Mushroom Substrate Preparation Odor-Management Plan

PENNSTATE

1855

College of Agricultural Sciences

Introduction

Over the past decade or more, the increased interest in municipal and feedlot waste composting has attracted the attention of environmental protection and regulatory agencies as well as neighboring communities. In the mushroom industry, it is important to emphasize the difference between the farming of mushrooms by preparing a selective substrate and what other industries do to make compost. (Mushroom composting is high-temperature [greater than 150 degrees Fahrenheit], whereas municipal-waste or green-waste composting is done at low temperatures [less than 150 degrees Fahrenheit].) The purpose of a management plan is to describe the substrate-preparation process, its operational variables and limitations, suggested testing and monitoring procedures, and to provide a contingency plan to minimize or avoid impact on the environment while maintaining substrate quality. Producing a substrate for the mushroom crop is the first step in mushroom cultivation for the white and brown commercial mushrooms. Poorly prepared substrate will result in lower yields and poor-quality fresh product that will negatively impact the profitability of the farm. Materials used in this substrate-preparation process are high in soluble nutrients that need to be kept separated from the natural water and land resources. Water is a key component in the process and excess water leachate is collected and managed for reuse in the process; because this recycled water is laden with soluble nutrients it needs to be kept separate from natural water resources.

A substrate is defined as a surface on which an organism grows or is attached. Compost is a mixture of decaying organic matter used to improve soil structure and provide nutrients. Composting is the process by which organic matter converts to compost for mushroom cultivation. Farmers use a composted substrate, defined as organic matter decomposed into a media for organisms (in this case, mushrooms) to grow on. A chain of chemical reactions and microbial decomposers, of which the mushroom is an organism in the chain, complete the composting for mushroom substrate preparation.

For the purpose of this plan, the term “process” or “activity” comprises the progression from receipt of raw bulk and supplement ingredients through the production of the finished mushroom compost, including the treating, handling, and storage of all materials and wastes relating to the process. Mushroom substrate describes the composted material used to grow a crop of mushrooms, whereas mushroom compost (spent mushroom substrate/compost) describes the material left after a crop of mushrooms is finished. Mushroom substrate preparation can be separated into various stages, often described as pre-wet, preconditioning, and Phase 1; however, these terms are not universally applicable.

Description of Mushroom Substrate

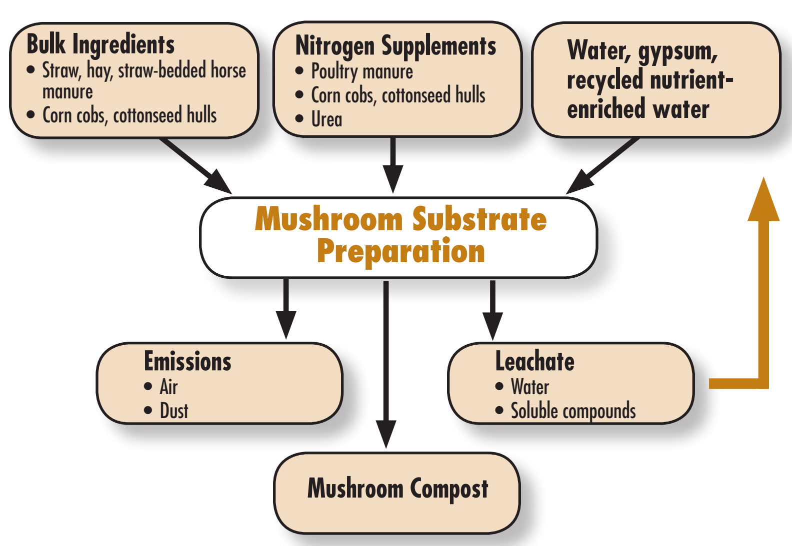
Mushroom substrate preparation involves two independent and interrelated processes: Phase I and Phase II (Schisler, 1983). Phase I is a primarily high-temperature chemical reaction process that completes the active fermentation of soluble carbohydrates, combining nitrogen (N) with carbohydrates to form complex N-lignin materials used by the mushroom. Phase II composting is the low-temperature microbial process, further decomposing Phase I bulk ingredients to eliminate soluble carbohydrates in favor of lipid and protein creation for mushroom consumption. One benchmark a composter should use to determine the success of Phase I is the conversion of ammonia to protein in the time allocated for Phase II. One objective for the substrate preparation process is concentrating and preserving carbon in a form that the mushroom and Phase II microbes can use as food. Many of these conversions take place in the high-temperature chemical reactions achieved in mushroom substrate preparation. These high-temperature reactions differ from municipal- and feedlot-waste composting. Another objective is the change and concentration of the nitrogen compounds in both quality and quantity. The last objective, unique to substrate preparation, is to increase the water-holding capacity of the bulk ingredients.

Compost ingredients nourish many microorganisms. With the building of the pile and the addition of water to the dry ingredients, these microbes grow and reproduce. In addition to a suitable temperature, microbes need available nitrogen and carbohydrates to grow and reproduce. During the composting process, these microorganisms also require oxygen. Without sufficient levels of oxygen, anaerobic conditions exist and can result in the production of offensive odors. Oxygenation is achieved by natural convection in conventional outdoor ricks. Ambient air enters through the sides of the stack, is heated, and rises upward in a process commonly referred to as the chimney effect. A lack of oxygen may occur after large quantities of water are added to the dry bulk ingredients, before sufficient heat is generated to start the draw of oxygen into the pile.

Later in the process, more chemical reactions take place. Although these reactions require less oxygen than the microbial phase, anaerobic conditions may still occur. As the substrate density increases during the process, it becomes more difficult for air to penetrate the pile from the sides. Phase I is considered complete when: the raw ingredients become pliable and are capable of holding water, the odor of ammonia is sharp, Mallaird browning reactions have occurred, and the compost turns to a dark brown color indicating carmelization.

Protecting water and air resources during substrate preparation involves efficient design and tidiness of operation with good housekeeping and water management. A well-run operation will appear clean, with very little leachate or still water present on the concrete slab, well-made and orderly windrows and ricks, and clean, well-maintained equipment. Employees, with the assistance of an on-site written contingency plan to protect the environment, should be properly trained to react during any environmental or operational crisis.

Figure 1. Process flow diagram.



Phase I: Mushroom Substrate Preparation

Site Details

The substrate-preparation area should be of adequate size to have room for the pre-wet piles, ricks, and all movement of raw materials. To prevent any impact on the environment, supplement storage locations should be chosen by considering the potential of soluble-nutrient leachate. It is desirable to store high-nutrient leachable materials, like poultry manure, under a covered area. Ingredients that cannot produce soluble nutrient leachate may be stored uncovered on unpaved ground. The location of raw material storage should be chosen with the consideration of traffic and the tracking of materials in relation to the ricks or forced-aeration composting facilities. The substrate-preparation area must be paved or covered with an impermeable material, and sloped so that all water and leachate flows towards an impervious collection area. A roof covering all or part of the substrate preparation will minimize the potential for soluble manure nutrients to impact ground and/or surface water (Figure 2). A roof will also minimize the leaching of nutrients into the site lagoon or holding tanks.

Collection basins should be designed and constructed to contain recycled nutrient-enriched water. The basins need to be agitated or aerated to reduce anaerobic activity, odors, and the settlement of solids. Screens and filters should be used to minimize the large solid particulates from entering the collection basins and kept out of the waste stream. A controlled amount of these extracted solids can be incorporated into the substrate preparation process. Wastewater can also be applied to mushroom compost storage piles or spread on crop fields in accordance with the land application procedures identified by the Mushroom Farm Environmental Management Plan (MFEMP).

Creating visual barriers to block windrows, storage structures, and wharfs from residential or community areas lessens the human perception of odor. Tree or vegetative barriers are ideal because, with certain varieties, the leaves actually absorb some of the odor-causing compounds. Barriers can create a change in direction for the wind's course. When a plume of air hits a barrier of trees, it is sent barreling upwards, away from the earth.

Figure 2. Substrate preparation with a covered roof.

Compost Components

Most of the ingredients used to make mushroom substrate are recycled agricultural by-products. The substrate used for growing mushrooms is produced from a mixture of bulk ingredients like straw, hay, and straw-bedded horse manure. The various manures provide nitrogen, and it is known that the more poultry manure a formula contains, the more intense the odors from the process will be. However, it is not cost-effective to use only non-manure supplements in a formula. Carbohydrate supplementation consists of cottonseed hulls and corn cobs, which add some bulk, balance the nitrogen-rich supplements, and provide heat to the process, which is especially valuable during the colder weather. The last ingredient is gypsum (calcium sulfate [$CaSO_4$]), which is a flocculating agent used to prevent greasiness. Although gypsum is a source of sulfur in the substrate, and sulfur is an element associated with many unpleasant emissions (e.g., hydrogen sulfide), it has been shown that the amount typically used has no significant influence on the amount of odors produced.

Inventory for each ingredient should be compatible with production requirements and have a minimum level kept on-site. Deliveries of poultry manure should be managed to have a minimum of one- but no more than a two-week supply on-site. Poultry manure should be maintained in an aerobic condition and stored under cover. All areas associated with the composting process (excluding the liquid treatment ponds and collection tank) should be kept free from the accumulation of runoff and compost leachate.

Pre-Wet Processing

The production of mushroom substrate begins with relatively dry raw materials. An essential component for successful Phase I composting is the uniform mixing and wetting of these bulk ingredients. The pre-wet processing systems are becoming increasingly complex with the introduction of stationary mixing lines and/or pre-wet turning machines. Some farms have implemented aerated floors during the pre-wet stage, while others use pre-wet bunkers or silos. The length of pre-wet time prior to the initiation of Phase I varies among farms, with some using a two-week pre-wet process. While an effective pre-wet process is important, care must be taken to avoid excessive wetting that impedes the flow of air into the substrate material and creates an anaerobic condition.

For pre-wet or pre-conditioning, ensuring that bulk ingredients are uniformly mixed and wetted is critical, along with frequently turning the piles for adequate aeration. The primary objective of the pre-wet process is to "de-wax" the straws, achieved by microbial and chemical activity. Sufficient water is needed to create and maintain microbial activity. However, during this stage, there is a very high oxygen demand inside the compost pile. Growers need to apply enough water to wet all straws for the microbes to grow, but too much water will fill the air spaces and create a lack of oxygen, resulting in anaerobic conditions and offensive emissions. It is suggested that during the pre-wet stage, the large windrow pile be turned or flipped every 24 to 48 hours to provide sufficient aeration, without sacrificing heat during the colder weather. In general, the length of time required to mix and pre-wet should be short to achieve less dry-matter loss and less time for the pile to go anaerobic. During the pre-wet process, large volumes of water are applied, but some or much of it will quickly leach from the pile. Pre-wet machines and lines will do a better job of incorporating large volumes of water into the dry bulk ingredients and generally have less runoff. Dip tanks or areas with deep water can be used but the mix and moisture uniformity is not as good, and non-aerated deep water is another source of offensive odors.

Figure 3. Pre-wet mixing machine.

Water management is critical for preparing productive substrate and controlling offensive odors that are produced under anaerobic conditions. Environmentally friendly water-management practices can best be described as "generous yet conservative." Good composting requires generous quantities of water early in the process. Too much water will create anaerobic conditions if it does not drain from the pile or does not get absorbed by the bulk ingredients; too little water will result in poor production and fresh quality. Sufficient water is required, but not so much as to result in the wash-out of ingredients and generation of large quantities of leachate. All the runoff water from a facility must be collected and kept well-aerated in a wastewater collection unit or recycling system approved by the Conservation District (or similar agency) in accordance to the farm-specific MFEMP. Properly managed water is nutrient-enriched and can provide nutrients to hay or straw, which encourages microbial activity, heating, and softening of the fibrous material. This recycled nutrient-enriched water must be kept aerobic.

Windrow/Rick and Bunker Operations

After a pre-wet stage, the substrate is either formed into a windrow/rick or loaded into a forced aeration composting system, such as an aerated bunker or silo. After the initial mixing, the primary goal in producing a mushroom substrate is to create and maintain an aerobic environment with high temperatures (greater than 150 degrees Fahrenheit, 70 degrees Celsius). Additional mixing may be required to achieve a higher degree of homogeneity (depending on the method in use). Aeration may be achieved by the mechanical turning of the windrows/ricks, or by storage in forced-ventilation bunkers or silos. Maintaining aerobic conditions throughout the mass of the substrate must be of primary importance in all systems, for reasons of both odor management and compost quality.

Properly managed ricks or windrows produce minimum odors. However, if anaerobic conditions are excessive, the emissions will be more offensive. Anaerobic conditions are created by poor anticipation of high-precipitation weather, equipment

Figure 4. Windrows or ricks on the left, pre-wet pile on the right.

breakdown, and poor water or compost management. Odor-management practices for a windrow or rick consist of water management and frequent turning, usually every 48 hours, for mixing and aeration. Other details include maintaining tight sides to encourage higher temperatures, which improve air movement within the rick. Moisture control is critical; minimum leaching from the bottom of the rick indicates optimum moisture content. Anticipating weather is also important to manage additional moisture during high-precipitation periods. Shade cloths can be used to help shield the rain or snow, and also to maintain surface moisture under dry conditions.

Forced-Aeration Composting (FAC)

Forced-aeration composting is environmentally friendly, reduces costs including labor and equipment, and has composting advantages that may improve yields over time. FAC consists of using a ventilation system, often pipes with nozzles embedded in the concrete floor of the substrate-preparation wharf. These pipes supply air to the bottom of the substrate material, reducing potential anaerobic conditions. From a biological-process point of view, more of the substrate will be in the higher temperature range and less in the cooler temperature range favorable for microbial growth. More substrate reaches a temperature zone where desired chemical reactions occur; therefore, the composting process proceeds faster than in conventional windrows. Fewer days in Phase I will mean less compost is being prepared at any moment, less space is required for the same substrate output, less labor is required, and less dry matter loss will occur. Some FAC occurs under cover, either in a horizontal silo, bunker, or under a roof. When covered, weather has less influence on the composting process, which means there will be better moisture control and anticipating the precipitation will not be as important. Over time all these advantages should result in more consistent substrate preparation, which should result in more consistent yields and higher production.

Proper odor-management practices for FAC are similar to traditional composting, where the large pre-wet piles are turned or flipped daily. The substrate in the bunkers should be turned or flipped every 2 to 4 days. Although high temperatures in the substrate may be maintained for a longer time, replacing lost moisture and mixing the substrate during forced-

Figure 5. Forced-aeration composting bunkers under construction.

aerated composting is still necessary. For farms using turning equipment to aerate, the materials should stand no longer than three days between each mixing to avoid anaerobic conditions. With forced aeration, the opportunity for turning and movement is limited and done to both achieve a homogeneous mixing and add moisture for the substrate. The time interval between turns or flips is shorter earlier in the process and longer towards the end of the bunker composting. Much like traditional composting, more water is added is added earlier in the process.

Loading compost into a bunker should be done in a way that keeps the material homogeneous and well-mixed. In addition, filling uniformity and density depends on good workmanship and may be a problem when the process is carried out too quickly. Although front-end loaders are easy to operate, they can have higher maintenance and labor cost and do not mix or blend the compost as well as other systems. Other loading options include overhead conveyors and bunker-filler machines. Both of these systems provide the benefits of less labor, better mixing, and distribution, but are more capital intensive.

Aeration needs vary by the system, but in general, during the active microbial stage, after filling,turning, or flipping, there is a higher demand for oxygen and more air is needed. After temperatures reach greater than 150 degrees Fahrenheit (70 degrees Celsius), less oxygen is required because of the chemical reactions taking place. Generous aeration is needed after filling and turning or flipping to ensure the biological oxygen demand of the microbes is met.

Two different aeration-management techniques are available that appear equally effective. Continuous aeration with variable volume-control airflow, and intermittent aeration, usually with a fixed volume of air, are both used to manage temperatures and oxygen. A third option is available in which the control systems will regulate aeration based on the oxygen levels. Depending on the stage in the process, oxygen levels are maintained between 3 percent and 15 percent. In general, after filling and turning, higher oxygen settings are used. Once higher temperatures are reached, less oxygen is required. This type of system relies on oxygen sensors, which are sensitive to moisture and thus sometimes unreliable.

Finished Phase I Substrate

If correct conditions are maintained, the substrate at the end of Phase I will be evenly decomposed, soft, moist, and evenly dark brown in color. Phase I is considered complete when the raw ingredients become pliable and are capable of holding water, the odor of ammonia is sharp, the dark brown color indicates carmelization, and browning reactions have occurred. At the filling stage, moisture content is considered good when water drips from a substrate squeezed in the hand. A good rule of thumb for this stage is: the less decomposed and longer in length a substrate, the more moisture it can hold. Shorter, more mature, or dense compost will hold less water. Anaerobic substrate will have a lighter-brown to yellowish-green color and a “sour” smell.

Monitoring

Written measurements and records may be kept during the substrate preparation. Examples of specific information that could be monitored and recorded are given below. Each batch of compost produced should be assigned a number or code, and the information for each batch written and/or entered into a computer for future analysis. If standard operating procedures are prepared for several batches at a time, daily recording of all details may not be required. When these procedures need adjustments, they are noted in the written procedure or crop record.

Information that may be recorded:

1. Bulk ingredients
   a. Date of arrival
   b. Number of bales, truckloads, etc., as needed
   c. Estimated weight of bales, truckloads as needed
   d. Estimated moisture of bales, cobs, hulls, etc., as needed
   e. Estimated nitrogen of bales as needed
   f. Name of supplier
2. Supplements
   a. Gypsum quantity
   b. Estimated poultry manure quantity as needed
   c. Estimated nitrogen and moisture content of poultry manure as needed
   d. Cold start nitrogen calculation as needed
3. Date materials are mixed and wetted up for pre-wet
   a. Estimated quantity of water added as needed
   b. Dates of turning or other movements
   c. Dates of adding additional supplements
4. Date of forming into ricks or filling forced-aerated bunkers, silos, or tunnels

a. Estimated quantity of water (if added), as needed
b. Date of machine turns
c. Samples taken and NH_4 and pH analysis as needed
d. Sample dried for moisture analysis
e. Nitrogen analysis as needed

5. Temperature and oxygen monitoring for ricks and FAC
   a. Temperature monitoring takes place from at least several different locations as frequently as possible
   b. Oxygen readings could be taken on a regular basis from near the bottom of the compost in a rick or near the top in a FAC bunker
   c. Adjust the fan to ensure 3 to 15 percent oxygen is maintained at all times
6. Weather monitoring—a weather monitoring station could be installed on the site to record the following data hourly, archived in both hard and electronic copy:
   a. Wind speed (m/sec)
   b. Wind direction (degrees true)
   c. Standard deviation of wind direction
   d. Air temperature (dry bulb and wet bulb)
   e. Rainfall (mm/day)
   f. Barometric pressure
7. Odor Complaints—a written record of complaints of odors should be kept, with the following information recorded for each complaint:
   a. Name of complainant
   b. Location of complainant
   c. Date and time of complaint
   d. Weather conditions prevailing at the time of complaint
   e. Any process operation existing at the time of complaint
   f. Steps taken to remedy any reason which may have contributed to the complaint

Odor-Reduction Opportunities

Odors are commonly associated with compost operations and can be minimized with proper management and relatively simple technology. Mushroom farmers can control and reduce the odor potential of the wharf area with several practices:

Water Management

- Maintain aerobic composting by using minimum but sufficient water during the whole process.
- Too much water will cause anaerobic conditions and nutrient leaching.
- Prevent or eliminate excessive standing water and poor drainage on a wharf, especially around raw material storage areas.
- Solids should be trapped before the collection basin. If solids are already present in the basin, frequent cleaning of the traps is required or the solids should be removed regularly.
- Leachate and recycled water in collection basins or impoundments should be well aerated and agitated.

Substrate-Preparation Management

- Nitrogen-rich raw ingredients contribute to the intensity of certain odors; therefore their use should be minimized, but remain sufficient for producing nutritious compost for optimum mushroom yields.
- A thorough mix of all ingredients, especially the manures used, will help to prevent anaerobic clumps of materials in the compost.
- The use of forced aeration will greatly reduce the anaerobic conditions in the compost pre-wet piles, windrows, or bunkers.

Contingency Plans

To minimize the environmental impacts for substrate preparation operations, including when power failures occur, easily accessible contingency plans should be prepared. These plans should ensure that the supply of oxygen is maintained to the compost. The fans for the FAC bunkers should be connected to a 24-hour call-out alarm system in the event of failure. The contingency plan should require the replacement of any unserviceable fan

Figure 6. Holding tanks for substrate leachate.

with a reserve fan or other appropriate remedial action. In addition, other possible preventative steps include a backup generator as an auxiliary source of power. If any turning machines involved in the substrate-preparation operation on-site would have a mechanical failure, a backup turning machine or appropriate prompt repairs become a priority. The contingency plan should include a list of personnel available to service any breakdown who can be on-site in a reasonable amount of time once notified.

Figure 7. Spent mushroom compost in passive composting windrows.

Mushroom Compost

Mushroom compost, also referred to as spent mushroom substrate (SMS) and spent mushroom soil, is the term given to mushroom substrate after it has been utilized by a mushroom crop. Concern has been raised over mushroom compost in past years mainly due to environmental concerns, disposal issues, and odor complaints. Through recent experimentation, processes that aid in the reduction of malodors associated with mushroom compost have been discovered.

Once cropping is complete and the mushroom substrate has been exhausted of nutrients, the substrate is usually pasteurized prior to its removal from the houses.. After the substrate has been pasteurized, it is referred to as mushroom compost. At that point, it can go on to be composted further either by active or passive composting.

Passive Composting

With passive composting, the process proceeds naturally with no further turning or addition of raw materials. Since the compost is not turned, it is best to mix the compost well in order to make a homogeneous mixture that leads to a more rapid decomposition process. In addition, a vegetative cover can be established to minimize odor-causing compounds. The vegetative cover helps with dust and erosion control, and the roots provide structure and reduce the anaerobic tendency of compost. Added benefits of using vegetative cover are controlling surface water and reducing ground water contamination. Passive composting proceeds slowly and is an anaerobic process, therefore, if disturbed prior to maturation, it can be a major source of malodors.

Active Composting

Active composting is a process in which the compost windrow is actively turned to promote aeration, better mixing, and a more rapid decomposition process. Actively prepared compost takes less time to mature and is turned regularly to maintain high temperatures for more consistent and efficient composting. Since the process of turning compost can release odors, it is best to select a time of day for turning that is least inconvenient for neighboring residences. Keeping track of wind direction can also help with selecting a proper time to turn compost.

Whether mushroom compost is being further composted or not, there are several management options that lessen the effects of malodors. Creating visual barriers to block windrows, storage structures, and wharfs from residential or community areas lessens the human perception of odor. Tree or vegetative barriers are ideal, because, with certain varieties, the leaves actually absorb some of the odor-causing compounds. Barriers can create a change in direction for the wind's course. When a plume of air hits a barrier of trees, the air is sent barreling upwards, away from the earth. In addition, trees trap airborne dust particles that carry odorous compounds, thereby reducing odor emissions from leaving the site. Controlling and containing liquids in storage reduces odor, since it is possible to maintain aerobic conditions by agitating. Less liquid surface area results in fewer airborne odor-causing compounds and decreased odors. Be sure to keep the liquid well agitated while in storage. Removing solid particles before they enter the liquid storage also helps maintain an aerobic condition.

Acknowledgments

Our thanks go to Tom Brosius, Marlboro Mushroom Company; Laura Phelps, American Mushroom Institute; and Chip Chalupa and Gene Taylor, Modern Mushroom Company for reviewing and commenting on the manuscript. Funding for this publication was provided by Protected Harvest and Pennsylvania NRCS.

References

Beyer, D. M., R. B. Beelman, P. Heinemann, K. M. Lomax, T. W. Rhodes, J. J. Kremser, C. Wysocki. "Influence of forced air, compost moisture, and gypsum on mushroom composting, odors, yield, and fresh quality," From recorded proceedings of the International Symposium on Composting and Compost Utilization, May 2002.

Beyer, D. M., R. Rynk, J. Pecchia, P. Wuest. "Improving odor management on mushroom farms." *Biocycle* 41, no. 7 (2001): 60–63.

Beyer, D. M. "Aerated composting." *Mushroom News* 48, no. 8 (2000):4–15.

Heinemann, P. H., G. Preti, C. J. Wysocki, R. E. Graves, S. P. Walker, D. M. Beyer, E. J. Holcomb, C. W. Heuser, F. C. Miller. "In-vessel processing of spent mushroom substrate for odor control." *Applied Engineering in Agriculture*, Vol. 19, no. 4 (2003): 461–71.

Heinemann, P., R. Graves, D. M. Beyer, E. J. Holcomb, C. Heuser, G. Preti, C. Wysocki, F. Miller. "Processing of spent mushroom substrate." *Mushroom News* 50, no. 5 (2002): 3–13.

Labance, S. E., P. H. Heinemann, R. E. Graves, D. M. Beyer. "Evaluation of the effects of forced aeration during Phase I mushroom substrate preparation. Part 1: Model development." *Transactions of the American Society of Agricultural and Biological Engineers* 49, no. 1 (2006): 167–74.

Labance, S. E., P. H. Heinemann, R. E. Graves, D. M. Beyer.. "Evaluation of the effects of forced aeration during Phase I mushroom substrate preparation. Part 2: Measurements and model results." *Transactions of the American Society of Agricultural and Biological Engineers* 49, no. 1 (2006): 175–82.

Pecchia J., D. M. Beyer, P. J., Wuest. "The effects of poultry manure based formulations on odor generation during Phase I mushroom composting." *Compost Science and Utilization* 10, no. 3(2001): 188–96.

Pecchia, J. A., D. M. Beyer, P. J, Wuest. "A study on Phase I compost management and odor production." *Mushroom News* 48, no. 9 (2000): 16–23.

Pecchia, J. A., D. M. Beyer, P. J., Wuest. "The effects of formulations and compost temperatures on odor generation in Phase I mushroom composting," in *International Composting Symposium*, ed. P. R. Warman, and B. R. Taylor, (Truro, Nova Scotia: CBA Press, 2000), 560–68.

Schisler, L. C. "Biochemical and Mycological aspects of Mushroom Composting," In *Penn State Handbook for Commercial Mushroom Growers*, ed. Department of Plant Pathology (University Park: The Pennsylvania State University, 1982), 3–10.

Sinden, J. W. "The Short Method of Composting." *Mushroom Science* I (1950): 52–60.

Prepared by David M. Beyer, professor of plant pathology,
John Pecchia, research manager of mushroom facilities, and
Lisa Bertsch, agricultural research conservationist, The Chester County Conservation District.

Visit Penn State's College of Agricultural Sciences on the Web: www.cas.psu.edu

Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

This publication is available from the Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802. For information telephone 814-865-6713.

4CM6/08mpc 4905