

FRUITING STRATEGIES AND FACILITIES FOR SAWDUST-BASED SHIITAKE PRODUCTION

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INTRODUCTION

Shiitake production on sawdust-based substrates is a new and developing technology in the USA and worldwide. Over the past two decades, shiitake production in the USA has grown from almost no production to 6.8 million pounds per year (USDA Agricultural Statistics Board, 1997). The percentage of shiitake grown indoors using sawdust-based production has increased dramatically over the same time period. We estimate that over 90% of fresh shiitake now produced in the USA is grown on sawdust-based substrates. Because of this increased supply and the further maturing of the market, average market prices have gone down. With this, the profit margin that farms can realize in the wholesale marketplace has become narrower. More than ever, it is imperative that shiitake farms keep their production costs low by making wise investment choices and sound management decisions.

There is no one *right* way to grow shiitake; there are many profitable ways. Not only is the technology evolving rapidly, but farm design and management strategies must be appropriate to local conditions and to the market being served. Growers must develop a production system for their unique set of climatic conditions and resources with a cost of production sustainably lower than their market price.

In order to help growers develop appropriate and profitable fruiting systems, underlying factors that influence farm design and crop management decisions will be examined. Next, fruiting strategies will be explored based on the biological needs of shiitake during the various stages of the fruiting cycle. Finally, the components of fruiting facilities and their requirements will be discussed, exemplified by a fruiting facility, designed for a specific set of conditions.

FACTORS DETERMINING FACILITY DESIGN AND CROP MANAGEMENT

Several interrelated factors shape the strategies and facilities used to fruit shiitake blocks. These include: a) market demand, b) climate, c) the resources and technologies available, d) the strain, substrate and incubation management used, and e) the

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OVER 90%
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SAWDUST

STRATEGIES
AND
FACILITIES
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FRUIT
SHIITAKE
BLOCKS

prevalence of disease and pest organisms. These factors are tempered by the grower's unique personality and economic constraints to shape the farm and its management. In designing a new farm, or in trying to understand the intricacies of an existing farm, it is useful to look at these factors individually to see how each influences farm management and design.

Market demand: A market-driven approach is essential; growers must grow for their markets. The farm must be designed and managed to supply specific market demands. A farm whose targeted market is seasonal can be quite different from a farm whose market requires a steady supply year-round. A farm whose projected market is for 50 to 100 pounds per week to local restaurants or farmers markets will be a different kind of farm than one supplying 500 to 1000 pounds per day to wholesale accounts.

A MARKET-
DRIVEN
APPROACH
IS
ESSENTIAL

Growers must consistently produce the quality and quantity of mushrooms needed, at a cost below their particular market prices. A farm supplying a market at \$7.00 per pound can afford to do things that a farm selling at \$3.50 would not be able to justify. A grower selling to a market with high quality standards would have to manage differently than one selling to a market where quality concerns are minimal. The first step in farm design is to understand the needs of your markets and develop an appropriate marketing strategy.

THE QUALITY
& QUANTITY
OF
MUSHROOMS
NEEDED

Climate: Each farm location has its own unique climate. The farm must be designed and managed to compensate for the weather that is likely to come its way.

EACH FARM
LOCATION
HAS ITS
OWN UNIQUE
CLIMATE

Shiitake is a temperate crop needing an environment for fruiting between 50° F and 75° F (10-25° C) with relative humidity in the range of 80%–95%. In areas of the world where temperatures stay within this range continuously or during seasons of the year where these conditions prevail, shiitake can be produced outdoors. Such is the case in southern China where shiitake is produced on sawdust-based *artificial logs* outdoors under straw-thatched shade coverings in fallow rice fields during the fall and winter.

As the climate diverges from the ideal, the cost of equipment for conditioning the air and the cost of facilities for maintaining a controlled environment increase. This puts space at a premium. Management must be such that it maximizes space utilization and minimizes heating and cooling needs. Insulated controlled-environment space can be better utilized by filling fruiting rooms with more blocks using space-efficient racking and by minimizing the length of the fruiting period. A farm in the tropics will be better served with strains that can be fruited at higher temperatures; lower temperature strains may be most appropriate in cool climates. Where needed, heating or cooling may be best restricted to those stages of the fruiting cycle where they are most critical. This calls for different rooms or zones on the farm where the environment can be managed for a specific stage of the fruiting cycle.

Resources and technologies available: The economic potential of a farm depends on the appropriate use of available resources and technologies. In areas where the labor resource is limited or expensive, investment in labor-saving equipment and management systems that minimize labor may be appropriate. Where labor is abundant and inexpensive, savings from labor-saving equipment and systems may not be justified.

Where possible, locally available equipment, building materials and techniques should be used. They are often less expensive and easier to service. Installing heating or cooling equipment that is exotic to an area may be too expensive to purchase and impossible to maintain once installed. In many areas there are under-utilized buildings that, with modification, could be used for shiitake production. The grower must determine if the costs and benefits of retrofitting these buildings outstrip the costs and benefits of constructing buildings designed specifically for shiitake production.

AMOUNT OF
INVESTMENT
CAPITAL WILL
HELP SHAPE
FACILITY
DESIGN

The amount of investment capital available and the cost of that money will help shape facility design. Most farms operate with a limited budget for investment in equipment and facilities. There is often a difference between what they want and what they can afford. As with any business venture, shiitake growers must see the potential to achieve a reasonable return on their investment. Where the cost of money or the rate of inflation is high, it is hard to justify investment in facilities, equipment or management systems that can only see their payback in the long term. Profitability depends on appropriate investment.

The history of mushroom production in a region contributes to farm design and management. In areas where shiitake has been grown using a particular management style, most start-up farms follow that style, often without regard for the system's merits. Where shiitake production is introduced into farms that produce other mushrooms, existing facilities and management styles are adapted to the new crop.

MUSHROOM
STRAIN
SELECTION
IS KEY

THE CHOICE
OF STRAIN
AFFECTS THE
ENVIRON-
MENT
REQUIRED

Strain, substrate and incubation management: Mushroom strain selection is key to any farm design and management. Shiitake strains differ in their environmental needs. Some need cool temperatures to induce mushroom production and develop mushroom primordia or pins. Others do not. Strains differ in mushroom quality in different environments. Most strains produce the highest quality mushroom in cooler temperatures but some maintain high quality mushrooms even in the heat. The choice of strain affects the environment required, so growers should take into account both the local climate and the cost of maintaining the desired environment as well as the market demands for quality.

Two main types of strains are in common use for sawdust production. There are those that are "fast and furious," producing mushrooms quickly but typically of only low to medium quality. Others are "slow and steady," having a longer production cycle but of higher quality. The fast types are typically managed with fewer fruitings. For these, usually only one or two fruitings are harvested compared to the 4 to 6 fruitings

taken from the slow strains. In general the fast strains are *warm weather strains* that do not require cool temperatures to fruit; the slow strains typically are *cool* strains that need cool temperatures to induce mushroom production. These differences impact all aspects of the farm: how big it must be, what temperatures must be maintained, the kinds of equipment needed, the labor needed for crop management and the quality of the mushrooms produced.

The substrate formula, size of the sawdust block and the management of the block during incubation also impact management during fruiting. Each of these factors influences the production potential of a block. Some combinations of strain, substrate and incubation management will cause blocks to produce heavily on the first fruiting, after which the blocks should be discarded, as subsequent production is limited. The farm should be managed accordingly.

In parts of France very large shiitake blocks are produced having a wet weight of 12 to 15 kilos (25-35 pounds). Fruiting racks must accommodate these larger blocks. These blocks are too large to soak in cool water between fruitings as is commonly done with smaller (2.5 kg) blocks to induce subsequent fruitings. Here, block size not only influences rack design but also crop management.

Where blocks have been removed from their bags during incubation for a curing period before fruiting, the farm must have facilities to soak blocks in water to induce the first fruiting. Where blocks are incubated fully in the bag this first soaking is not needed.

Diseases and Pests: Crop management must provide for control of diseases and pests. Long term viability requires shiitake farm design and crop management to address control of bacterial and fungal disease organisms as well as a host of invertebrate pests such as mushroom flies and mycophagous mites.

Farm design and management must take into account the unique disease and pest organisms prevalent in the farm area. Initially, new farms in areas where mushrooms have been produced for some time or where wood rotting mushrooms abound in nature will have more pressure on their crop from disease and pest organisms. This is because populations of these organisms will already be high. In time, however, all shiitake farms will be faced with populations of new disease and pest organisms adapted to their newly created niche—the mushroom farm. Options for disease and pest intervention should be built into all shiitake farms

FRUITING STRATEGIES

There are many strategies for producing mushrooms from colonized shiitake blocks. All successful strategies must accommodate the environmental and biological needs of shiitake, which differ from one stage of the fruiting cycle to the next. These needs are outlined below by fruiting cycle stage. This is followed by descriptions of some common fruiting room systems designed to manage the fruiting cycle to optimize mushroom production and minimize the impact of pests and diseases.

LONG TERM
VIABILITY
REQUIRES
CONTROL OF
BACTERIAL
AND FUNGAL
DISEASE
ORGANISMS

SUCCESSFUL
STRATEGIES
MUST AC-
COMMODATE
ENVIRON-
MENTAL AND
BIOLOGICAL
NEEDS OF
SHIITAKE

THE FRUITING CYCLE OF SHIITAKE

Shiitake production has three main phases: 1) the preparation and inoculation of substrate, 2) the incubation of shiitake in the substrate, and 3) the fruiting cycle where mushrooms are produced. Typically, separate facilities are used for each of these phases. The sawdust-based substrate is prepared by: mixing in supplements and water, bagging and heat-treating this mixture to eliminate competing organisms, and finally inoculating the bagged mixture with active shiitake mycelium. During incubation shiitake mycelium breaks down the substrate and accumulates nutrients needed for producing mushrooms. Shiitake is usually incubated for two or three months in the cultivation bag, housed in a 70° F- 75° F environment before it is ready to produce mushrooms. With some incubation systems the cultivation bag is partially or completely removed after several weeks. Then incubation is completed in three to five weeks with the substrate out of the bag in specially controlled curing rooms.

Once blocks have been fully incubated and are ready to produce mushrooms, they can enter the fruiting cycle (Figure 1). To begin the fruiting cycle, shiitake must be induced to shift from vegetative growth to mushroom production by environmental cues such as shifts in: temperature, the substrate water content and their gas environment. After induction, small mushroom primordia or "pins" form below the block surface. Pins continue to grow and develop over a 3 to 7 day pinning period after which distinct caps and stems are discernible. "Fruitbodies" or mushrooms mature from these pins and are typically harvested within 10 to 20 days after induction during the fruiting period. Blocks are then given a resting period of 7 to 10 days where shiitake resumes active vegetative growth. Blocks are then induced to produce another crop or break of mushrooms to start another round of the fruiting cycle. Depending on the management system, one to six fruitings are harvested before the blocks are discarded.

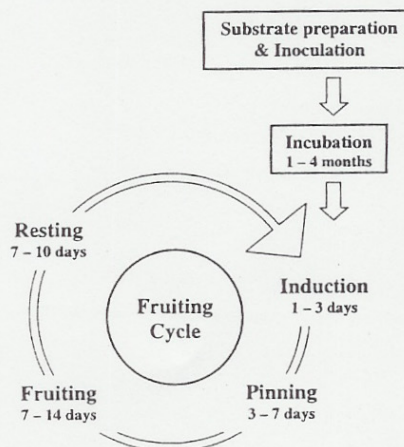


Figure 1. The fruiting cycle of shiitake on sawdust-based substrates.

Each stage of this fruiting cycle—induction, pinning, fruiting and resting—has a unique set of environmental conditions that are optimal for a given strain. It is the responsibility of individual growers to understand the specific needs of their strain and manage the blocks and the farm environment accordingly.

Although individual strains differ in the environmental conditions needed for each stage of the fruiting cycle, it is important to consider the conditions required by a broad range of strains when designing a farm. The following is a general description of conditions needed by a range of strains during the fruiting cycle and how these conditions can be used to manage the crop.

Induction: Blocks that have been incubated fully in their cultivation bag can be induced to produce mushrooms by removing all or part of their bag and placing them into a fruiting room environment that is cooler and more moist than their incubation environment. The environmental cues of a drop in temperature and a shift in gas concentrations compared to the environment in the closed bag induce mushroom production.

Blocks that are out of their bag, after having fruited, or after incubation out of the bag in a curing room, will need to be re-hydrated as a part of induction. This is often done by submerging the blocks in cool (50° F-60° F) water. Alternatively, blocks can be induced to fruit by irrigating them or injecting them with water, in conjunction with a shift in room temperature. These practices re-hydrate blocks after fruiting and cause a shift in the block temperature. They also force air out of the block, changing the gas concentrations inside the block. These cues induce pinning.

If soaking is the only environmental cue that is given for induction, pinning and subsequent mushroom production will be very synchronous. All mushrooms will mature from a single induction event. This allows for rapid cycling of the blocks through fruiting. It can also result in the production of many smaller mushrooms. With a single induction event, pins will compete for water and nutritional resources in the block as they all mature at once. Providing more than a single induction event by fluctuating the temperature (50° F to 68° F) daily in and out of the induction range (50° F - 60° F) over a period of several days will make the production less synchronous. This lengthens the fruiting cycle but mushroom quality is typically enhanced because fewer, but bigger mushrooms are produced.

Pinning: This stage is the most sensitive to environmental conditions. Young primordia develop just below the block surface where they can easily abort if temperatures are not favorable or if they dry too rapidly. The temperatures needed are strain dependent but range between 55° F and 75° F. Most *cool-weather* strains will not pin above 60° F - 62° F. *Warm* strains can tolerate higher pinning temperatures.

YOUNG
PRIMORDIA
DEVELOP
JUST BELOW
THE BLOCK
SURFACE

The evaporation rate should be low during pinning to avoid drying of the developing pins. The rate of evaporation from the block surface is determined by: the temperature and relative humidity (RH) of the air (which dictate how much water a volume of air

can hold), and the amount of air passing by the block per unit time. For pinning, the temperature should be low (55° F-65° F), the RH should be high (90%+), the air speed in the room low, and ventilation at a minimum (0.5 air changes /hr., 1,500-3,000 ppm CO₂).

Irrigation may be needed during this stage to avoid excessive drying of the blocks. However if the block surface is kept too wet, drying of the block interior will be too slow. This delays pinning and increases the chance for bacterial infection.

Fruiting: Temperatures can be higher during this stage (60° F-75° F) and the rooms can be drier. The RH can be 80%-90% with more air movement in the room. More ventilation (0.5-1.5 air changes/hr) is typically needed to purge excess humidity and CO₂.

High CO₂ concentrations in the room will cause the stems to be longer, resulting in more waste if the market demands a short stem length. Strains differ in their sensitivity to CO₂; some have long stems even at 800 ppm, whereas others will tolerate 2,500 ppm.

Most shiitake strains will produce a higher quality mushroom under cooler conditions (60° F to 65° F) Some strains produce quality mushrooms at higher temperatures but their shelf life is typically shorter unless grown very dry.

Irrigation is not advised during fruiting unless followed immediately by aggressive drying. Wet mushrooms do not store well and are not well received in the marketplace. A persistent film of water on mushroom caps and block surfaces is the ideal breeding ground for bacterial disease.

Resting: Warmer temperatures facilitate more vigorous vegetative growth. If the temperature can be raised during resting, the time needed to renew nutritional resources is reduced, shortening the fruiting cycle. Elevating the block temperature at the end of resting allows for a greater shift in temperature for inducing the fruiting cycle.

Likewise, if blocks are drier at the end of resting, a greater shift in block moisture content is possible at induction. Drying the blocks during resting is effective at curbing populations of contaminants on the block surface. Typically, resting temperatures should be higher (65° F-78° F) than pinning or fruiting temperatures. Drier conditions are common with RH between 75%-85%, more air circulation, and more ventilation or dehumidification to get rid of excess humidity

FRUITING-ROOM SYSTEMS

Shiitake management systems differ in the number of rooms used to manage the various stages of the fruiting cycle. The most common system uses only one room for all stages of the fruiting cycle, other systems use two or more rooms. Each system has distinct advantages and disadvantages.

MOST
SHIITAKE
STRAINS
PRODUCE A
HIGHER
QUALITY
MUSHROOM
UNDER
COOLER
CONDITIONS

One-room fruiting systems have blocks of all ages and in all stages of the fruiting cycle housed in one room. Each week a subset of new blocks is added to the room to replace a set of discarded blocks to assure a continuous mushroom supply. Additionally, where blocks are fruited multiple times, groups of blocks that have finished resting after each successive fruiting are soaked to induce subsequent breaks each week. Consequently, at any time this one room contains blocks that are pinning, fruiting and resting--all under one environment. The oldest and most diseased blocks share the room with the youngest, most pest- and disease-free blocks.

The main advantage of this system for smaller farms is that only one room and one environmental control system is needed to achieve a steady supply of mushrooms. The disadvantages are that the room environment cannot be optimized for any one stage of the fruiting cycle and the spread of pests and disease goes unchecked.

Growers using a one-room system must either maintain cool, moist conditions favorable to pinning or allow the room to fluctuate daily between pinning conditions and the warmer, drier fruiting conditions. The ability to dry down the room to control bacterial populations is limited by the moist environmental conditions needed by blocks that are pinning. Likewise, blocks that are in their resting stage are typically wetter and cooler than is optimal.

ONE-ROOM SYSTEM

There is never a time when the fruiting room can be emptied and sanitized to break the build-up of pest and disease populations. Once disease organisms are established in these rooms, it is difficult to manage the crop to minimize their impact.

Two-room fruiting systems are typically designed with one room controlled for a specific stage of the fruiting cycle. Blocks are moved from one room to the next, depending on their stage. There are three main types of two-room systems: one using a separate resting room, another using a separate pinning room and the third having a room reserved for first-break blocks.

TWO-ROOM FRUITING SYSTEMS

- 1) Resting-room system: This two-room system uses one room for resting and the other room for pinning and fruiting. The resting room is kept warmer and drier; the pinning/fruiting room is kept moist and cool for pinning. The blocks in the resting room can be spaced closer together than in the pinning/fruiting room because no space is needed between blocks for harvesting during this stage.

RESTING- ROOM SYSTEM

An advantage of this system is that less production space is needed per pound of mushroom produced per week compared to a one-room system. This is partially because of the tighter block spacing in the resting room. The warmer conditions in this room also reduce the time needed for the resting stage, shortening the fruiting cycle. The build-up of disease and pest populations on the block surfaces is interrupted by the dry conditions in this room. Blocks in this non-fruiting room can be treated with disease and pest controlling agents that would not be allowed in rooms where mushrooms are being harvested.

A disadvantage of this system is that labor costs are higher due to the need to move blocks between rooms after fruiting. Additionally, the pinning/fruiting room must be controlled primarily for pinning. Often these conditions are cooler and wetter than is optimal for blocks that are fruiting. In warm climates, maintaining pinning conditions for fruiting blocks may be cost prohibitive. Mushroom caps are typically thicker and larger when the temperature fluctuates daily during maturation to a degree unacceptable for pinning blocks. With most strains, shelf life is improved if the fruiting conditions are drier than is optimal for pinning. Control of bacterial diseases on mushroom caps during fruiting is facilitated by drier conditions than is generally possible in rooms with pinning blocks.

**PINNING-
ROOM
SYSTEM**

- 2) Pinning-room system: A second two-room system uses a room controlled specifically for pinning. The blocks in this pinning room can again be spaced closer together because no harvest is expected. This room is maintained cool and moist within a narrow range (55° F-57° F and 95% RH). Once pins have formed, the blocks are carefully moved into a second fruiting/resting room where the environmental conditions are drier and warmer than the pinning room. The temperature in this second room can be allowed to fluctuate daily to speed fruiting and resting while maintaining good mushroom quality.

Advantages of this system are that the environment around the blocks in this most sensitive pinning stage can be finely controlled, resulting in a more reliable pin set. Space is well utilized. There can also be some disease control advantage. Blocks straight out of their incubation bags and those that have just been soaked to induce fruiting using a disinfectant in the soak water to reduce populations of disease organisms are the most disease free blocks on the farm. They are separated with this system from more heavily diseased blocks until their pins emerge.

**FIRST-BREAK
ROOM
SYSTEM**

- 3) First-break room system: A third type of two-room system is focused on disease control on farms taking several fruitings from each block. One room is used only for fruiting blocks fresh from incubation. After their first fruiting, resting and soaking, blocks are moved from the first-break room to a second room for all subsequent fruitings. Blocks straight from incubation are the least diseased and the most susceptible to infection by diseases and pests. The main advantage to this strategy is that fresh blocks are separated from the high pest and disease loads associated with older blocks. There is little extra labor involved in switching rooms after soaking. The environment in each of these two rooms is managed like a one-room system with all the associated disadvantages.

**MULTIPLE
CROPPING-
ROOM
SYSTEMS**

Multiple cropping-room systems are perhaps the ideal for disease control and the ability to optimize the environment for each stage of the fruiting cycle. With these systems all blocks in a room are of the same age and at the same stage of the fruiting cycle. The room is managed as a single crop with the room environment modulated according to the crop stage. Disease control is facilitated because blocks are isolated from those of different age. Stage-specific disease or pest mitigation is possible, and once the crop is complete the rooms can be emptied and disinfected before a new crop is loaded into the room.

The main disadvantage of this system is cost. To achieve a steady weekly production of mushrooms one such cropping room, with all its environmental controls, would be needed for each week of the fruiting period. A farm taking five fruitings per block over a fifteen-week period would need fifteen cropping rooms. This system can be economical if the farm is large enough so that each room holds several thousand blocks.

This system is usually cost prohibitive for smaller farms. However, in areas where many small farms are marketing together, a steady weekly supply can be orchestrated with each farm managed as one or more cropping rooms. Fill dates and soak dates need to be staggered among farms so the same number of rooms or blocks are induced to produce mushrooms each week. This type of scheduled production is used in Ireland for producing fresh-market *Agaricus* where small family farms fill two to four crop rooms. These small satellite farms pool their production through a mother company with other farms on different fill schedules to achieve a steady supply for their market.

A four cropping-room system is a modification of a multiple cropping-room system where blocks in each room are in the same stage of the fruiting cycle but are of different age. Each room contains four groups of blocks, one group fruiting for the first time and a second, third and fourth group on their respective fruitings. All blocks in a room are pinning, fruiting or resting at the same time. The room environment is managed in each room for the crop stage of the blocks in that room. A steady production is realized by inducing only one room to fruit per week. At any one time one room is pinning, another is resting and two are picking.

**A FOUR
CROPPING-
ROOM
SYSTEM**

With this management the entire room is emptied at once. To empty the room one group of blocks is discarded after its fourth fruiting. The blocks that just finished their first, second or third fruitings are soaked to induce subsequent crops. While the room is emptied it can be disinfected. The room is then refilled with three groups of blocks from the soak tanks and one group of new blocks to replace those that were discarded. At this time the room environment is controlled for pinning. Once pins have formed, the room environment is modulated to fruiting conditions for the harvest, then to resting conditions. After this the room is again emptied for another cycle.

This system has several advantages. The room environment can be optimized for the crop stage. Each room is emptied between fruitings, allowing the rooms to be thoroughly disinfected. Fruiting-stage-appropriate disease intervention is also possible. The number of environmentally controlled rooms needed to achieve a steady weekly production is less than a standard multiple cropping-room system.

The main disadvantage of this system is that new blocks are grown with older, more diseased blocks. This system is also most appropriate where larger room sizes can be used to offset the higher cost of each room's environmental control equipment. All of the blocks from a room must be soaked at once to synchronize the crop induction and to empty the room for disinfecting. Therefore, many more soak tanks are needed than if a one-room system is used.

NO TWO
FARMS ARE
ALIKE

There are other management systems for controlling the crop through the stages of the fruiting cycle. The fruiting facilities must be appropriate to the management system used. Where room conditions are to be modulated to accommodate different stages of the fruiting cycle, appropriate heating, cooling and ventilation equipment must be in place. Management systems with less stringent environmental control requirements can get by with less such equipment. The design of the fruiting facility is a synthesis of many different factors, including the management system.

FRUITING FACILITIES

Shiitake production on sawdust substrates is a new and developing technology. Consequently, almost no two farms are alike even if they are using identical strains in the same locality and marketplace. Fruiting facility designs are evolving rapidly, drawing on the experiences of existing farms.

There are basic design requirements for environmental control and disease management that any fruiting facility design should incorporate. The specific types and capacities of equipment used to fulfill these requirements will be unique to each farm's circumstances.

Where heating and/or cooling is needed, it is advisable to analyze the heat loss and gain of the facility based on local climate and the target crop environments. This information should be used to size equipment and optimize building insulation. Air handling systems that move air in and through the fruiting house must be sized appropriately to the facility and its management to deliver needed air volumes at desired air speeds.

General fruiting-house design requirements are given below. This is followed by one of our shiitake fruiting-house designs to illustrate a synthesis of these basic design requirements for one specific set of climatic conditions, resources and markets.

Heating. Where heating is required, the availability and costs of fuel and technologies will influence the source of heat. Heat supplied to the room at lower temperatures is typically preferred so that the drying of the air is minimized. Hot water heating systems can deliver heat to the room with coil temperatures below 150° F Heat should be delivered evenly to the room either with a heat exchanger placed in the return stream of recirculation air or with hot water piping distributed around the room.

Cooling. Several modes of cooling can be used, depending on climate and resource availability. When outside temperatures are cool enough, fresh air can be used for cooling. Large volumes of fresh air needed for cooling a room often require humidification. In dry climates, evaporative cooling can be used to cool rooms where a large volume of air is brought through a water-holding pad. As the air passes through the pad it evaporates water, cooling the incoming air. It is usually not possible to drop room temperatures on demand with these systems, particularly if the outside air is humid.

In most cases, refrigerated cooling coils are needed to take heat from the room air. Cold refrigerator coils condense water from humid air. This condensed water can then freeze on the coils, making them very inefficient. It is better to run these coils at warm temperatures to minimize these effects. For this, it is advisable to use refrigeration evaporator coils that are sized larger than their condensing unit. Standard air conditioning units are easier to modify in this way than are heat pumps.

Humidification/dehumidification. Control over drying is essential to shiitake production. Water, as free water and as vapor, is needed during the fruiting cycle. Consequently fruiting rooms must be designed to handle this water load. They should have floors that drain water and be made of materials impervious to water and water vapor.

WATER IS
NEEDED
DURING THE
FRUITING
CYCLE

In most climates the air must be humidified. Walls, floors and, at times, blocks can be irrigated by hand or mechanically to raise the room humidity. Alternatively, misting, fogging or steaming systems can be used to put vapor directly into the air stream. Steam systems are only appropriate in cold climates as they add substantially to the heat load. Cool-mist fog-nozzles can be placed directly in the air distribution tube in the fruiting room to achieve uniform humidification. Wet areas in the room from non-uniform humidification are often plagued with bacterial disease problems. Humidification systems are often best controlled by timers as humidistats are generally ineffective at the higher humidities used on shiitake farms.

Fruiting rooms can require dehumidification at times to remove excess water. Moist air can be removed from rooms by ventilation, provided that the outside make-up air is dry enough and at a desired temperature. Alternatively, air conditioning and heating systems can be run simultaneously, which will cause water to condense from the warm room air onto the refrigeration coils, drying the air in the room.

Ventilation. Fresh air is needed in fruiting houses to purge excess CO₂ produced by the growing shiitake mycelium. The room temperature can be adjusted using ventilation when the outside conditions are favorable. Fresh air can also be used to remove water vapor from the room. Ventilation capacity should be designed to exchange from a minimum of one-half air change per hour to at least two air changes per hour.

PURGE
EXCESS CO₂
PRODUCED
BY SHIITAKE
MYCELIUM

There are several methods for ventilating fruiting rooms: fresh air can be blown in, stale air can be sucked out or fresh air can be pulled in. Regardless of the method used, air inlets must be sized for air outlets. Fresh air will only come in if there is a way for stale air to get out.

When the temperature or humidity of outside air needs to be altered for the crop, it is best to mix the incoming fresh air with air being recirculated within the room. This tempered mixture is then fully conditioned before it is discharged onto the crop. The best system is to blow fresh air into the stream of recirculation air before it is conditioned. This creates a positive pressure in the fruiting room that automatically

opens exhaust vents with gravity louvers. Alternatively, the stream of recirculation air can pull in fresh air by venturi effect as it passes a louvered inlet. This system will not automatically open exhaust louvers.

Fresh air inlets and exhaust vents should be screened with a fine 100-mesh screen to exclude insect pests. These screens must be cleaned regularly to remove deposits of spores that impede airflow.

Air circulation. Air should be circulated within the fruiting room to avoid stratification of temperature or gas concentration in the room. Warm air tends to rise and CO₂ tends to sink. Gentle, almost imperceptible mixing of the air is all that is needed.

The air speed in the room also influences the evaporation rate. The more air that goes by a block in a given time, the more water that block will lose. Consequently circulation can be used to control the drying of the blocks. For example, room air speed can be increased after irrigation to dry off the mushroom caps and block surfaces. Alternatively, room air speed can be reduced around pinning blocks to decrease drying.

The objective of any room air circulation system is to get even air speed throughout the crop area so the rate of drying and temperature will be uniform. This is typically achieved using perforated plastic convection tubing run above the crop racks along the length of the room. Air is continuously moved through this tube with a recirculation fan, which pulls air through heating and cooling coils. Humidification jets are often located in this convection tube so that the air exiting is fully conditioned.

The air inlet to this air handling system should be filtered to exclude shiitake and other spores from depositing on the heating or cooling coils and on the fan blades. This filter should be changed at least once per week.

LIGHT INTEN-
SITY AND
DURATION
WILL AFFECT
MUSHROOM
COLOR

Light. Light influences the color of the mushroom caps. Low light levels will result in light colored mushrooms; higher levels produce darker mushrooms. Growers must produce the color of mushroom in demand with their market. Both natural light and cool white florescent light can be used. Light intensity and duration will affect mushroom color. The warmer the fruiting room conditions the more light will be needed. Many growers use a lighting cycle of 8 hours on and 16 hours off per day in their rooms.

Pest and disease control. Other pest and disease control considerations are needed in addition to filters recommended on the recirculation inlet and screens on the ventilation inlets and outlets. All surfaces, including walls, ceilings, floors, air-handling systems, fruiting racks, transfer carts, soak tanks, ladders and picking baskets should be washable, smooth and able to withstand disinfectants. Wood surfaces should be avoided because they harbor pest and disease organisms and are difficult to sanitize. If rooms are to be steamed off between crops, all building materials must be able to withstand high temperatures and saturated air.

Provisions for materials handling and harvesting. One of the largest costs of production on most shiitake farms is the labor needed to move blocks and to harvest mushrooms. Even on farms where the cost of labor is low, much of the day's activity is spent moving mushrooms or blocks. Consequently, farms should be designed around materials handling needs.

LARGEST
COST OF
PRODUCTION
FARMS IS
THE LABOR

Farms typically use some form of racking systems to hold blocks during the fruiting cycle in order to more fully utilize space. There are many different kinds of racking systems. These range from very primitive bamboo systems to specially designed aluminum systems, where air handling is an integral part of the shelving. *Agaricus* rack systems are often modified for shiitake production by covering the bed boards with plastic. Common *Agaricus* racking is 16 to 18 feet tall with a cat walk half way up between racks for picker access to the top shelves. Alternatively, ladders are used or the rack height is kept low. Other systems hold blocks on pairs of metal rebar, galvanized electric conduit or plastic tubes located on opposite sides of vertically oriented wood or galvanized metal 2" X 4" framing material.

Regardless of the construction, blocks must be accessible to pickers. The longest comfortable reach for a picker is less than 2.5 feet, making five feet the maximum shelf width. Many farms use narrower racking systems for ease of block handling and mushroom picking. Typical block spacing during fruiting is close to one block per square foot of shelf space. For example, a three foot deep shelf can hold three 5.5 pound (wet weight) blocks across the width, at a spacing of one block per lineal foot of shelf length.

TYPICAL
SPACING
DURING
FRUITING IS
ONE BLOCK
PER SQUARE
FOOT OF
SHELF
SPACE

Racking systems should be made of materials with surfaces that can be sanitized. Wood racking will harbor disease and pest organisms, and can fail structurally after several years.

Aisles should be wide enough to accommodate harvesting and the movement of blocks. Some farms use wide aisles so blocks can be moved directly from the fruiting racks to movable soak tanks. The labor saved during soaking can offset this loss in fruiting space. Each farm will reach its own balance between the need for space utilization and the constraints of efficient materials handling.

Integrating the various components of a fruiting facility into the specific set of farm conditions and constraints within a desired crop management framework can be a daunting undertaking. In most cases, there will be some trial and error involved in optimizing the system. Exposure to the trials and errors of others is invaluable in avoiding common pitfalls. We have worked with and designed shiitake farms around the world: very few are alike although many are profitable. One specific fruiting-house design follows as an example of a synthesis of components for a specific region, having a market demand for consistent weekly production.