grown through all the compost, so that the compost straws are entirely covered by the white, thread-like mycelium of the mushroom.

Managing the crop after casing requires that the compost temperature be kept at around 75°F for up to 5 days after casing, and the relative humidity should be high. Thereafter, the compost temperature should be lowered about 2°F each day until small mushroom initials (pins) have formed. Throughout the period following casing, water must be applied intermittently to raise the moisture level to field capacity before the mushroom pins form. Knowing when, how, and how much water to apply to casing is an "art form" which readily separates experienced growers from beginners.

5. Pinning

Mushroom initials develop after rhizomorphs have formed in the casing. The initials are extremely small but can be seen as outgrowths on a rhizomorph. Once an initial quadruples in size, the structure is a pin. Pins continue to expand and grow larger through the button stage, and ultimately a button enlarges to a mushroom (Figure 6). Harvestable mushrooms appear 18 to 21 days after casing. Pins develop when the carbon dioxide content of room air is lowered to 0.08 percent or lower, depending on

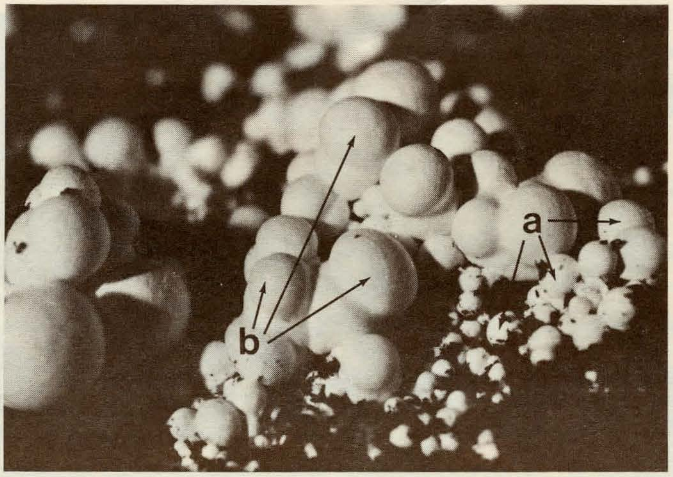

Figure 6. Mushrooms forming on the casing — a ¾ to 1½ inch layer of loam soil or neutralized peat moss. Arrows point to: (a) pins; (b) buttons; the two developmental stages that precede harvest.

the cultivar, by introducing fresh air into the growing room. Outside air has a carbon dioxide content of about 0.04 percent.

The timing of fresh air introduction is very important and is something learned only through experience. Generally, it is best to ventilate as little as possible until the mycelium has begun to show at the surface of the casing. It is also important to keep the relative humidity high by watering the walls and floor while the mycelium grows through the casing, and to stop watering at the time when pin initials are forming. If the carbon dioxide is lowered too early by airing too soon, the mycelium stops growing through the casing and mushroom initials form below the surface of the casing. As such mushrooms continue to grow, they push through the casing and are dirty at harvest time. Too little moisture can also result in mushrooms forming below the surface of the casing. Pinning affects both the potential yield and quality of a crop and is a significant step in the production cycle.

6. Cropping

The terms flush, break, or bloom are names given to the repeating 3- to 5-day harvest periods during the cropping cycle; these are followed by a few days when no mushrooms are available to harvest. This cycle repeats itself in a rhythmic fashion, and harvesting can go on as long as mushrooms continue to mature. Most mushroom farmers harvest for 35 to 42 days, although some harvest a crop for 60 days, and harvest can go on for as long as 150 days.

The air temperature during cropping should be held between 57° to 62°F for good results. This temperature range not only favors mushroom growth, but cooler temperatures can lengthen the life cycles of both disease pathogens and insect pests. It may seem odd that there are pests which can damage mushrooms, but no crop is grown that does not have to compete with other organisms. Mushroom pests can cause total crop failures, and often the deciding factor on how long to harvest a crop is based on the level of pest infestation. These pathogens and insects can be controlled by cultural practices coupled with the use of pesticides, but it is most desirable to exclude these organisms from the growing rooms.

The relative humidity in the growing rooms should be high enough to minimize the drying of casing but not so high as to cause the cap surfaces of developing mushrooms to be clammy or sticky. Water is applied to the casing so water stress does not hinder the developing mushrooms; in commercial practice this means watering 2 to 3 times each week. Each watering may consist of more or fewer gallons, depending on the dryness of the casing, the cultivar being grown, and the stage of development of the pins, buttons, or mushrooms. Most first-time growers apply too much water and the surface of the casing seals; this is seen as a loss of texture at the surface of the casing. Sealed casing prevents the exchange of gases essential for mushroom pin formation. One can estimate how much water to add after first break has been harvested by realizing that 90 percent of the mushroom is water and a gallon of water weighs 8.3 lbs. If 100 lbs of mushrooms were harvested, 90 lbs of water (11 gal) were removed from the casing, and this is what must be replaced before second break mushrooms develop.

Outside air is used to control both the air and compost temperatures during the harvest period. Outside air also displaces the carbon dioxide given off by the growing mycelium. The more mycelial growth, the more carbon dioxide produced, and since more growth occurs early in the crop, more fresh air is needed during the first two breaks. The amount of fresh air also depends on the growing mushrooms, the area of the producing surface, the amount of compost in the growing room, and the condition or composition of the fresh air being introduced. Experience seems to be the best guide regarding the volume of air required, but there is a rule of thumb: 0.3 $ft^3/ft^2/min$ when the compost is 8 inches deep, and of this volume 50 to 100 percent must be outside air.

A question frequently arises concerning the need for illumination while the mushrooms grow. Mushrooms do not require light to grow, only green plants require light for photosynthesis. Growing rooms can be illuminated to facilitate harvesting or cropping practices, but it is more common for workers or mushroom farmers to be furnished with miner's lamps rather than illuminating an entire room.

Ventilation is essential for mushroom growing, and it is also necessary to control humidity and temperature. Moisture can be added to the air by a cold mist or by live steam, or simply by wetting the walls and floors. Moisture can be removed from the growing room by: 1) admitting a greater volume of outside air; 2) introducing drier air; 3) moving the same amount of outside air and heating it to a higher temperature since warmer air holds more moisture and thus lowers the relative humidity. Temperature control in a mushrom growing room is no different from temperature control in your home. Heat can originate from hot water circulated through pipes mounted on the walls. Hot, forced air can be blown through a ventilation duct, which is rather common at more recently built mushroom farms. There are a few mushroom farms located in limestone caves where the rock acts as both a heating and cooling surface depending on the time of the year. Caves of any sort are not necessarily suited for mushroom growing, and abandoned coal mines have too many intrinsic problems to be considered as viable sites for a mushroom farm. Even limestone caves require extensive renovation and improvement before they are suitable for mushroom growing, and only the growing occurs in the cave with composting taking place above ground on a wharf.

Mushrooms are harvested in a 7- to 10-day cycle, but this may be longer or shorter depending on the temperature, humidity, cultivar, and the stage when they are picked (Figure 7). When mature mushrooms are picked, an inhibitor to mushroom development is removed and the next flush moves toward maturity. Mushrooms are normally picked at a time when the veil is not too far extended. Consumers in North America want closed, tight, mushrooms while in England and Australia open, flat mushrooms are desired. The maturity of a mushroom is assessed by how far the veil is stretched, and not by how large the mushroom is. Consequently, mature mushrooms are both large and small, although farmers and consumers alike prefer medium- to large-size mushrooms (Figure 8).

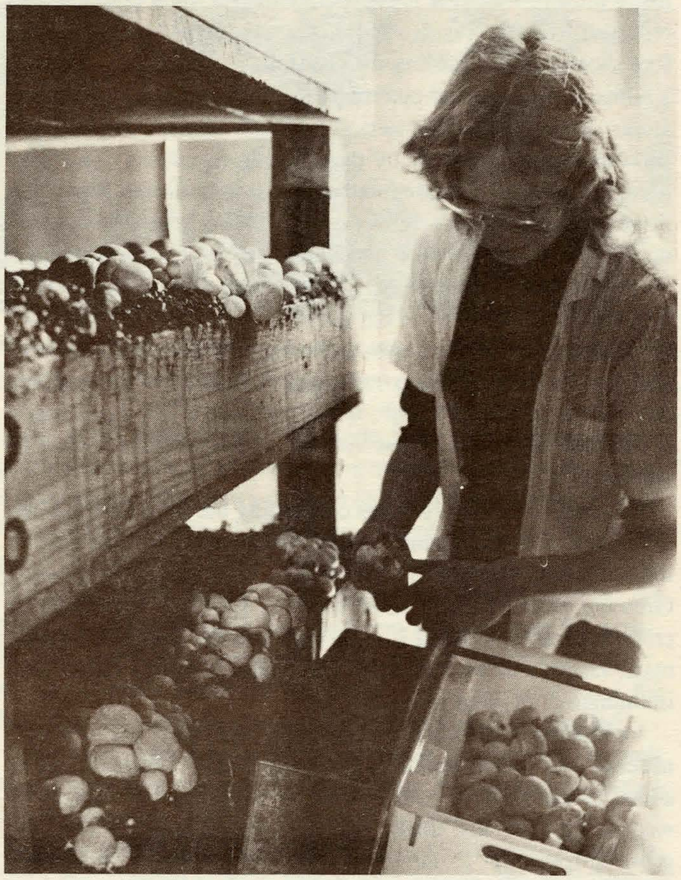

Figure 7. Mushrooms being harvested. Each mushroom is hand harvested, the base of the mushroom is trimmed, and the clean, mature mushroom placed in a basket.

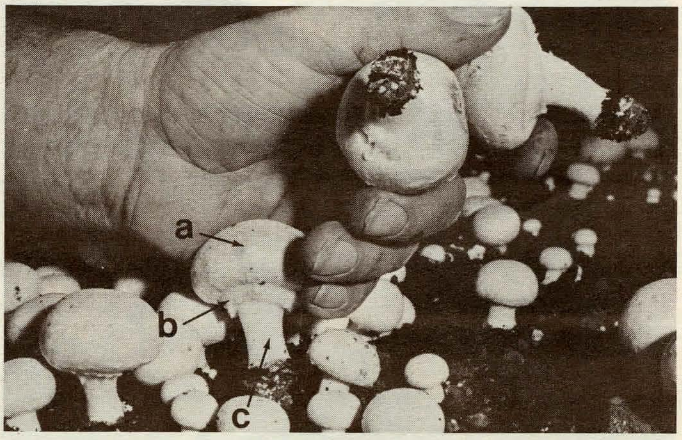

Figure 8. Mature mushrooms of differing sizes. To harvest a mushroom the cap is grasped by the fingers, twisted gently and pulled at the same time. Arrows point to: (a) cap; (b) veil; (c) stem.

Picking and packaging methods often vary from farm to farm. Freshly harvested mushrooms must be kept refrigerated at 35° to 45°F. To prolong the shelf life of mushrooms, it is important that mushrooms "breathe" after harvest, so storage in a nonwaxed paper bag is preferred to a plastic bag.

After the last flush of mushrooms has been picked, the growing room should be closed off and the room pasteurized with steam . This final pasteurization is designed to destroy any pests which may be present in the crop or the woodwork in the growing room, thus minimizing the likelihood of infesting the next crop.

Conclusion

It takes approximately 15 weeks to complete an entire production cycle, from the start of composting to the final steaming off after harvesting has ended. For this work a mushroom grower can expect anywhere from 0 to 4½ lbs per square foot; the national average for 1980 was 3.12 lbs per ft^2. Final yield depends on how well a grower has monitored and controlled the temperature, humidiy, pests, and so on. All things considered, the most important factors for good production appear to be experience plus an intuitive feel for the biological rhythms of the commercial mushroom. The production system used to grow a crop can be chosen after the basics of mushroom growing are understood.

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