
# PRODUCING SHIITAKE MUSHROOMS: A GUIDE FOR SMALL-SCALE OUTDOOR CULTIVATION ON LOGS

Updated 11/22/95

The two most popular mushrooms in the world are the common button mushroom **(Agaricus species)** and the shiitake or black forest mushroom **(Lentinus edodes),**. The shiitake, meaning "mushroom of the shii or oak tree" in Japanese, is highly prized in the Orient for its flavor and reputed medicinal value. It is a major agricultural commodity in Japan, where about half the world's supply of shiitake mushrooms is produced.

Until recently, only imported, dried shiitake mushrooms could be purchased in the United States. Shiitake mushroom production began in this country about 15 years ago, and with it came a new demand for fresh mushrooms. The demand is increasing rapidly as consumers discover the delicious, meaty flavor of fresh shiitake mushrooms. With these mushrooms commanding an average wholesale price of $4 to $5 a pound, thousands of farmers and investors across the country are interested in producing them.

For individuals interested in production on a hobby scale or for limited local sale, growing shiitake mushrooms will probably be quite rewarding. Commercial production, however, requires a substantial commitment of time and money. As with any agricultural commodity, profitability depends on the grower's production and marketing skills, as well as on market supply and demand. Shiitake production is fairly new to this country, and the technology is evolving rapidly. Information on the economics of production is still being developed. Growers should experiment on a small scale before committing substantial resources to commercial production.

The shiitake mushroom is a wood-decay fungus and must be grown on logs or sawdust. Production on sawdust is a highly specialized process that must be conducted in buildings with close control of temperature, light, and moisture. The risk of contamination and loss is much greater with sawdust than with logs, particularly for inexperienced growers. This publication deals solely with outdoor production on logs and explains techniques suitable for small producers and hobbyists.

### Areas Suitable for Production

Shiitake mushrooms grow on dead hardwood trees in a warm, moist environment. The combination of warm temperatures and high rainfall promotes rapid growth of the shiitake **mycelium,** the mass of threadlike structures from which the mushroom grows. A sudden change in temperature or moisture triggers the fruiting response, resulting in mushroom production. In western North Carolina these conditions occur naturally. Fruiting occurs primarily in spring and fall because of the seasonal rains and temperature changes. Shiitake mushrooms can also be produced in eastern North Carolina, but it is important to have an adequate means of keeping the moisture level of the logs high.

### Tree Selection and Log Preparation

Because shiitake mushrooms grow on logs, many growers make mushroom production part of their woodlot management plan. If logs must be purchased, care should be taken that the proper tree species are selected, that only healthy trees are cut, and that the logs are handled properly.

Shiitake mushrooms will grow, with varying degrees of success, on a wide range of tree species. In North Carolina, red and white oaks are excellent mushroom producers. Results from tests done by Carolina Agrotech, Inc., and Warren Wilson College indicate that sweetgum may also produce well with some strains. Shiitake mushrooms grow best on logs with a high wood density, high ratio of **sapwood** to **heartwood**, and strong (but not too thick) bark. Growers are advised to experiment with the logs available. Logs from different tree species require different management strategies. For example, thin-barked logs must be handled carefully to prevent damage to the bark. Logs with thin bark also lose moisture faster than logs with thick bark, and log moisture content should therefore be monitored closely.

Trees should be cut while they are dormant, preferably in the late winter or early spring before bud break, for two important reasons. First, the shiitake mycelium requires carbohydrates for growth, and carbohydrates in the wood are at their highest levels when the tree is dormant. Second, the bark of the logs must be intact and must adhere to the logs well. If the trees are cut after the sap begins to flow in the spring, the bark will have a tendency to "slip" and can be damaged easily. Some growers have reported success with trees cut in late fall.

Once the trees have been cut, it is important to keep the moisture content of the wood high and the bark dry until the logs are inoculated with the shiitake fungus. If the logs cannot be inoculated within a few weeks of felling, trim the limbs and leave the trunks of the trees intact. If the trees must be cut into logs at the time of felling, take measures to prevent moisture loss. If the weather is dry and windy, store the logs in a bulk pile and cover them loosely with burlap, muslin, or other porous material. If the weather is rainy, stack the logs loosely to permit good air circulation and cover them loosely.

Most small-scale producers rely heavily on manual labor, so it is important to prepare logs that are easy to handle. Logs from 3 to 4 feet long and 3 to 8 inches in diameter are best. The logs must be from live, healthy trees that are free of decay. They should be fairly straight and uniform, with the bark intact. Logs with large sections of bark that has been damaged or removed during harvest are not recommended.

**Spawn Selection**

The shiitake fungus is introduced into logs by inserting the mycelium in the form of **spawn**, a process known as **inoculation**. A listing of current spawn suppliers is available from your county Cooperative Extension Center. Spawn is available in two forms: sawdust and dowels (Figure 1). These materials are inoculated with the shiitake fungus by the supplier and are ready to use upon receipt. Both materials are covered with a fuzzy, white growth (mycelium) similar in texture to bread mold. The spawn can be stored in a refrigerator or cold room for several months but should be held at room temperature for several days before inoculation. Sawdust spawn is usually sold in bags or bottles. Dowels are usually sold in bags of 1,000. Results from some studies suggest that sawdust spawn produces mushrooms faster than dowels and is generally less expensive. Many new producers, however, find that dowels are easier to use and have a higher rate of success because moisture control is not quite as critical.

**Figure 1. Shiitake spawn is available in sawdust (left) or on wooden dowels (right).**

Many companies in the United States sell shiitake mushroom spawn, but few data have been published on the performance of the various **strains** in the Southeast. Tree species and growing environment greatly affect the performance of shiitake strains. Be sure to ask the supplier for spawn suitable to your area. Most suppliers sell three types of strains according to the weather conditions under which they fruit: warm, cold, or a wide range of temperatures. Purchasing several strains from two or three suppliers increases the chances of finding a strain suited to your conditions.

**Inoculation**

Logs are usually inoculated in early spring shortly after they have been cut. In western North Carolina, inoculation can be started in March and should be completed by late April. Farther east, February and March are better. Regardless of the season, inoculation should take place as soon after cutting the trees as possible. When logs are fresh, the moisture content is high and competing wood decay fungi have probably not become established. Log moisture content should be between 35 and 55 percent at the time of inoculation. (Methods for determining log moisture content will be discussed later.)

Sawdust or dowels are placed in holes drilled into the logs (Figure 2). Spawn suppliers provide information on the hole depth and diameter. Holes should be spaced 6 to 8 inches apart in rows along the length of the log with 2 to 4 inches between rows. The holes should be staggered in a diamond pattern to ensure rapid growth of the fungus throughout the log (Figure 3). Closer spacings increase the rate of colonization and result in more rapid mushroom production. Spawn costs, however, are also greater.

**Figure 2. Holes are drilled in the log with a high-speed drill.**

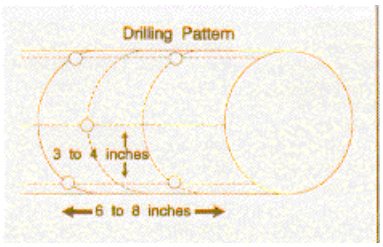


**Figure 3. Pattern for drilling holes in logs.**

An electric hand drill can be used for inoculating a small number of logs. For a large number of logs, however, a high-speed drill (operating at 6,000 to 10,000 rpm) made especially for this purpose is more practical. For dowels, the appropriate drill bits can usually be purchased through the spawn supplier. For sawdust, use a bit that is the same diameter as the **sawdust plunger** used to inject the spawn into the holes.

Spawn should be placed in the holes immediately after they have been drilled to prevent contamination by other fungi (Figure 4). Immediately after the spawn has been inserted, seal the holes with hot wax or foam plugs to prevent the spawn from drying.

**Figure 4. Dowels are pounded into the holes with a hammer.**

Several kinds of wax can be used. Many growers simply use paraffin, sometimes mixed with a little mineral oil. The wax must be very hot when applied to ensure an airtight, flexible seal. If the wax is too cool, pinholes may develop as the wax cools and the seal will be thick, opaque, and easy to knock off. Small electric deep-fat fryers or camp stoves may be used to heat the wax. In either case, use extreme caution to prevent fire; keep a fire extinguisher close at hand. Hot wax may be applied to the filled holes with special wax applicators, which look like kitchen turkey basters, or with a brush (Figure 5). Be sure to use a natural hair brush because most synthetic brushes will melt in the hot wax.

**Figure 5. Holes filled with spawn are sealed with hot wax.**

Foam plugs may be cut from the foam **backing cord** made for filling cracks in concrete slabs. It is available through building suppliers. The foam backing cord can easily be cut into 1/4- to 1/2-inch discs with a razor blade. Although using the foam plugs is safer than working with wax, it takes much longer to make the plugs and insert them than it does to melt and apply hot wax. Also, many growers have reported that squirrels and birds sometimes remove the plugs from the logs.

| Some Terms to Know | |
|---|---|
| **Backing cord** | Ropes of a spongy foam material designed to be inserted between fresh sections of concrete to allow for expansion. Used in shiitake production to make plugs for capping the holes in logs. |
| **Fruiting** | The formation of the edible fruiting bodies of a fungus—that is, the mushrooms. |
| **Heartwood** | The old, dark-colored portion of the wood in the center of a tree trunk or limb. |
| **Humidity blanket** | A nonwoven, porous, synthetic material used to control evaporation from the logs. |
| **Incubation** | The period during which the logs are maintained under conditions favorable for the mycelium to grow throughout the sapwood of the log. Also known as *spawn run*. |
| **Inoculation** | The process of introducing the mushroom mycelium into the wood. |
| **Mycelium** | The mass of interwoven filamentous hyphae that form the vegetative portion of a fungus. |
| **Pinning** | The process of forming primordia. |
| **Primordia** | Little mushroom buds visible on the surface of the logs; the earliest stage of mushroom development. |
| **Sapwood** | The young, light-colored portion of the wood near the outside of a tree trunk or limb. |
| **Sawdust plunger** | Tool for injecting sawdust spawn into holes in logs. |
| **Shade cloth** | A heavy synthetic fabric, usually black polypropylene, used to shade the logs. |
| **Spawn** | The vegetative stage of mushroom mycelium growing on a substrate, such as sawdust or wooden dowels. |
| **Spawn run** | Incubation period during which the vegetative stage of the mycelium grows throughout the sapwood of the log. |
| **Strain** | A selected mushroom variety. |

**Table 1. Terms associated with shiitake production.**

### Spawn Run

After inoculation, logs should be stacked and the fungus given time to spread throughout the sapwood. This process, known as **spawn run** or **incubation**, takes from 6 to 18 months, depending on fungus strain, the amount of spawn in each log, the size and moisture content of the log, and temperature. The goal is to provide favorable conditions for the shiitake mycelium so it can spread through the logs as quickly and evenly as possible. At the same time, conditions should be made as unfavorable as possible for competing fungi. Productivity of the logs depends on how well the shiitake fungus establishes itself during spawn run. Providing optimum growing conditions at this time is crucial for successful production.

For spawn run, the logs should be placed in a warm, shady area with good air movement but protected from strong winds. An 80 percent canopy of pine, hardwoods, or **shade cloth** is desirable. Do not attempt to grow shiitake mushrooms in total darkness; some light is required for spawn run and fruiting. The optimum quantity and quality of light required is not known. If you can read this publication while standing next to your logs in the middle of the summer in midafternoon, there is enough light. Too much light is also not desirable, however, because it encourages growth of some competing fungi, can heat the logs to unsafe temperatures, and causes excessive moisture loss. Special **humidity blankets**, available through some spawn suppliers, can be placed over the logs to help hold in moisture.

### Stacking Methods

There are many log stacking systems. The system you choose should depend on your preference and the spawn run site. Two common systems are crib stacks and lean-to stacks. Crib stacks are built of horizontal layers of logs laid perpendicular to each other (Figure 6). Each layer contains four to eight logs in stacks about 4 feet high. Although these stacks use space efficiently, are self-supporting, and allow for good air movement, there is a pronounced difference in temperature and humidity between the top and bottom layers of the stack. Lean-to stacks are composed of vertical rows of logs supported against a horizontal rail or wire (Figure 7). They do not require lifting logs to various heights, as with the crib stack system, and picking is easier, but they require a large amount of space and there are differences in temperature and humidity between the two ends of the logs.

**Figure 6. Crib stacking system.**

**Figure 7. Lean-to stacking system.**

**Log Moisture Content**

The optimum log moisture content for shiitake mycelium is from 35 to 55 percent. The shiitake mycelium will die if the moisture content of the log drops below 25 percent. Water should be readily available at the production site so that the logs can be irrigated if necessary to prevent excessive drying during spawn run and to induce fruiting later in the production cycle. If the log moisture content drops below about 40 percent or there is no rain for a two- to three-week period, the logs should be immersed in water or sprinkle irrigated.

The easiest way to monitor log moisture content is to prepare reference logs that can be checked periodically. Reference logs are representative logs selected at the time of cutting. Choose two or three logs from each load or source of logs. Weigh these logs as soon as possible, record their weights, and permanently identify them by painting a number on them or attaching an aluminum tag. Then treat them like all the other logs. These logs can be weighed whenever an estimate of current log moisture content is required.

Choose another set oflogs to use in measuring initial moisture content. Again, select two or three logs from each load or source. Soon after the logs have been harvested, cut thin slices (about 1 inch thick) across the grain at least 6 inches from the ends of the logs. Put the slices in a plastic bag immediately to prevent them from losing moisture until they can be weighed. Weigh the slices to get their initial fresh weights. Place the slices in an oven at $200^{o}$ F for 6 to 12 hours. Reweigh several of the slices and put them back in the oven for 2-hour intervals until they stop losing weight. Then reweigh all the slices to find their oven-dry weights. The fresh weight minus the oven-dry weight equals the water weight that was present in the sample initially.

Water Weight = Fresh Weight - Oven-dry Weight

For example, if the initial fresh weight of the slice was 8 ounces and the oven-dry weight was 4.2 ounces:

Water Weight = 8 ounces - 4.2 ounces = 3.8 ounces

To calculate the initial moisture content of the logs, divide the water weight by the initial fresh weight of the slice and multiply by 100:

Initial Moisture Content = Water Weight/Fresh Weight x 100

For the example,

Initial Moisture Content = 3.8 ounces/8 ounces x 100 = 48 percent

Average the initial log moisture contents from all the sample slices to get the average moisture content for all the logs.

To calculate the dry weight of each of the reference logs, multiply the fresh weight of the log by 1 minus the average moisture content divided by 100:

Dry Weight = Fresh Weight x (1 - Average Moisture Content/100)

For this example, if the fresh weight of a log is 23 pounds:

Dry Weight = 23 x (1 - 48/100) = 23 x (1 - 0.48) = 11.96 pounds

Keep a notebook with the date, reference log number, initial fresh weight, dry weight, current weight, and log moisture content. Many growers write the dry weight and the reference log number on an aluminum tag and attach it directly to the reference log. Whenever it is necessray to know the log's moisture content, it can be calculated by subtracting the dry weight of the log from its current weight and multiply by 100.

Log Moisture Content = Current Weight - Dry Weight/Current Weight x 100

For example, if the current weight of the reference log is 20 pounds and we found earlier that the dry weight was 11.96 pounds:

Log Moisture Content = 20 - 11.96/20 x 100 = 40 percent

As the shiitake mycelium decays the logs, their dry weight changes dramatically. Therefore, this method provides a reasonable estimate of

the moisture content for only the first year or so after inoculation. For a more detailed explanation of how to determine log moisture content, refer to the **Shiitake Growers Handbook** by Paul Przybylowicz and John Donoghue, published in 1988 by Kendall/Hunt Publishing Company, Dubuque, Iowa.

**Moisture Management**

How well log moisture content is managed during spawn run has a major influence on the future productivity of the logs. The objective is to keep the interior moisture content between 35 and 55 percent while keeping the bark as dry as possible. An experienced grower can tell when logs need to be irrigated by their feel and appearance. The beginner, however, should carefully monitor log moisture content as described previously. An overhead sprinkler irrigation system is usually used to maintain log moisture during spawn run. When irrigation is required, soak the logs thoroughly. It is better to irrigate for long periods of time (6 to 12 hours) every week or two than to irrigate for an hour or two every few days. Extending the time between waterings allows the bark to dry, creating unfavorable conditions for the most common competing fungi and molds.

**Log Temperature**

Log temperature is also important for spawn run. For most strains, the optimum temperature for incubation is $72^{o}$ to $77^{o}$. Irrigation can quickly lower the log temperature if necessary, and solar energy can be used to warm the logs by orienting them so that they intercept the most sunlight. Be careful not to overheat them, however.

**Fruiting**

**Fruiting** of the shiitake fungus occurs after the mycelium has thoroughly colonized the logs. One sign that spawn run is almost complete is the appearance of mycelium on the log ends. It is usually white and fuzzy, but it may be brown from exposure to the air. The bark and outer wood will also feel slightly spongy, but the most obvious sign is the appearance of **primordia**, the beginning of mushrooms.

If the logs are left alone, seasonal changes in temperature and moisture will cause fruiting to occur naturally. For a steady supply of mushrooms, however, it is necessary to control fruiting time. This control can be achieved by carefully selecting shiitake strains, by soaking or sprinkle-irrigating the logs at specific times, and by using some type of structure to provide some control of temperature. Many growers restack the logs before fruiting occurs to provide more space for the mushrooms to grow and to facilitate harvesting. If rain is not in the forecast when fruiting is desired, the logs can be irrigated or soaked in water (Figure 8) for 24 to 48 hours to induce fruiting. As the logs dry, **pinning,** the appearance of mushroom primordia, occurs. Excessive moisture will lower mushroom quality; low humidity and drying winds will stop the mushrooms from growing. Protect the logs by covering the stacks loosely with plastic tarps or humidity blankets or by building simple rigid structures over the stacks. Mushrooms will usually appear within a week of soaking.

**Figure 8. Structure for soaking logs.**

It is possible to force fruiting on a fairly regular cycle. This tactic is recommended for commercial producers to ensure a continuous supply of mushrooms throughout most of the year. For forced fruiting, logs are soaked every two to three months. For winter production, the logs must be soaked and then stored in a heated building ($59^{o}$ to $68^{o}$F during the day; $50^{o}$ to $59^{o}$F at night) with the humidity kept between 60 and 85 percent. The fruiting season can be further extended by selecting a variety of strains with different fruiting requirements, covering the logs, and irrigating. Logs that are allowed to fruit naturally will produce for three to five years. Forcing reduces the productive life of the logs to two or three years.

**Pest and Disease Management**

A number of diseases can destroy the shiitake fungus or compete with it for water and nutrients. Some insect and animal pests can also reduce yields or quality.

Fortunately, if the environment in and around the logs is properly managed, disease fungi should not be much of a problem. The most common disease fungi in North Carolina are the **Trichoderma**, referred to as green molds; **Hypoxylon**; and **Polyporous versicolor**, a bracket fungus. To minimize disease problems, it is important to provide optimum growing conditions for the shiitake mycelium during spawn run. Keep the log moisture content between 35 and 55 percent, keep the bark as dry as possible, provide good air circulation, and do not expose the logs to direct sunlight.

Insects that might present a problem include termites, bark beetles, and springtails. Slugs and snails are probably the most commonly encountered pests of shiitake. They cause serious damage by feeding directly on the mushroom caps. Methods of control include sprinkling lime and wood ash around the stacks, putting a layer of gravel on the ground around the stacks, removing all dead leaves and other organic debris, and keeping the soil surface dry. Birds, squirrels, and deer also feed on shiitake mushrooms. Very creative strategies are required to protect the mushrooms from these animals. Growers have reported some degree of success in controlling wildlife damage by erecting scarecrows, keeping dogs in the area, leaving a radio on, or constructing a tall fence.

**Harvesting**

Daily harvesting is required during fruiting periods (Figure 9). Mushrooms should be picked while there is still a small curl at the edge of the cap, usually five to seven days after the mushroom first appears. Mushrooms should be cut or twisted off at the base of the stem. They should be gently placed into smooth-sided, clean, vented containers. Do not stack the mushrooms more than 6 inches high to prevent bruising. Cool the mushrooms as soon after harvest as possible to a temperature between $32^{o}$ and $36^{o}$F and maintain the relative humidity at about 85 percent. Under these conditions, the mushrooms will store well for at least two weeks. They can also be dried very successfully. The simplest way is to place them in a forced-air drier at about $120^{o}$F.

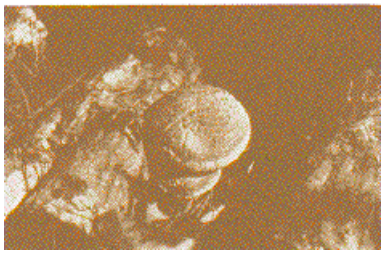

**Figure 9. Mushrooms ready for harvest.**

**Resting Period**

After harvest, the mycelium must be given time to accumulate nutrients for the next fruiting cycle. In forced fruiting systems, the logs should rest for at least 40 days. If forced to fruit too soon, the mycelium will be stressed, few mushrooms will be produced, and future production will probably be reduced. During the period of rest and regrowth, keep the logs warm and maintain their moisture content between 30 and 40 percent. Under natural conditions, logs will usually produce two crops per year, one in the spring and one in the fall. Forced fruiting can result in three to six crops per year. The number of fruiting cycles depends on tree species, log size, temperature, and moisture.

**Packaging**

Bulk shiitake mushrooms are commonly sold in 3- to 5-pound, vented, waxed cardboard boxes. They are also sold in small 2- to 4-ounce retail packages consisting of trays wrapped with a gas-permeable plastic film.

**Marketing**

Many people can grow shiitake mushrooms. The successful producers, however, are the ones who can also market them. If production is small and seasonal, marketing efforts should be concentrated in the local area. Marketing opportunities include high-quality restaurants, health food stores, local supermarkets, farmers' markets, tailgate markets, newspaper ads, and direct sales.

Before large-scale production is initiated, negotiations should be started with food service and produce brokers or directly with large-scale buyers of fresh produce. Some large-scale shiitake mushroom producers may also be interested in marketing other growers' mushrooms. Your county Cooperative Extension Service agent or a North Carolina Department of Agriculture marketing specialist may be able to advise you on opportunities in your area.

**Production Economics**

The final decision on whether or not to grow shiitake mushrooms commercially rests on economics. As stated earlier, detailed information on production costs and income is still being developed. Based on experiences in other areas of the United States and overseas, a cord of approximately 125 logs will yield about 500 pounds of mushrooms, or 4 pounds per log. At a selling price of $4 per pound, mushrooms from one cord of wood should generate $2,000.

Initial costs for obtaining one cord of logs, by either cutting or buying them, is approximately $100. The spawn for inoculation costs approximately $100. Production costs for labor, supplies, marketing, and amortized costs of refrigeration and irrigation amount to an additional $800 to $1,300. Returns to the grower for his or her labor, capital, and management should be approximately $500 to $1,000 per cord of logs.

Growing shiitake mushrooms can be profitable at today's market prices. Profit margins, however, will probably decrease as national production increases and supply approaches demand. The small-scale producer will face competition from large-scale producers as well as from companies that grow shiitake mushrooms on sawdust. The successful grower will be one who produces a quality product at minimum cost while developing and maintaining an effective marketing strategy.

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This pamphlet is a substantial revision of Woodland Owner Note No. 20, Growing Shiitake, by Michael Levi, Associate State Leader, CRD/ANR.

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