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Mushrooms And Penn State

Past, Present, Future

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PREFACE

For forty-five years The Pennsylvania State University has conducted research and educational programs to assist the Commonwealth's mushroom industry.

This publication presents a brief history of domestic mushrooms and the role played by Penn State in adapting this unique crop for commercial production. In many sections of this account the actual words of the people who conducted the research are preserved.

The farm value of mushrooms grown in Pennsylvania during the 1968-69 production season exceeded $42 million. Pennsylvania produces more than 60 percent of all mushrooms grown in the United States; mushrooms are the most valuable single crop sold for cash in the Commonwealth. Truly, the Commonwealth of Pennsylvania and The Pennsylvania State University obtain a portion of their uniqueness from mushrooms.

Mushrooms enjoy widespread attention from teachers and students, scientists and businessmen, consumers and hobbyists. This history has been prepared to tell the story of Pennsylvania's most unique farm crop to groups of diverse interest. Also, it brings together information from scattered sources that should be of interest to mushroom growers and scientists. Further, this historical account commemorates the opening of Penn State's Mushroom Test-Demonstration Facility.

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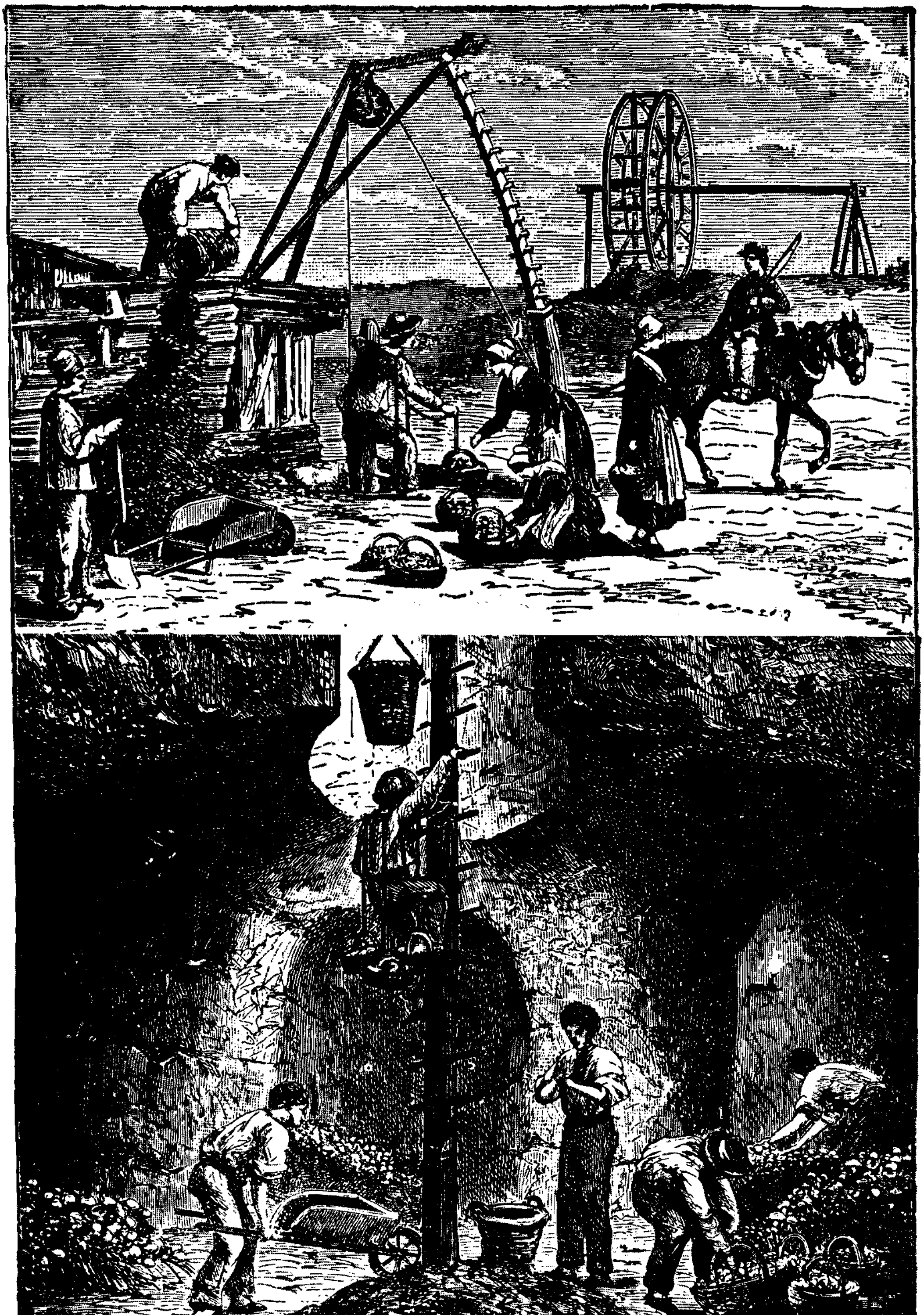


Gathering mushrooms in the Paris caves for market (early 1800s)

MUSHROOMS AND PENN STATE
Past, Present, Future

During the lifetime of Louis XIV of France (1638-1715), French classicism was at its zenith. The Louvre and Versailles palaces were constructed, and the art and science of mushroom growing were born. By 1800 underground caves of Paris were widely used for mushroom growing. Stacks of horse manure were allowed to heat and compost. This material was formed in ridge beds on the cave floors with walkways between ridges. The compost was then inoculated with cultures of wild fungi. Later English and other Europeans took up mushroom growing. From these primitive beginnings, contemporary mushroom farming has evolved.

Although there was a plentitude of native species of wild fungi in North America, it was not until after the American Civil War that mushrooms were grown commercially in the United States. English, French, and Scandinavian gardners employed by the wealthy citizens of New York City and Philadelphia were undoubtedly the first to culture mushrooms in the New World. Around 1885, Dr. J. Franklin Styer, Harry Hicks, a Mr. McCaffrey, gardner to J. E. Kingsley, and others were growing mushrooms under benches in their greenhouses in Chester and Philadelphia Counties. Similarly, mushrooms were grown in greenhouses at Jamaica, Rochester, Mamaroneck, Astoria, and other places in New York State.

Special Houses for Mushroom Growing

Seren Rasmussen, head gardner for the John Wyeth family of Westtown, Pennsylvania, grew mushrooms as early as 1892. In 1894 he constructed a large building exclusively and successfully used for mushroom growing. This predates a mushroom building designed by Harry Hicks by one year. Hicks' building still stands at Willow Street and Apple Alley, Kennett Square, Pennsylvania. However, mushrooms were never grown successfully in the latter structure, probably due to inadequate ventilation.

Mushrooms have been grown in unused coke ovens, coal and limestone mines, wine press buildings, wine cellars, greenhouses, ice houses, old breweries, basements of apartment houses, natural and man-made caves, cinder block houses, rhubarb sheds, and many other unusual structures, including an old dairy barn which was so damp that cows that were kept in it died of pneumonia. Incidentally, the mushroom yields were also poor in this barn. Mushroom houses have been constructed of adobe, sod, concrete, cinder blocks, wood, metal, and other materials. Some popular articles indicate that mushrooms can be grown in almost any dark hole; this is not true. Successful commercial mushroom culture requires special houses or well ventilated caves. While mushrooms usually are grown in the absence of light, darkness is not a requirement.

The evolution of mushroom houses has been gradual and the results of much trial and error. Many types of sheds, cold frames, and other structures were tried. However, shortly after World War I, the mushroom growers of Chester and nearby counties adopted a fairly standard type of house. These buildings were of wood or hollow tile, windowless, measured about eighteen feet wide by sixty feet long by fifteen feet high, and contained about 4000 to 5000 square feet of growing space arranged in tiers of fixed beds. These buildings were called "standard singles" and had sloping roofs, a natural ventilation system, and were heated during the winter months. In 1921, construction costs were between $1800 and $2000 for a wooden mushroom house and slightly more than $3000 for one of hollow tile. Somewhat later, growers began building two of these units under a single roof; these were called "standard doubles."

A typical small mushroom farm of today consists of a series of "double" mushroom houses, an open composting yard, and storage areas. A typical "double" is of cement block construction and is about sixty feet long by thirty-eight feet wide. Usually some type of headhouse or packing room is associated with a mushroom farm. Here mushrooms are packaged and equipment and materials are stored. Mushroom beds are about five to six feet wide with an aisle on each side and at the ends for picking, watering, and crop protection. Usually there are six or seven tiers of beds; lower beds are raised above the floor; sideboards on the beds are about eight inches high. A typical house has a catwalk for picking the upper beds, hot water heat, and is used for two crops per year — one starting in the fall, the second in mid-winter.

In a special report written in 1947, Dr. James W. Sinden of The

Pennsylvania State College (University) observed: "Mushroom growing in the United States is undergoing a quiet revolution which has not yet been reported in the literature nor has this change been recognized by most mushroom growers of Chester County. During this year (1947) at least ten million pounds of mushrooms will be grown in trays. Credit for originating this system belongs to the Knaust Brothers, Coxsackie, New York; the Yoder Brothers operating a mine at West Winfield, Pennsylvania, and Chef Boy-Ar-Dee Quality Foods, Inc., Milton, Pennsylvania also have contributed to the development of the system." Dr. Sinden made considerable contribution to this development, too.

With the tray system, the compost is placed directly into movable boxes which are transported by a tractor with a fork-lift or by other means to the various growing areas. The tray system allows greater use of mechanization and of improved composting methods. Tray operations tend to be considerably larger than those with fixed beds. This method has led to larger houses and greater capital investments in equipment. However, the bed system is more commonly used on smaller mushroom farms as well as on some of the larger ones even in 1970.

The Commercial Mushroom Versus Wild Fungi

Only one species, *Agaricus bisporus*, is cultured commercially on mushroom farms in the U.S.A. There are, however, a number of varieties of this commercial mushroom, notably whites, creams, and browns. In Japan and other countries in Asia, and in the Netherlands other species of fungi are grown commercially. In addition other species of fungi are field-gathered and sold as food specialities in American stores; these are imported, largely from Central Europe. The quality and exact species of fungi in these products are subject to question.

No rules exist by which an untrained person can distinguish poisonous from edible wild fungi. There are several thousand kinds of wild fungi found in the United States. One species, the fly mushroom or deadly amanita, contains muscarin and a complex of other poisons. Other wild fungi, such as morels and most puff-balls, have deliciously pleasant flavors and are wholesome. However, no wild fungi should be eaten unless it is known beyond any shadow of a doubt that the species which are picked are edible. Identification should be based upon scientific knowledge, not upon second or third hand information "inherited from a grandmother who picked mushrooms in Central Europe." Wild species do not grow in mushroom houses because of the care given in producing pure spawn and pasteurized compost. Therefore, you can be sure that commercially grown mushrooms are edible.

Early Development of *Mushroom Spawn*

Agaric mushrooms have a cap (pileus), a stalk (stipe), a butt (base), and root-like threads (mycelium) which grows beneath the soil in the compost. On the underside of the cap are the gills which radiate from the stalk, like spokes of a wagon wheel. At first these gills are covered by a thin layer of tissue (the veil). As the mushroom matures, the veil stretches and finally the mushroom opens, revealing the gills. From these are released the spores which are analogous to the seeds of higher plants. Each spore is a tiny bit of protoplasm surrounded by a thin wall. These spores are carried by the wind, and if they fall in a suitable spot, they germinate and produce the thin thread-like mycelium or vegetative phase of growth When conditions are right, pins are formed; these enlarge and become mushrooms.

Mushroom growers use the term *spawn* for the vegetative culture of mushroom mycelium ("hair-like roots") and substrate (material on which the mycelium grows). Spawn is used to "seed" the mushroom beds. Spore culture spawn is produced by germinating and culturing spores on a suitable medium; the tiny black spores are obtained when the veil of the parent mushrooms open. In 1893 two French scientists first reported germinating spores; however, it was not until the 1902 report of Dr. Margaret C. Ferguson that this method was generally understood. In 1905, Dr. B. M. Duggar developed a tissue method of making pure spawn; this method consisted of removing a piece of tissue from the mushroom cap and culturing it on a suitable medium under sterile conditions. Today mushroom growers buy spawn from special laboratories; however, this was not always the case.

Spawn was first obtained by digging up wild mycelium from meadows where wild agarics grew and horses were active. Later, beds were inoculated by the French Flake Spawn Method. The procedure was to inoculate new beds by scattering dried or fresh pieces of compost taken from established beds.

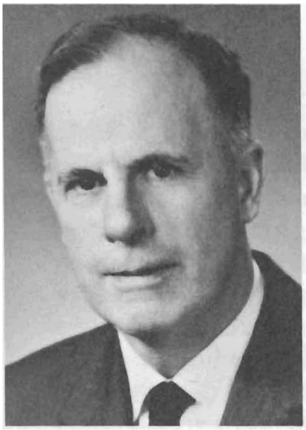
The English Brick Spawn Method replaced and represented a considerable improvement upon flake spawn. The American Spawn Company made brick spawn in the following manner, according to A. C. Davis: "A mixture of horse and cow manure was sifted until very fine; this was then wetted and run thru clay moulds, similar to fire brick manufacture. Bricks were ten inches long, seven inches wide, and one inch thick. They were placed on trays and taken to long drying racks where they were left in sunshine until they were so dry that you could not dent them with your fingernail. The bricks were then inoculated in six places with spore cultures growing on potato slices. Two bricks were sandwiched over the potato slices, so that each was spawned with the same piece of potato. The bricks were then stacked in an incubation room in a sandstone cave and left until the mycelial threads penetrated the bricks. Then the bricks were taken to sun drying racks and dried until very hard. These bricks were then ready to be used. The grower used a saw or other sharp device for marking them into squares or pieces. He hit the mark or line with a hammer or other instrument and broke the brick apart and sprinkled the pieces on the bed."

Variations in the above method of making brick spawn were practiced by other spawn makers. Brick spawn sold for about fifteen cents per brick and was used for more than sixty years by the American mushroom industry. Both flake and brick spawns were often contaminated by molds, mites, insects and had uncertain yielding abilities.

Manure or Bottle Spawn also was used for many years by mushroom growers. Horse manure was composted, washed, shredded, and packed in quart milk bottles; improved culture bottles which eliminated the necessity of breaking the bottle replaced milk bottles fairly soon after the development of the Manure Spawn Method. With either container, a center core of manure was removed by a type of drill. The manure-filled bottles were then plugged, and the flasks and the medium were sterilized so as to kill the molds and most of the bacteria. After the medium cooled, it was inoculated by raising the cotton plug and inserting bits of a culture of mushroom stock spawn down the hole in the center of the medium. The plug was then replaced, and the culture was kept at a temperature of about 70°F to encourage spawn growth. This spawn was then sold to the growers.

Sinden Develops Grain Spawn

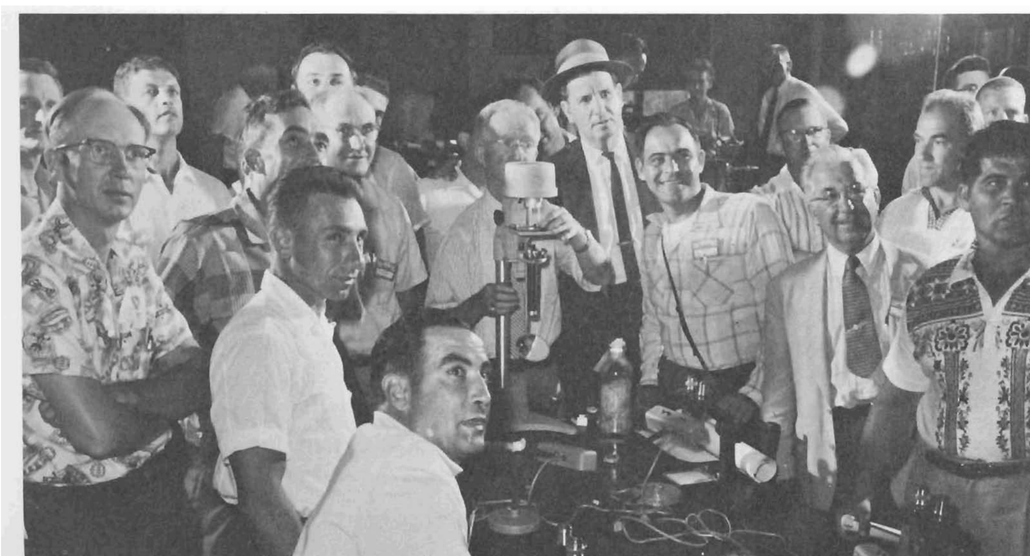
In the late 1920's mushroom growers even with the development of manure spawn still had serious problems in obtaining productive, reliable, spawn free from pests and diseases. In 1930, The Pennsyl-



Dr. James W. Sinden

Professor C. A. Thomas

Dr. Leon R. Kneebone with two of his graduate students



Laboratory session at first Penn State Mushroom Growers' Short Course in 1956 vania State College (University) employed Dr. James W. Sinden to work on mushroom problems. The following is his account of the development of Sinden Grain Spawn.

"Previous to coming to The Pennsylvania State College in April, 1930, I had worked for six years in the Laboratory of Plant Mycology at Cornell University as an instructor and graduate student. One of my duties was the maintenance of diseased plants for class use. This entailed the inoculation of plants and of soil with mycelium of various disease-producing fungi. This was accomplished in some cases by the introduction into soil of these fungi growing on various media.

"On coming to The Pennsylvania State College it was my duty to study the development of mushrooms, particularly in relation to nutrition in the beds; one of the ultimate aims being to discover a substitute for manure. I was told to not work on spawn as all the problems in this field were settled and the process was known in its entirety and no further improvements could possibly be made. I was told also that the process of making spawn was a secret one and that only a few people had the knowledge or the ability to carry it on.

"In order to familiarize myself with the growth of mushrooms, I composted manure as nearly as possible in the ordinary manner and planted it with manure spawn obtained from the commercial spawn makers of Chester County. I was immediately struck with the variation in yields and feared that this might be a result of the spawn planted. Some beds produced well while others nearby produced indifferently or more slowly. I realized that in order to carry on experimental work on mushroom growing, it was essential to eliminate any variation from this cause. Therefore, before attempting further experimentation with the compost in the beds, I undertook in the laboratory to find a method by which I could grow the mycelium. The first experiments were with manure treated in much the same manner as used by spawn makers in Chester County. I found that this was unsatisfactory for my purpose. I sought further for a medium on which the mycelium would grow more vigorously and which would give me a uniform product. One of the first of these used was grain, specifically wheat, which was placed in flasks with a small amount of water and heat sterilized. On introduction of the mushroom mycelium, I found that it grew very vigorously and in a manner entirely different than anything I had previously seen. I repeated the experiment several times. I was then ready to use it in preliminary tests in experimental growing of mushrooms.

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"I composted the manure and when it was ready to plant, three out of thirty beds were planted with this new kind of spawn; the other twenty-seven beds were planted with manure spawn obtained from Chester County spawn makers. The mycelium from the new medium immediately grew faster and more vigorously, so that within a week I was convinced that it had advantages over the other spawn in the same beds. Those beds planted with the mycelium on grain came into production earlier and showed greater vigor throughout the crop."

Upon the encouragement of Dr. F. D. Kern, then Chairman of the Department of Botany and Plant Pathology at Penn State, the College (University) applied for a patent on the Sinden Spawn Process. Several patents were obtained on the Sinden Grain Spawn Method in 1932 and 1933. The proceeds from these royalties amounted to about $250 thousand and were administered by the Pennsylvania Research Corporation for Penn State. This corporation issued licenses to a number of spawn makers who were then instructed by Dr. Sinden on the process; the laboratories were periodically inspected to make certain they maintained proper quality control. A royalty was collected on each unit of spawn sold.

Controversy concerning grain spawn during the early years of the patent was vigorous and gives some insight into how new ideas and methods are accepted with reluctance. The following are typical growers' comments made at a special hearing held in 1932. Grower A: "About 180 individuals out of 600 mushroom growers are using grain spawn this year. I know of none who are not pleased with it." Grower B: "In a few years manure spawn will be as much a thing of the past as brick spawn is now." Grower C: "Grain spawn is about a week earlier, more vigorous, and probably will outyield the manure spawn." Grower D: "The saving from grain spawn over manure spawn is $480 for each spawning of my plant." However, the spawn makers were reluctant to accept grain spawn. Typical spawn makers' comments at this 1932 hearing were: Spawn maker A: "There are a number of growers who used the grain spawn for the first planting, but replaced it with manure spawn because the grain spawn failed to run well." Spawn maker B: "I know of several cases where grain spawn failed." Spawn maker C: "What the spawn makers object to most in the use of the grain spawn is that you stretch it too far." Spawn maker D: "We have pointed out certain defects of grain spawn but I think all of the spawn makers feel that, under most conditions, it is giving good results and should be put on the market."

In 1934 Dr. S. W. Fletcher at The Pennsylvania State College (University) observed in a report to the Pennsylvania Research Corporation: "The strategy of the spawn makers seems to be to stave off the inevitable as long as possible, knowing that grain spawn spells ruin to some of them in a business that already is overcrowded. Four of the five licensed spawn makers have used the license not to introduce the grain spawn, but merely as a means of discrediting it — 'We have grain spawn, but we do not recommend it.' When the present license period terminates, the College should decide whether these licenses are entitled to a renewal."

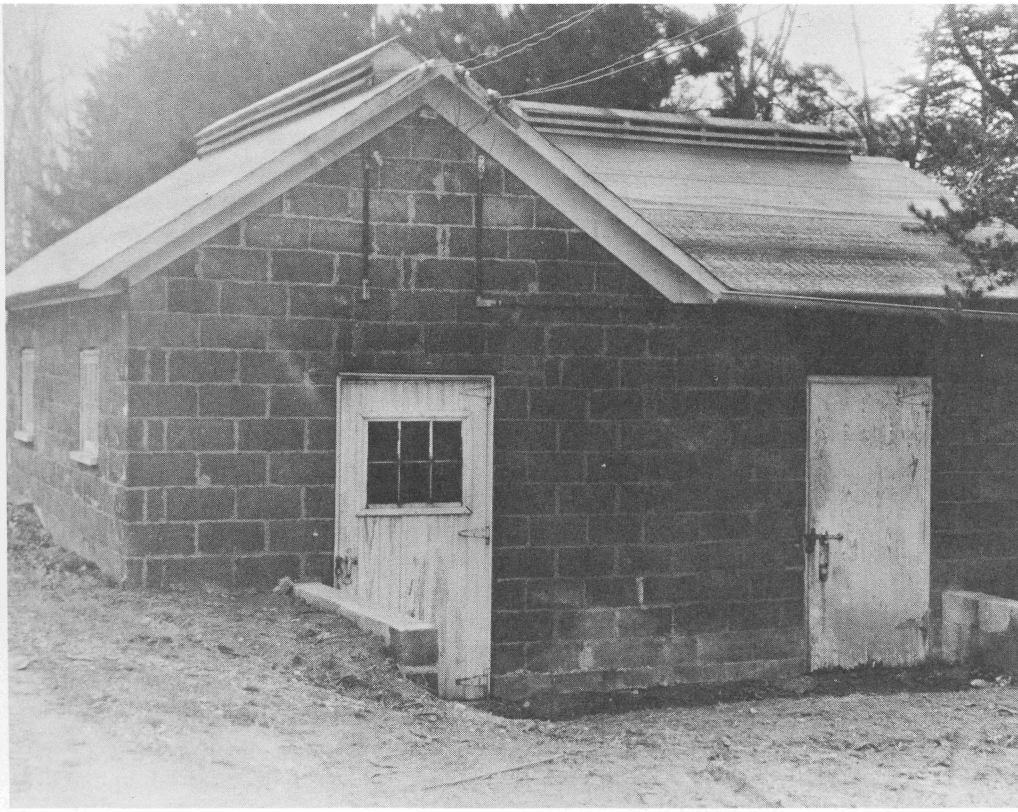
The 1933 Rettew Patent on a tobacco stem spawn created some competition for grain spawn. Controversy between advocates of grain and tobacco spawns, over patent rights, over the use of proceeds from licensing and royalty fees, and over facets of spawn production continued for many years. Nevertheless, grain spawn is now universally used by commercial mushroom growers.

In 1949, when the life of Sinden Grain Spawn Patent was about to expire, Dr. F. D. Kern reported: "Grain spawn is easy to produce and to use: it is relatively more vigorous, and one unit is three times more effective than manure spawn. Grain spawn has resulted in savings to growers of more than $3 million. With Dr. James W. Sinden's discovery of grain spawn, some practical means was needed whereby high quality spawn in a sufficient quantity could be assured to the growers. Through its program of licensing, the Pennsylvania Research Corporation has made a unique and substantial contribution to the mushroom industry through the wise management of the Sinden Grain Spawn Patent."

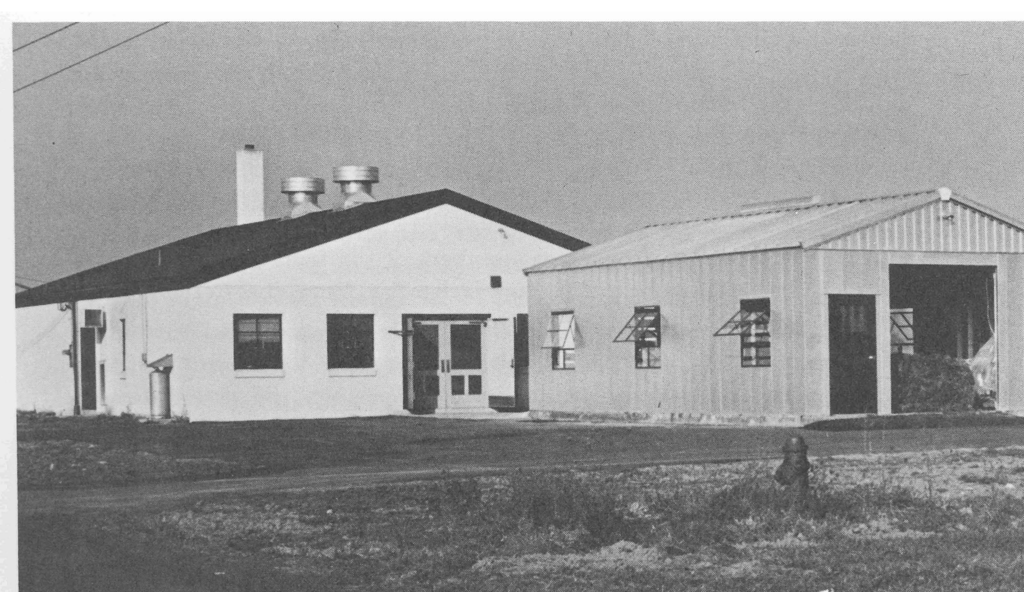
Dr. E. F. Osborn, Vice President for Research at Penn State, observed: "As of 1969, royalties from this patent have been the principle source of income for the research fund administered by the Pennsylvania Research Corporation. This fund, based on the mushroom patent royalties and augmented by royalties from other patents and by investment income, remains a sizeable and active budget used entirely in the support of the University's total research program. Over the years several hundred members of the faculty have received needed financial support for their research from the Pennsylvania Research Corporation fund."

Penn State Mushroom Spawn Laboratory

Development of grain spawn led to the testing of mushroom varieties, the development of new commercial strains, and the maintenance of a permanent spawn bank at Penn State. In 1969 there were twenty



The first mushroom research facilities at Penn State as they appeared in 1936. This building was constructed by a gift from the Mushroom Growers Cooperative Association



The Penn State Mushroom Research Center shortly after completion in 1960 commercial spawn laboratories in the U.S.A.; thirteen produced spawn for sale and seven for their own companies exclusively. Over three million quarts of mushroom spawn were produced in 1968; the total sales value was about $2 million.

The Mushroom Spawn Laboratory located at Penn State was started by Dr. James W. Sinden and has been under the direction of Dr. Leon R. Kneebone since 1953. This laboratory maintains and tests some 300 strains of the commercial mushroom and an additional 300 varieties and species of other edible fungi. According to Dr. Kneebone, as many as three-fourths of all mushrooms grown commercially come directly or indirectly from Penn State cultures. The culture bank has been maintained for the past twenty years by Mrs. Perrina Shultz, biological technician. Dr. Kneebone is actively attempting to develop new mushroom strains which will give greater yields. In addition some 400 pathogenic or competitory molds and other organisms are kept isolated and are cultured for research and instructional purposes.

First Mushroom Research Facilities at Penn State

On October 15, 1927 the Mushroom Growers Cooperative Association (MGA) presented a check to representatives of Penn State for the construction of a test mushroom house. This house, completed in 1928, was twelve feet wide by twenty feet long by ten feet high and was constructed of concrete blocks. Its wooden ceiling was insulated with six inches of sawdust; the building was equipped with sectional dampers, had five windows, three tiers of beds, steam heat, water, and electricity.

In 1934, Walter Maule, Secretary of the Mushroom Growers Cooperative Association, presented the College with a $400 check to expand the mushroom research house. Construction costs were "skyrocketing" even then. Dr. James W. Sinden had to request additional support from the MGA. On March 14, he wrote: "The Department of Grounds and Buildings is holding up construction on our mushroom house pending the receipt of $25 which they claim they need to undertake construction as originally planned. If you can make this available to us, I shall greatly appreciate it." This mushroom house was used by Drs. Hein, Sinden, and Kneebone. In 1962 the house was extensively renovated; in 1970 it was torn down to make way for new construction in the College of Arts and Architecture.

The Composting Process

Horse manure is a major ingredient that goes to make most mushroom composts. Most manure comes from race tracks or pleasure horse stables. Manure may be composted through the first stage or phase by a custom composter who may be some distance from the mushroom farm, or by the grower himself adjacent to his mushroom houses. Composting is carried out on a special wharf with a concrete, gravel, or cinder surface. Adequate drainage is important in maintaining proper sanitation levels on the composting wharf.

The first step in composting is the building of the pile. Specially built compost turners and tractors equipped with various attachments for handling manure are used. Piles are usually constructed seven to twelve feet wide, about six to eight feet high, and as long as necessary or as is convenient. During the building of these piles, the manure is wet through but not to the point of run-off. Gypsum and other supplementary materials are added to the manure according to standard recipes or to the needs as determined by an analysis. The pile immediately begins to heat due to the activities of micro-organisms. The temperature in the piles range between 130° to 175°F. The compost is turned at intervals of three to five days and is usually turned three to four times. The bulk of the pile is greatly decreased, and both the physical and biological nature of the compost changes so as to be more favorable for mushroom growth. This step is called Phase I Composting.

Following Phase I, the compost is placed in the beds or trays, and then undergoes Phase II Composting — the "cookout," or pasteurization process. The compost, with self-generated heat and the addition of live steam, is maintained at temperatures of 115° to 145°F for about seven to eleven days. During this process certain important changes occur in the compost that favor the growth of commercial mushrooms rather than other organisms. Pasteurization destroys the harmful nematodes, insects, mites, and fungi.

Studies in biology and chemistry of both Phase I and II Composting are currently being conducted by researchers at Penn State, at the USDA (Beltsville, Maryland), at commercial farms in the U.S.A., and other mushroom research stations around the world.

Nutrient Supplementation of the Compost

F. C. Steward, Chief in Botany Research at the New York State Agricultural Experiment Station, Geneva, was one of the first researchers to experimentally supplement composts with cottonseed meal in 1927. He reported: "The number of plants produced by the beds containing cottonseed meal was 5.5 times that produced on the manure beds. Moreover, the plants from cottonseed meal beds were on the average 12.5 percent heavier so that the total weight of mushrooms produced by the cottonseed meal beds was 6.3 times that produced by the other beds." Drs. Illo Hein, E. B. Lambert, J. W. Sinden, and B. B. Stoller in the United States, R. L. Edwards in England, A. H. Demolon in France, and others helped to develop means of adding organic and inorganic supplements at the start or during composting.

At the Fifth International Conference on Mushroom Science held at Philadelphia in 1962, Drs. L. C. Schisler and James W. Sinden presented the alternatives of supplementing at spawning or casing with various nutrients. The addition of various vegetable proteins increased yields up to 30 percent when added at time of casing; continued research in 1966 reported 50 percent yield increases with ground seeds or protein-oil combinations. The application of this type of supplementation became possible with changes in spawning methods. The term given this development is SACing—Supplementation At Casing. Dr. L. Schisler of Penn State has continued these studies and has found a stimulation of both yield and mycelial growth by vegetable oils. His investigations into lipid metabolism of the cultivated mushroom hold great promise for regulation of yield and quality of mushroom produced.

Synthetic Composts

The price of manure to mushroom growers varied greatly in the 1930's. In 1930 some Chicago, Illinois, growers paid \$.50 per ton. In 1932 other Chicago growers paid \$5.00 to \$5.50 while growers in nearby Des Plaines paid only \$2.00 to \$2.50 per ton; the replacement of horses by cars, trucks, and tractors during the 1930's meant a diminishing supply of horse manure for the mushroom industry.

Drs. Illo Hein and James W. Sinden of Penn State, E. B. Lambert of the USDA, and B. B. Stoller, presently of Santa Cruz, California, were among the first to anticipate this problem and to experiment with synthetic composts. In 1938 Dr. Sinden published *Synthetic Compost for Mushroom Growing* which presented a formula for making a synthetic compost containing straw, urea, and wheat. By 1945 the price of manure was \$18 per ton in the Chester County area, and there was a switch to synthetic compost. Sinden continued to improve his synthetic composts; he published *Synthetic Compost for Mushroom Growing (Further Studies)* in 1946. This study and applications of these studies at commercial operations led to a widely used synthetic compost of corn cobs, legume hay, gypsum, ammonium nitrate, muriate of potash, dried brewers' grains or dried poultry manure, and water.

In 1965 a survey of eighty mushroom growers showed that thirty used synthetic compost, nineteen used a mixture of manure and synthetic compost, and thirty-one used straight horse manure compost. Increased numbers of pleasure horses and expanding numbers of race tracks have increased the availability of horse manure which as of 1969 competes favorably with synthetic compost.

Short Methods of Composting

At the First International Mushroom Conference held at Peterborough, England in 1950, Dr. James W. Sinden of Penn State and E. Hauser of Gossau-Zurich (Switzerland) reported on a short method of composting in which only seven to fourteen days were required for Phase I Composting. This radical departure from prevailing composting methods was based on ten years of experimentation with various nutrient levels, analysis of compost constituents, pile size, and other factors.

Dr. E. B. Lambert at the USDA and Dr. Sinden carried on a vigorous and friendly correspondence for a time over the merits of the short method and Dr. Lambert's somewhat longer methods of composting.

In one letter to Sinden, Lambert observed: "I would like to present a united front with you in advocating narrow heaps, but I have a feeling that your excellent results are due in large part to optimum moisture at spawning, aerated pasteurizing, and good ventilation in the house and little, if any, to the narrow heaps. Without experimental evidence to the contrary, I cannot help feeling that heaps twelve feet wide would better suit the needs of the average grower than ones six feet wide."

A portion of Sinden's reply was: "By reducing the size of the piles at the West Winfield Mushroom Farm, we have been able to eliminate the anaerobic zone and at the same time have practically all of the aerobic fire-fanged area on the outside of the pile. This is achieved by compacting the outside edges of the pile but leaving the center very loose. Even in mid-winter, the temperature rises to 149°F within two inches of the exterior, and most of the pile is 158°F and up to 170°F in synthetic composts. Whether this is the best procedure for composting, we do not know, but the results are the most uniform we have ever observed. Pile after pile behave exactly alike; until a more certain way of producing 1.75 pounds of mushrooms per square foot of bed surface, in sixty days, using only a three man crew on its composting ground to prepare 360 tons of manure a week is developed, I imagine the West Winfield growers will use the Short Method." Dr. Sinden's method is widely used in the industry today.

After the Compost Is Made

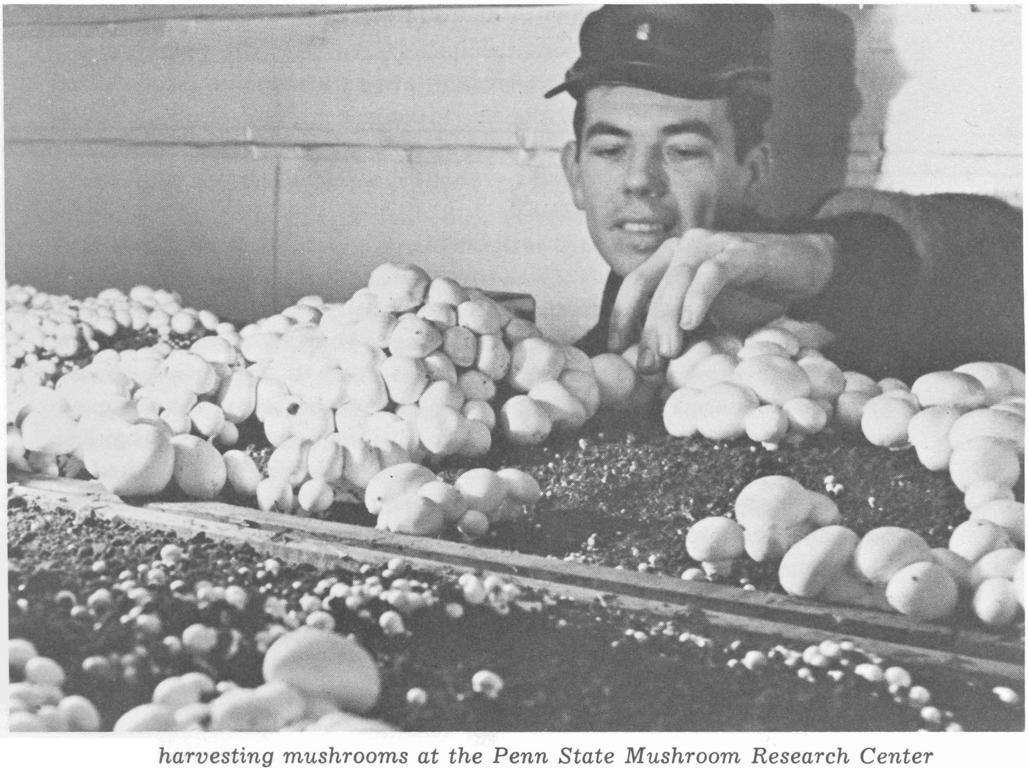
After Phase II, the compost is "seeded" with grain spawn. The spawn is broadcast on the bed surface and worked (ruffled) into the compost. A modern technique is to mechanically mix the spawn and the compost — "mixed spawning." The growing house or spawning room is kept at a temperature of around 75°F with a high humidity for a period of two to three weeks. During this period, the mycelium grows throughout the compost. This period is called Spawn Run.

After spawn run, an inch of pasteurized soil is applied to the surface of the compost. This soil is called the casing layer and tends to bring on fruiting. The temperature following casing is gradually dropped to about 55° to 60°F. In about ten to fourteen days the young mushrooms (pins) appear. Within a period of about four to seven days after the appearance of the pins, the mushrooms may be large enough to harvest. Mushrooms appear in flushes or breaks — periods of several days of heavy yields followed by about a week of sparce yields, followed again by heavy yields.

During the 1930's U.S. growers averaged about one pound of mushrooms per square foot of bed space. Presently, the average is about two pounds per square foot per crop. In mushroom houses without air cooling, most growers raise two crops per year. However, in certain caves or in air-cooled mushroom houses four to five crops can be grown per year. Yields of four to six pounds per crop are achieved experimentally or under specialized conditions in commerical houses.

Careful regulation of the metabolic gases, including carbon dioxide, are necessary after casing; this requires that the mushroom house have an adequate ventilation system. Drs. J. David Lockard and L. R. Kneebone of Penn State investigated metabolic gases produced by the mushroom; they reported that mycelium produces ethylene, acetaldehyde, acetone, ethyl alcohol, and ethyl acetate in addition to carbon

Apparatus used to study gas relationships of mushroom spawn



harvesting mushrooms at the Penn State Mushroom Research Center dioxide which had been reported by German workers and other scientists. In the future, gas relationships of mushrooms may be exploited in controlling the ventilation of mushroom houses or for other purposes.

Mushroom Pests — Insects, Mites, and Nematodes

One early grower complained that he could not pick his mushrooms, "because clouds of flies snuffed-out his lantern, so he could not see." Phorid, sciarid, and cecid flies, springtails, many species of mites and nematodes, and sowbugs were probably introduced into the first mushroom caves along with the wild spawn.

The need for control measures for mushroom pests was soon recognized by USDA entomologists, including C. H. Popenoe, O. E. Gahm, and A. C. Davis. From 1930 to 1940, Dr. C. C. Compton, then with the Illinois Natural History Survey, Urbana, Illinois, conducted cooperative research with mushroom growers on insect and mite problems. He recalls the extreme reluctance of the growers to let anyone in their mushroom houses. "They were very secretive and only after considerable persuasion was it possible to gain entry into mushroom houses."

C. A. Thomas was appointed as assistant professor of economic entomology, July 1, 1925, at the Bustleton Field Station of The Pennsylvania State College (Univeristy). At first he conducted research on soil insects. In early November 1925, Thomas attempted to rear mushroom pests in quart milk bottles filled with spawn. This was the first bit of research on mushrooms conducted by a member of the Penn State staff.

On December 6, 1925, Thomas noted: "Today I went to West Chester and talked to William Vandegrift, Chester County Agricultural Agent, in regard to the proposed new mushroom grower's cooperative association and the experiment station for the study of mushroom insects and disease. I watched the growers bring their loads of mushroom baskets to the hotel yard in Kennett Square, where the baskets were loaded on four large and one smaller auto vans to be sent to New York and Philadelphia. The baskets are carried to these cities by the Mushroom Transportation Company which charges a few cents on each basket. There are about fifty commission men handling the mushroom trade in these two cities — their names were on placards along the wall of the shed and the baskets assigned to each were placed in front of their sign. About 17,500 three-pound baskets were shipped from here tonight. The mushroom industry in Chester County (1925) is worth about $18 million according to Mr. Vandegrift." This trip was the first official visit into the mushroom industry by a Penn State researcher.

During his thirty-five years of work with mushroom growers and with the animal pests of mushroom crops, Penn State's C. A. Thomas taught the value of sanitation and made many important observations on the life history of mushroom-infesting flies, mites, and nematodes. His illustrated wall chart on mushroom pests still hangs in many mushroom houses, and his 1942 Penn State Bulletin entitled, *Mushroom Insects, Their Biology and Control,* is the most valuable publication printed on this subject to date. Almost all of Thomas's work was done as cooperative-type research, directly with mushroom growers. His remarkable wit and ability to diagnose problems made him a friend of all mushroom growers. He died April 7, 1962.

Upon the retirement of C. A. Thomas in June of 1960, the research program on mushroom pests was moved from Kennett Square to the University Park Campus of Penn State, and Dr. Robert Snetsinger was employed to continue the work. He has conducted a program of testing pesticides for use in control of mushroom pests. Dr. Snetsinger and his students have also been very interested in detailed studies of the life history of cecid, phorid, and sciarid flies, and pyemotid or pigmy mites in order to develop preventive control programs. In 1966 Dr. Robert C. Tetrault, an extension entomologist at Penn State, took over the job of making recommendations for the control of mushroom pests.

Research on the Diseases of the Mushroom Crop

Dr. Walter S. Beach was the first Penn Stater to study mushroom diseases; he started working with mushroom growers in 1926. From 1918 to 1933, he was stationed at the Bustleton Station (now in Philadelphia); in August, 1933 Dr. Beach's position was moved to the University Park Campus. For thirty-seven years he worked on the diseases of vegetables, tobacco, turf, and mushrooms. He investigated the use of formaldehyde treatment of casing soil for bubble disease and studied the development of plaster mold and of mat diseases; he also recognized the value of casing soil treatment and sanitation. In 1937, he authored, a Penn State Bulletin entitled, *Control of Mushroom Diseases and Weed Fungi.*

Dr. James W. Sinden, while at Penn State, also conducted studies on mushroom diseases, including the recognition of a virus disease of mushrooms (La France disease) and the evaluation of Zineb and other fungicides for disease control. Presently, Drs. Leon Kneebone, Lee Schisler, and Paul Wuest of Penn State all have some degree of interest in pathogens affecting mushrooms. Dr. Kneebone's publication on *Mushroom Pathogens, Weed Molds, Indicator Molds and Competitors,* is a valuable introduction to the problem. Also his classroom laboratories given yearly at Penn State Mushroom Short Courses have served to inform the mushroom grower on various aspects of disease identification and control. Dr. Schisler in conjunction with Dr. Sinden and Miss Edith Sigel of the Butler County Mushroom Farms, Inc., discovered that La France disease was spread through the mushroom spore and that mummy disease was caused by a bacterium. Dr. Kneebone and some of his students also studied mummy disease and the virus disease affecting mushrooms. Dr. Wuest in his role as extension specialist has helped mushroom growers with disease problems since August of 1964 and also has studied microbial populations in the casing soil.

Some Facts on Mushroom Marketing

Alfred O. Rasmussen, professor emeritus at Penn State, remembers that his father sold mushrooms for $1.50 per pound in 1892. The mushrooms were hauled by wagon from Westtown to the railroad station at West Chester; the team was left at a livery stable near the old Turk's Head Hotel. Rasmussen's father took the train to the Broad Street Station in Philadelphia and then delivered the mushrooms to Edmund Munk, a commission agent on Dock Street. The agent shipped the mushrooms to wealthy clients in New York, Baltimore, Washington, D.C., and delivered some to his own customers.

A number of spawn makers in the early 1900's promoted spawn sales with "get rich schemes." One company claimed: "All that is necessary to start you on the road to a small fortune, depending entirely upon yourself and the amount of space you have, is a mushroom garden, handled along the lines we provide you. In America we have the largest market in the world. Mushrooms bring a higher price in this country than in any other part of the world. Seldom, if ever, are they sold for less than $1.00 per pound and $1.25 per pound is to be had most of the year. Mushrooms can be grown in your cellar along the shady side of the house or under trees, in the barn or under sheds. For instance, we will say that you have a bed ten feet square, 100 square feet. At a low estimate, this bed will produce 200 pounds of mushrooms. At a price of $1.00 per pound, your income will be $200. Deduct $3.00 for the spawn, three bricks at $1.00 per brick, and the small cost of filling the bed with ordinary stable manure, and you can realize the splendid profits to be made from a very small investment."

C. H. Mahoney, F. A. Bessey, and E. I. McDaniel of Michigan State College (University), East Lansing, Michigan, nicely stated the true situation in 1936. "Few crops are so exacting in their requirements as mushrooms, and few crops demand so much skill, care, and capital in their management. With few crops is the percentage of failure so high as with mushrooms. Despite these facts, well-recognized by those experienced in this field, few crops are so subject to promotion holding out extravagant and unwarranted promise. The experienced grower has only averaged between 4 and 6 cents per pound gross above cost of production during the past four years."

The cost of producing mushrooms in the U.S.A. in 1930 was about 26 cents per pound: the breakdown was interest on investment, depreciation, and upkeep of buildings, 5 cents; raw materials, 14 cents; and labor, 7 cents according to Dr. E. B. Lambert. In 1964, Dr. W. L. Barr, a Penn State economist, reported the total average cost of growing a pound of mushrooms was 25 3/4 cents: this breaks down to interest on investment, depreciation, and upkeep of buildings, 8 cents; raw mateirals, 8 1/2 cents; and labor 9 1/3 cents. In 1930 the average yield was one pound of mushrooms per square foot of bed surface; in 1964 yields averaged 2.2 pounds per square foot of bed surface. Depending upon the efficiency of the grower, costs of production per pound varied about 7 cents a pound in Barr's study.

Production of mushrooms in the United States totaled 189 million pounds in the period of July 1, 1968 to June 30, 1969. Production in Pennsylvania was 121 million pounds for the year ending June 30, 1969; this accounted for 64 percent of the U.S. production. The farm value of mushrooms to Pennsylvania was $42,272,000 during the period July 1, 1968 to June 30, 1969, before processing. Mushrooms are the single leading Pennsylvania cash crop. California, Delaware, Michigan, New York, Maryland, Illinois, and Ohio also are important producers of mushrooms. The Pennsylvania counties of Chester, Berks, Butler, Delaware, Allegheny, Westmoreland, Lancaster, Monroe, Lawrence, and Northumberland are noted for mushroom growing.

In 1954, the average consumption of mushrooms in the United States was seven ounces per person; in 1961 it was fourteen ounces; and in 1969 was eighteen ounces. Dr. Kermit Bird, Agricultural

Economist of the USDA, predicts that by 1985 over 500 million pounds of mushrooms will be consumed in the U.S., about two pounds per person. Since mushrooms are relatively perishable, a relative high percentage (about 74 percent in 1968-1969) is processed rather than sold fresh.

A Crisis and Research in Agricultural Economics

In the 1961-1962 mushroom season, the Formosan mushroom growers began to export canned mushrooms in considerable quantities to the United States; five and one-third million pounds were received. By the 1969-1970 season over twenty million pounds were exported to the U.S. from Formosa. The continuing increase in canned Formosan mushrooms and a developing mushroom industry in South Korea has led to greater competition for U.S. growers, closer margins for the processor, and a general adjustment in the U.S. mushroom industry. One important factor influencing production in Formosa and Korea is their low cost for labor.

On January 20, 1964 representatives of the mushroom industry met with Dr. Russell E. Larson, dean of the College of Agriculture, and members of the University staff. At that meeting representatives of the mushroom industry indicated an immediate need for production cost data to be used in a brief to be filed with the U.S. Tariff Commission. The need for a comprehensive long range study of both growing and processing aspects of the industry was also discussed. Drs. Larson and M. E. John, head of the Department of Agricultural Economics and Rural Sociology, established a task force to work on cost data and long range economic problems.

By February 10, 1964 Drs. W. L. Barr, R. O. Herrmann, A. Stemberger, C. A. Becker, William Butz, and R. H. McAlexander were working on an economic analysis to determine adjustments required to improve the competitive status of Pennsylvania mushroom growers. Drs. Herrmann and Stemberger found limited availability of fresh mushrooms in Southern, Great Plains, and Rocky Mountain states. They also suggested new promotional possibilities for wider use of mushrooms. Dr. Butz, working with staff members of the Departments of Agricultural Engineering and of Horticulture developed and tested more efficient methods for processing of mushrooms. Dr. Butz also determined processing costs in the mushroom canning industry, and with his graduate students recommended procedures for improving the handling and transport of air shipments of fresh mushrooms.

Dr. R. H. McAlexander recognized the need for expanded economic analysis of the U.S. mushroom industry. Dr. Barr identified the need for new production technology which would reduce hand labor and increase yields of mushroom crops. C. W. Porter and Dr. W. R. Kriebel of the Agricultural Economics Extension staff have worked with the mushroom industry on marketing problems.

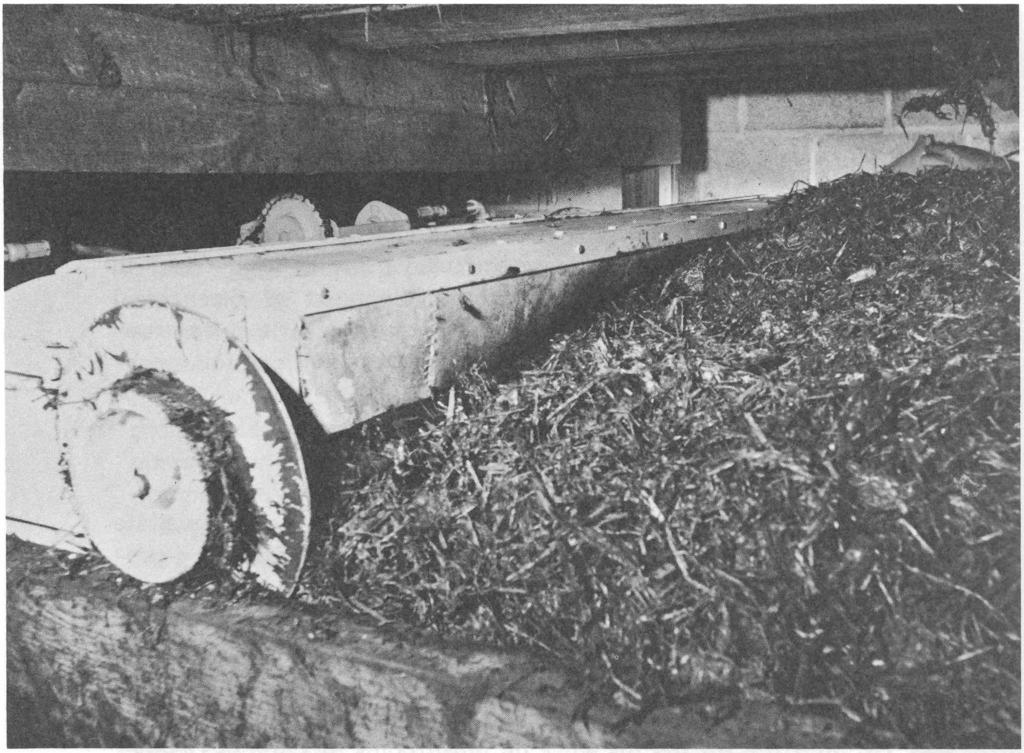
The general recommendation of the Penn State economic task force was that the Pennsylvania mushroom industry must reduce costs of production, processing, and marketing. To accomplish this, researchers in agricultural engineering and mushroom production would need to find means to reduce costs of labor and increase crop yields. Also mushroom growers must keep better records. Additional economic research and educational programs were recommended to assist the mushroom grower in adjusting to improved production techniques and changing market conditions.

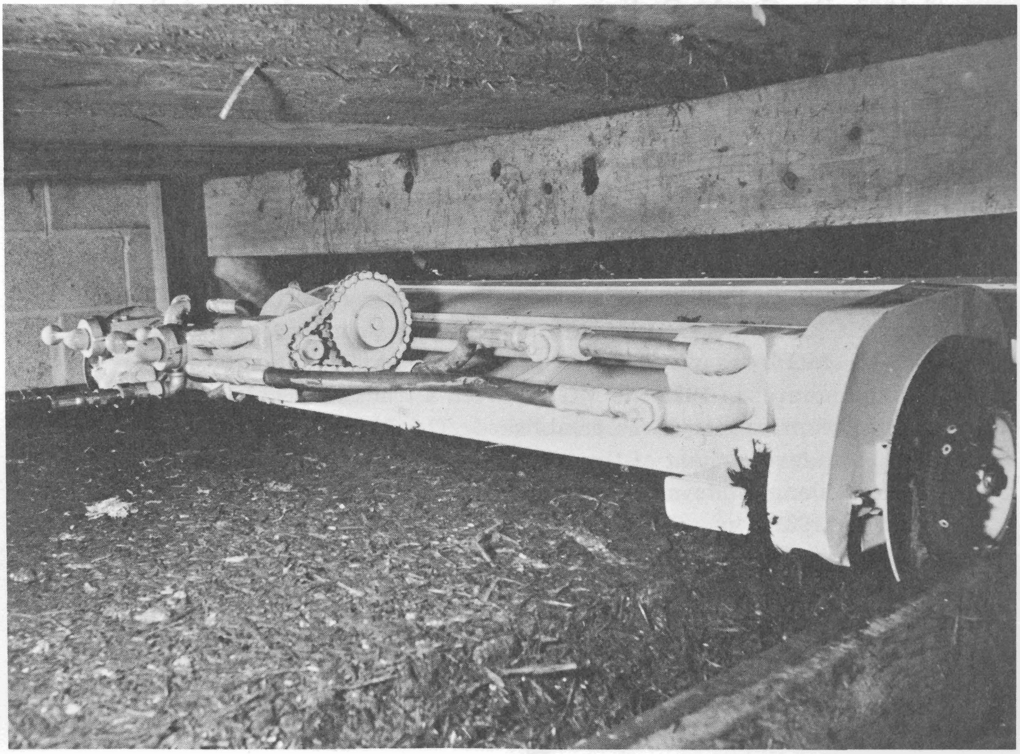
Agricultural Engineering

The technology of the mushroom industry has been largely dependent upon abilities of growers to improvise. They designed, adapted, and constructed their own mushroom houses, compost turners, conveyors, and other equipment.

Some people have contended there are as many as 650 growers in Pennsylvania and 1000 growers in the United States. But, in 1969, Dr. Kermit Bird of the USDA reported there were only 451 growers in Pennsylvania and a total of 629 growers in the U.S.A. Because of the small number of growers and the improbability of achieving a major market for mass-production machinery, manufacturing companies are not interested in spending research money to develop special equipment for mushroom growers.

Research on engineering aspects of mushroom production started at Penn State in 1964. Feasibility studies were undertaken in several areas including mechanical harvesting. Dr. Morris Schroeder, professor of agricultural engineering developed a mechanical spawn mixing machine for the bed system. This machine meters spawn at desired rates, mixes the spawn uniformly within the compost, and levels and compacts the compost so as to be ready for casing. The design drawings for this machine have been released to interested manufacturers. Dr. Schroeder also has developed a unitized ventilation machine which results in precise control of temperature and air movement within a mushroom house. Recently, Dr. Sverker Persson, associate





Two views of Penn State's mechanical spawn mixing machine professor of agricultural engineering, was assigned to develop a mechanical harvester; preliminary work has begun on this project. Henry Wooding and Joseph McCurdy, associate professors of Agricultural Engineering Extension, have conducted a number of educational programs for the mushroom industry. The general trend in mushroom engineering is toward the development of mechanical equipment to reduce labor costs and to provide a refined environmental control so as to create the best possible conditions for mushroom growth.

Mushroom Processing

Dr. Frank McArdle, associate professor of horticulture at Penn State has worked on the problem of mushroom shrinkage during the processing phase. He has found means of reducing shrinkage losses during canning which resulted in improved efficiency and reduced production costs in the canning of mushrooms. By defining the nature of the mushroom shrinkage problem, it has been possible to develop new and improved systems designed to save labor and reduce product loss. Dr. McArdle started his work on mushrooms in 1961. In October of 1967, Dr. Gerald D. Kuhn became associate professor of Food Technology Extension at Penn State; he has conducted extensive educational programs for the mushroom processors.

Mushroom Growers Organize

Mushroom growers have recognized the need to cooperate for their common interest in obtaining supplies, obtaining better prices, promoting mushroom sales, and encouraging research and educational programs. The Mushroom Grower's Cooperative Association (MGA) was their first big venture into the field of cooperation. On April 8, 1926, the MGA organized to aid growers in purchasing supplies, including manure; in 1928 the MGA started a trucking service; in 1930, its mushroom cannery was established. The MGA played a leading role in the development of the industry by encouraging research programs at Penn State and the USDA. The *MGA Review,* first published in 1932, was the first educational periodical for American mushroom growers.

In 1954, American Mushroom Institute (AMI) was planned and on January 31, 1955 was fully organized. The AMI has served to unite the mushroom growers in a program of cooperative advertising and self improvement through education. It has published a monthly newsletter, *Mushroom News,* since 1955. In 1962, it sponsored the Fifth International Mushroom Congress held in Philadelphia. The AMI provides many services to its members.

The Pennsylvania Food Processors Association is a national trade association of nearly thirty companies that process some 90 percent of the mushrooms canned in the United States. This organization is concerned to a high degree with mushrooms; it's quarterly publication, *The Pennsylvania Packer,* deals with the processing of mushrooms and other crops. The Food Processors Association has cooperated with Penn State staff members on many research projects designed to improve the quality of processed mushrooms.

Both the AMI and the Pennsylvania Food Processors Association have worked closely with food editors in developing new mushroom recipes, conducting other educational programs to encourage wider use of mushrooms, and in providing other useful information for their members and for consumers. Both organizations have lobbied for state and federal support and protection and also have fostered research and educational programs at Penn State, the USDA, and other institutions.

Educational Programs for Mushroom Growers

Dr. Leon R. Kneebone recognized mushroom growers needed formal training in production methods and in the recognition of diseases and pests of their crop, an opportunity to discuss and share experiences with other mushroom growers on an organized basis, and a better understanding of their industry. From July 9 to 12, 1956, the First Mushroom Industry Short Course was held at the University Park Campus of The Pennsylvania State University. In this and courses that have followed annually the attendance has exceeded 200 each year and includes delegates from fifteen to twenty states and several foreign countries.

The Cooperative Extension Service has assisted the Pennsylvania industry through the offices of the county extension agent and Penn State specialists. The Extension agricultural agents in counties where mushrooms are grown have assisted the mushroom industry; William Vandegrift of Chester County, was one of the first in this line of agents. At Penn State many of the researchers have carried on extension-type programs in addition to their research and resident teaching activities. In 1964 Dr. Paul J. Wuest was appointed assistant professor of Plant Pathology Extension with duties as mushroom specialist; he has conducted many workshops and other programs to help the mushroom grower. Dr. Wuest also has done much to coordinate activities on mushroom research and education on the Penn State campus; he has arranged for periodic meetings of various staff and graduate students so that they can talk about what they are doing on their mushroom related projects. He also helped the administration organize various committees relating to the mushroom industry.

In order to establish a direct line of communication between Penn State and the mushroom industry, Dean Russell E. Larson established a Mushroom Liaison Committee. This committee of industry representatives and Penn State staff members meets once or twice a year to discuss the industry's needs and the University's program in mushroom research and education to insure good cooperation and understanding among those involved with mushrooms. The first Mushroom Liaison Committee meeting was held on February 24, 1965, at the Nittany Lion Inn on the University Park Campus of Penn State.

Research and extension specialists at The Pennsylvania State University have authored hundreds of educational articles in *Mushroom News, The Pennsylvania Packer,* Experiment Station bulletins and progress reports, and many important scientific publications. Over the years the staff at Penn State has answered many thousands of letters and phone calls concerning problems of the mushroom industry and questions from the general public. Specialists from Penn State have made hundreds of visits to mushroom farms to help growers with their problems.

Students have helped in the research programs at Penn State, and the facilities have played an important role in instruction. A number of students have helped support their education by their work in mushroom programs.

New Mushroom Facilities at Penn State — A Step to the Future

Inadequacy of facilities greatly hampered mushroom researchers at Penn State during the 1940's and 1950's. The mushroom growing house which had been constructed in 1928 and enlarged in 1934 was not satisfactory for studies that required a closely regulated environment. The cellar used for mushroom disease studies was destroyed to permit the construction of the forestry building. For a considerable time the insect control research was conducted at C. A. Thomas' home at Kennett Square and in space provided by the MGA.

The need for new facilities at Penn State was recognized by the mushroom industry and administrators of the College of Agriculture. The first step was taken when the Mushroom Research Center was constructed in 1960. The building was built with special funds from state legislation; however, the state funds were not adequate to complete construction and equipping of the building. Additional funds were made available by Dr. M. A. Farrell, then director of the Agricultural Experiment Station at Penn State, and from special grants from the American Mushroom Institute and the mushroom industry at large.

The Penn State Mushroom Research Center consists of a main building sixty feet by forty feet of concrete block construction and a steel composting shed. The main building contains three growing rooms, two pasteurizing rooms, an office-laboratory, a work room, and equipment and storage rooms. With the destruction of the old mushroom house in 1970 because of the construction of a new arts building, the General State Authority appropriated replacement funds for the enlargement of the Mushroom Research Center. With the loss of the old mushroom house to construction, the staff on mushroom research has had to postpone studies on disease control and the effects of environmental management practices on mushroom growth.

In May of 1968, Dean Russell Larson and Director M. A. Farrell appointed a special committee to develop a facility in which all modern technologies of engineering, biology, and economics would be combined to produce mushrooms as efficiently as possible. The facility was to serve as a testing grounds for the application of research and demonstrate to the mushroom grower the effectiveness of the various technologies to commercial mushroom farming. With this goal in view, the committee of Drs. Morris E. Schroeder, professor of agricultural engineering; W. L. Barr, professor of farm management; Lee C. Schisler, associate professor of plant pathology; and Robert Snetsinger, associate professor of entomology undertook to develop such a facility. Plans were completed during the fall and winter of 1968, and construction was started in the late spring of 1969. The Mushroom Test-Demonstration Facility was completed in the spring of 1970.

The Penn State mushroom specialists are convinced that the success of the mushroom industry in Pennsylvania lies in the adoption of new technologies demonstrated in this facility and others that may emerge in the future.

PAST AND PRESENT

Mushroom Research and Extension Staff

University Park Campus

Plant Pathology (including Botany)

Dr. Walter S. Beach was instructor in 1918; assistant professor in 1919; associate professor in 1924; professor in 1948; retired in 1955 and lives in State College, Pa.

Dr. Illo Hein, assistant professor starting November 15, 1927 for a two-year period; after which he was a cytologist for the USDA. Died March 4, 1948.

Dr. James W. Sinden, assistant professor starting April 1930; associate professor July 1939; professor July 1945; resigned March 1953. Currently with Hauser Champignonkulturen AG, Gossau/Zurich, Switzerland.

Dr. Leon R. Kneebone, professor of botany and plant pathology, 117 Buckhout Laboratory.

Dr. Lee C. Schisler, associate professor of plant pathology, 116 Buckhout Laboratory.

Dr. Paul J. Wuest, assistant professor of plant pathology, 115 Buckhout Laboratory.

Thomas G. Patton, Jr., research assistant in plant pathology, 111 Mushroom Research Center.

Entomology

Charles A. Thomas, appointed assistant professor of economic entomology July 1, 1925; associate professor in 1939; professor in 1945; he retired in 1960 and died April 7, 1962.

Dr. Robert Snetsinger, associate professor of entomology, 7 Armsby Building.

Dr. Robert C. Tetrault, assistant professor of Entomology Extension, 202 Armsby Building.

Horticulture

Dr. Frank J. McArdle, associate professor of food science, Horticulture Processing Laboratory.

Dr. Gerald D. Kuhn, associate professor of Food Technology Extension, 106 Head House 1.

Agricultural Engineering

Dr. Morris E. Schroeder, professor of agricultural engineering, 222 Agricultural Engineering Building.

Dr. Richard A. Keppeler, associate professor of agricultural engineering, 208 Agricultural Engineering Building.

Dr. Sverker P. E. Persson, associate professor of agricultural engineering, 227 Agricultural Enginering Building.

Joseph A. McCurdy, associate professor of Agricultural Engineering Extension, 202 Agricultural Engineering Building.

N. Henry Wooding, Jr., associate professor of Agricultural Engineering Extension, 203 Agricultural Engineering Building.

Agricultural Economics and Rural Sociology

Dr. W. L. Barr, professor of farm management, 103D Weaver Building.

Dr. W. T. Butz, professor of agricultural economics, 201 Weaver Building.

Dr. A. P. Stemberger, professor of agricultural economics, 111A Weaver Building.

Dr. R. O. Herrmann, associate professor of agricultural economics, 201C Weaver Building.

Charles W. Porter, associate professor of Agricultural Economics Extension, 28 Weaver Building.

Dr. Wesley R. Kriebel, associate professor of Agricultural Economics Extension, Weaver Building.

Mushroom Test-Demonstration Facility

Harry Muthersbaugh, supervisor, Mushroom Test-Demonstration Facility.

Most staff members devote only a portion of their time to mushroom research and have resident teaching and other duties. In addition other staff not directly working on mushroom related research have, are, and will provide specialized services and advice of use to the mushroom industry. Office addresses given in this section are as of January 1, 1970.

LIST OF THESES

List of theses completed at The Pennsylvania State University as of June, 1969 on topics involving mushroom production, processing, or merchandizing; the name enclosed in parentheses indicates the major professor.

Plant Pathology (including Botany)

Anderson, F. A. Effect of temperature on spore survival of fungus pathogens and competitors of the cultivated mushroom, *Agaricus campestris* L. ex Fries; 1956, M.S., (Kneebone).

Schisler, L. C. A physiological investigation of sporophore initiation in the cultivated mushroom, *Agaricus campestris L.* ex Fries; 1957, Ph.D., (Kneebone).

Allison, W. H. An investigation of antibiotics as a control of bacterial blotch on the cultivated mushroom; 1957, M.S., (Kneebone).

Merek, E. L. A study of the mummy disease of the cultivated mushroom, *Agaricus campestris L.* ex Fries; 1960, Ph.D., (Kneebone).

Lockard, J. D. An investigation of the metabolic gases produced by the cultivated mushroom, *Agaricus bisporus* (Lange) Sing.; 1962, Ph.D., (Kneebone).

Allison, W. H. Influence of compost pH and of casing soil pH on mushroom production; 1963, Ph.D., (Kneebone).

Hager, R. A. An investigation of X-disease of the cultivated mushroom, *Agaricus bisporus* (Lange) Sing.; 1966, Ph.D., (Kneebone).

Wardle, K. S. The effects of various lipids on growth of mycelium of *Agaricus bisporus* (Lange) Sing.; 1968, M.S., (Schisler).

Entomology

Chung, S. L. Environmental effects upon paedogenetic reproduction of a cecid fly, *Mycophila speyeri* Barnes (Diptera: Cecidomyiidae); 1964, M.S., (Snetsinger).

Risoldi, Ciro G. An investigation of the Baermann funnel technique of collecting mushroom-infesting nematodes; 1965, M.S., Ag. Sci., (Snetsinger).

Chung, S. L. Comparative effects of certain environmental factors upon the life cycles of two mushroom-infesting cecid flies (Diptera: Cecidomyiidae); 1967, Ph.D., (Snetsinger).

Wagner, V. E. A survey of fly populations in two communities in southeastern Pennsylvania; 1967, M.S., (Snetsinger).

Wicht, M. C., Jr. The biology and control of mushroom-infesting pyemotid mites (Acarina: Pyemotidae); 1969, Ph.D., (Snetsinger).

Horticulture

Dommel, R. M. Mushroom shrinkage during processing: Some influencing factors and composition changes; 1964, M.S., (McArdle).

Valensky, R. J. Chemical treatment and packaging of unbleached frozen mushrooms for prevention of enzymatic oxidative browning; 1968, M. S., (McArdle).

Lee, Y. A. Carbohydrate transformations during storage of mushrooms; 1969, M.S., (McArdle).

Agricultural Economics

Ermel, F. C. Alternative production plans for 3, 10, and 20 double mushroom houses under average and recommended management; 1968, M.S., (McAlexander and Barr).

Brosius, T. P. Practices and costs of different methods of spawning; 1969, M.S., (Butz and Barr).

Coale, C. W., Jr. An economic-engineering analysis of mushroom processing plants; 1969, Ph.D., (Butz).

Furry, J. L., II. An economic analysis of compost preparation in Chester County, Pa. 1967-68 crop year; 1969, M.S., (Barr).

Poorbaugh, D. R. Air transport of fresh mushrooms: Problems and Potentials; 1969, M.S., (Butz).

Agricultural Engineering

Wagner, J. L. Engineering evaluation of the mushroom production bed system with an investigation of mechanical harvesting feasibility; 1965, M.S., (Schroeder).

Hetherington, G. R. Designing and development of a machine to perform mixed spawning for the bed system of mushroom production; 1967, M.S., (Schroeder).

SOME IMPORTANT PUBLICATIONS ON MUSHROOM RESEARCH

by Staff Members of
The Pennsylvania State University

Hein, I. 1929. An experimental mushroom house. *Torreya* 29:131-132.

Hein, I. 1930. Straw Compost for mushroom culture. *Mycol.* 22:39-43.

Hein, I. 1930. Soybean stover compost for mushroom culture. *Mycol.* 22:227-231.

Hein, I. 1930. Studies on the mycelium of *Psalliota campestris*. *Amer. Bot.* 17(3):197-211.

Thomas, C. A. 1931. Mushroom insects their biology and control. *Pennsylvania State College Agr. Exp. Sta. Bull.* 270:1-42.

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SUMMARY OF HIGHLIGHTS FROM PENN STATE'S MUSHROOM PROGRAMS

The College of Agriculture of The Pennsylvania State University began its mushroom research programs in the fall of 1925. Some major Penn State contributions to this industry are:

1) development of the grain spawn process
2) improved mushroom varieties
3) synthetic composts
4) improved and short methods of composting
5) methods of supplementing the compost
6) procedures for controlling insects, mites, and diseases
7) improved processing procedures
8) a task force study of economic problems
9) advances in equipment and facilities for growing mushrooms
10) educational programs to instruct the mushroom grower
11) supplying resource materials for students, teachers, and the general public on mushroom culture
12) graduate instruction on various aspects of mushroom science
13) a deeper understanding of the art and science of mushroom growing

For many years research efforts dealt only with the biological problems of mushroom growers. But, in the past decade the College of Agriculture has greatly expanded its mushroom research facilities, staff assignments, and educational activities. Penn State now does work on processing, engineering, and marketing of the mushroom crop as well as biological studies.

This history of mushroom research at The Pennsylvania State University reflects on a small scale the kinds of contributions Penn State makes to the Commonwealth.

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