To the Graduate Council:

I am submitting herewith a dissertation written by Virginia I. Lohr entitled "Spent Mushroom Compost: Its Physical and Chemical Characteristics and its Use in Soilless Growth Media for the Production of Vegetable Transplants." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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SPENT MUSHROOM COMPOST: ITS PHYSICAL AND CHEMICAL CHARACTERISTICS AND ITS USE IN SOILLESS GROWTH MEDIA FOR THE PRODUCTION OF VEGETABLE TRANSPLANTS

A Dissertation

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ABSTRACT

The use of fresh spent mushroom compost (SMC) and SMC which had been aerobically composted for five weeks as replacements for peat in soilless media were studied.

Determination of physical and chemical characteristics revealed that fresh and aged SMC had high concentrations of calcium and potassium, high percentages of air space, low water buffering capacities, and high soluble salt concentrations. Fresh SMC had very high levels of ammonium, was basic, shrank excessively, and held little easily available water. Aged SMC held adequate amounts of easily available water, contained low levels of ammonium, and had a pH near neutral.

Lettuce (*Lactuca sativa* L.), tomato (*Lycopersicon esculentum* Mill.), cucumber (*Cucumis sativus* L.), and marigold (*Tagetes patula* L.) transplants were grown from seed in leached and unleached potting mixes containing 0, 25, or 50% (by volume) peat and/or fresh or aged SMC, with 50% vermiculite. Heights, quality ratings, dry weights, percent dry weights, and tissue element concentrations were measured. Plants similar to control plants were produced in 25% aged SMC, with 25% peat and 50% vermiculite. Acceptable plants of slightly reduced quality were produced in 50% aged SMC with 50% vermiculite. Reduced growth and symptoms of ammonium toxicity were seen in plants grown in fresh SMC. Leaching improved yields of lettuce and marigolds grown in 25% SMC and of all crops grown in 50% SMC. Tissue concentrations of calcium and potassium were higher and of magnesium and phosphorus were lower in plants grown in SMC than in those in the control mix.

Broccoli (Brassica oleracea L. var. italica), lettuce, tomato, and marigold transplants were grown from seed in media containing 50% vermiculite (by volume), fresh or aged SMC in a range of levels from 0 to 50%, and peat (comprising the remaining portion). Heights, dry weights, and percent dry weights were measured. Crop responses to fresh and aged SMC had significant linear and quadratic trends. Generally, percent dry weight decreased linearly, while dry weight and height rose initially and then dropped as the level of SMC in the growing medium increased. Lettuce, marigolds, and tomatoes grew best in 25% aged SMC, while cucumbers grew best in 37.5% aged SMC.

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CHAPTER I

INTRODUCTION

Demands for water, air, and nutrients are much more intense for container grown crops than for field grown crops (6, 21, 45). The physical conditions of a growing medium within a container are different from those in the field (52). For these reasons, field soil, by itself, is unsatisfactory as a growing medium for use in containers. Traditionally, growers have amended field soil by adding such materials as sand, peat, or manure to improve its properties for use as a growing medium in containers (21, 52, 95). For example, the widely used John Innes recipes for potting mixes, developed in the late 1930's, were based on combinations of soil, sand, and peat (21).

Much of the horticultural industry has now turned to soilless mixes for use in containers. This change was brought about by a combination of factors. Large quantities of soil of consistent quality became less available for general use by the industry (19). Soil required sterilization, a costly procedure (4). Special equipment and care were needed to insure the destruction of pathogens and to prevent the build-up of toxic levels of substances, such as manganese (21). The weight of soil made it difficult to handle and expensive to ship. In addition, the contamination of soil with herbicides became an increasing problem (121, 133).

Soilless mixes based on peat and sand were developed at the University of California (UC) in the 1950's (21). At Cornell University, mixes based on peat with vermiculite or perlite were studied

(101). The UC and Cornell mixes became very popular and are still widely used (19, 22, 101).

As the use of peat by the horticultural industry grew, its cost rose. This promoted a search for other readily available and inexpensive products to substitute for peat in soilless potting mixes. The use of such materials as pine bark and sawdust increased, especially for the production of container grown nursery stock (92).

Bark and sawdust are not readily available everywhere. New electric generating plants which burn wood by-products may soon be competing with the horticultural industry for those wastes, even in areas where they are currently cheap and plentiful (13, 92).

The search for suitable components for potting mixes continues (40, 86, 96, 127, 128). The uses of a variety of locally available waste products are being explored (13, 28, 92). For example, research has been conducted in Hawaii on the use of pineapple wastes and ground tree fern trunks (28), in North Carolina on peanut hulls (13), and in Connecticut on fermentation residues (34).

This research project was designed to examine the uses of spent mushroom compost as a component in soilless potting mixes. Spent mushroom compost, a by-product of the mushroom industry, is the organic mixture in which mushrooms have been grown. It is made from a mixture of such ingredients as straw, horse manure, peat, limestone chips, gypsum, cottonseed meal, and urea. This material is infused with fungal mycelium and is used as the growth medium for mushrooms. After approximately 45 days, an economical crop of mushrooms is no longer being produced. The material is then termed "spent", and must be replaced. It is sterilized to inhibit the growth of diseases and insects which affect mushrooms and is then discarded.

In 1979 in the United States, 213,180,000 kilograms (kg) of mushrooms were produced (115). This constituted a substantial rise from production levels of 81,915,000 kg in 1967. The plant from which compost was obtained for this study produced approximately 780,000 kg of mushrooms per year, and disposed of about 120,000 cubic meters of spent compost. Assuming their ratio of compost to mushrooms is typical, nearly 33 million cubic meters of SMC are produced in the United States every year. Much of this material is offered for sale at nominal rates.

The uses of spent mushroom compost in various potting mixes have been superficially investigated by White (121) in Pennsylvania, Henny (54) in Florida, and Rathier (91) in Connecticut. These researchers all advised against using spent mushroom compost directly from mushroom houses. They suggested that the material be aged before use, but gave few or no details about why or for how long. Only Rathier (91) presented any experimental results to indicate that fresh spent mushroom compost was harmful to plant growth, and his results appeared inconclusive.

The main objective of this study was to determine the usefulness of spent mushroom compost as a replacement for peat in a standard soilless potting medium for the production of transplants. To achieve this objective, the following studies were conducted.

1. The physical and chemical characteristics of fresh and of aerobically aged spent mushroom compost were determined.

2. The effects of level, aging, and leaching on the usefulness of spent mushroom compost as a replacement for peat in standard soilless media for the production of transplants were determined.

3. Transplants grown in a high quality peat-vermiculite medium and transplants grown in media containing spent mushroom compost and vermiculite were compared.

4. The effects of compost level, aging, and leaching on element concentration in transplants grown in soilless media were measured.

5. The growth responses of transplants grown in varying doses of fresh and aged spent mushroom compost were studied.

CHAPTER II

REVIEW OF LITERATURE

Alternative Substrates for Container Grown Crops

With the rise in the cost of peat moss, a major ingredient in both the University of California and the Cornell soilless potting mixes (21, 101), came the search for less expensive alternative substrates for container grown crops (13, 33, 92, 105, 128). The need to dispose of waste products also prompted research in this area (17, 23, 25, 34, 40, 41, 46, 96, 106, 127).

Much research has been done on the use of hardwood and coniferous bark in media for container grown crops (1, 5, 25, 83, 90, 107, 120, 133). Pine bark was shown to be very useful, and it is currently in widespread use in the nursery industry (1, 13, 44, 93). Some problems with phytotoxicities in fresh bark, especially from hardwood trees, have been found (1, 25, 26, 107, 110, 128, 133).

Fly ash, a waste product from the generation of electricity from coal, is readily available in many parts of the United States (40, 41). Furr and others grew various vegetables in soil alone and in soil amended with 10% (by weight) fly ash (41). They found that the effect of fly ash on yield was variable. They also stated that different batches of fly ash could vary considerably, due to variations in the coal and in the methods of its combustion. Fretz and coworkers used fly ash in varying concentrations, up to 80%, with bark to grow Cotoneaster dammeri and Taxus x media (40). They found no major differences in yields associated with fly ash concentrations. Some elemental differences, which varied with the species, were observed. They suggested that some boron toxicity might result from the use of fly ash by the nursery industry.

Leaf compost was examined by Sawhney (96) and was shown to contain very high levels of soluble salts. He demonstrated that leaching the compost readily reduced the salts to levels which were considered ideal.

Pertuit and Mazur (86) examined various poinsettia (*Euphorbia pulcherrima*) growth substrates, including rubber from ground automobile tires. They found no differences among plants grown in bark, peat, or perlite at 30 or 60% by volume with soil. They did find, however, that the fresh weights of plants grown in any of those mixes were more than 100 times greater than those of plants grown in either 30 or 60% rubber.

The attempts by Criley and Watanabe (28) to find useful alternative potting ingredients were more successful than those of Pertuit and Mazur (86). They studied plant growth in media containing sphagnum peat, aged wood shavings, aged pineapple wastes, or ground tree fern trunks. They reported that fresh wood shavings and fresh pineapple wastes were not useful due to high carbon to nitrogen ratios. They found few differences in the response of chrysanthemums (*Chrysanthemum morifolium*) to any of the media tested, and concluded that all could be used as alternatives to soil based media.

In examining the effects of peanut hulls, pine bark, and peat moss on azalea (*Rhododendron indicum*) growth, Bilderback and coworkers found that, while all mixes tested produced high quality azaleas, greater growth occurred in each of the mixes which contained peanut hulls than in the control mix (13).

Regulski (92, 93) has been studying gasifier residue, the waste product resulting from the burning of wood chips and bark. He showed that this inexpensive material could be successfully used to produce various nursery crops (92). Gasifier residues were shown to have desirable physical properties which could be further improved by combining the residues with peat (93).

Sewage sludge compost as an amendment to potting media has also been studied by various researchers (23, 106, 108, 114, 127). They have generally shown that it can be used effectively, and that it supplies some essential nutrients. Touchton and Boswell (114) recorded problems due to excess zinc levels. Sterrett and others noted phytotoxic levels of zinc and copper in plants grown in sludge of high heavy metal content, but not in those grown in sludge of low heavy metal content (106). In examining the use of sludge in media for growing vegetable transplants, Sterrett and others were particularly concerned with levels of heavy metals in the transplants and in the final harvested products (108). They found that levels of heavy metals in the edible portions of plants were little influenced by the content of metals in the media in which the transplants were originally grown. They concluded that sludge could safely be used for the production of vegetable transplants.

DeRoo (34) reported on the use of fermentation residues. These are waste products from the production of organic acids and antibiotics by microorganisms. As the material is largely spent fungal mycelial tissue, studies on its use may have direct application to studies of spent mushroom compost. Like spent mushroom compost, fermentation residues contain high levels of calcium sulfate (gypsum). DeRoo determined the physical and chemical characteristics of these residues and evaluated their usefulness in growing chrysanthemums, junipers (*Juniperus horizontalis*), tomatoes (*Lycopersicon esculentum*), corn (*Zea mays*), and oats (*Avena sativa*). Crop responses varied widely. Junipers grew better and remained greener than control plants, while tomatoes were stunted and had mottled, yellow leaves when grown in the fermentation residues. DeRoo examined the reduced growth in tomatoes and was able to show that the reduced growth response was not due to the high levels of zinc or gypsum in the residues or to salinity problems (35). He was unable to determine the cause of the reduced growth.

Spent Mushroom Compost as a Growth Medium for Plants

Spent mushroom compost (SMC) as a waste product has been available for many years. In 1931, Sprague and Marrero (104) reported on its use as an organic matter source for growing field plants. Its use was of particular interest because machinery had been replacing animals on farms, making manure less available. Sprague and Marrero were interested in comparing various sources of organic matter, including SMC and manure, in order to assess their effectiveness in improving soil physical conditions. SMC was shown to be beneficial as a replacement for manure in loam, clay loam, and sandy soils. Sandy soil was the only soil type in which SMC was superior to peat as a replacement for manure. The organic matter content of SMC was found to be relatively resistant to decomposition. The authors suggested this was because SMC had decomposed substantially before use, therefore it contained many compounds which were resistant to decay.

While the work of Sprague and Marrero (104) was very thorough, their findings on SMC are no longer directly applicable. The SMC available today is unlike the material they tested in 1931. They worked with spent mushroom soil, which was made by alternating layers of straw and manure with soil. Today, mushrooms are usually grown in a thick layer of organic matter without soil (39, 43, 49, 131, 132). This layer is topped with a shallow casing layer placed over the substrate after the fungal mycelia have proliferated. While some mushroom producers still use soil in this casing layer, most have switched to other materials (65, 130). Soil appropriate for casing purposes is as difficult to obtain as soil for use in potting mixes (65, 129). A commonly used casing material is peat mixed with limestone chips.

More recently, Wang (118) re-examined the use of SMC as an organic matter additive to soil. Corn yields increased with SMC applications. This was attributed to improved nitrogen status rather than to changes in soil physical properties.

In 1976, White (121) reported on the use of aged SMC in soilless growing media for Easter lilies (*Lilium longiflorum*). He used mixes containing sphagnum moss peat and SMC which had decomposed, weathered, and leached for two to three years. These materials were used in 10%

increments from 0 to 100% by volume. He also compared fertilization from slow release and liquid formulations. The rate of fertilization was decreased as the rate of SMC increased, to compensate for the higher fertility of SMC compared to peat. As a result, response to fertilization was somewhat confounded with response to SMC. No statistical analyses of the results were presented, and only mean values were reported. The fresh weight and plant height responses of lilies to SMC appeared to be quadratic, with the highest yields reported from 10 to 60% SMC. The length of the forcing cycle increased steadily with increased levels of SMC.

White (121) reported that concentrations of phosphorus, manganese, iron, and zinc in leaf tissue decreased and potassium increased as SMC in the media increased. Analysis of extracts of the mixes receiving slow release fertilizer revealed increased potassium, magnesium, calcium, nitrates, pH, and soluble salts as the percentage of SMC increased. Phosphorus decreased slightly as SMC increased.

In the introduction to his article, White (121) stated that SMC should be aged for two to three years before it is used. He did not state specifically why SMC should be aged, why he recommended two to three years, nor how to determine when the compost is ready for use.

Henny (54) examined the use of SMC in the production of foliage plants. She suggested that SMC be aged, by aerobic composting, so that a relatively stable material would result. SMC that was aged for nine months was used alone or in combination with pine bark in her study. These treatments were compared to a pine bark with peat control mix. The report covered two separate experiments, one which incorporated leaching and pH control, and one which did not. Little statistical analysis was provided on the simpler experiment, and no statistical analysis accompanied the experiment involving leaching and pH control. Henny concluded that leaching was effective in reducing total soluble salts and that iron sulfate could be used to reduce pH. Since no damage from the high salts or high pH in SMC was seen, the need for these practices is questionable. Generally, Henny showed that the foliage crops tested in SMC grew as well as or better than those grown in the control mix. During the nine month experiment, a problem with shrinkage in the 100% SMC treatment was noted.

Rathier (91) recently reported on the use of SMC for greenhouse crops. He compared crops grown in 33% SMC by volume in combinations with perlite and soil or peat. He compared treatments containing SMC fresh from a mushroom farm with treatments containing SMC which had aged aerobically for six to twelve weeks. He added 3 kg of limestone per cubic meter of mix of composted SMC, perlite, and soil, 4.5 kg of limestone to the mix of fresh SMC, perlite, and peat, and 11 kg to the mix of soil, perlite, and peat. No lime was added to the mix of fresh SMC, perlite, and soil, or to the mix of composted SMC, perlite, and peat. No explanation was given for this apparently haphazard addition of lime. Flowering was delayed in chrysanthemums grown in fresh SMC. Those grown in composted SMC tended to flower even sooner than those grown in the control mix. The author found no effect of treatment on blooming date in marigolds. He noted generally improved foliage color in tomatoes grown in SMC, but no effect for marigolds (Tagetes). Poor color in the tomato control plants was attributed to lack of fertilizer. Rathier showed that the level of ammonium nitrogen was higher at the start of the experiment in the mixes containing fresh SMC than in the other treatments. After six weeks, the level of ammonium was similar and low in all treatments. Rathier concluded that fresh SMC should not be used or that it should be used in small amounts to dilute the soluble salts and ammonium nitrogen levels.

In a brief report on the use of SMC to produce container shrubs, Eames (36) concluded that SMC was totally unacceptable as a substrate component for that purpose, due to shrinkage and lack of stability.

Spent Mushroom Compost as a Mushroom Casing Layer

Some SMC has been recycled by the mushroom industry itself. It has been composted, and then re-used as the casing layer (65, 129, 130). While the requirements for mushroom growth are different from those for green plants, examination of the research on the use of SMC as a casing layer for mushrooms could provide insights into the use of SMC as a substrate for green plants.

The use of aged SMC as a casing layer for mushrooms was considered because problems with commonly used casing materials arose (65). The cost of peat rose and top soil was increasingly difficult to obtain. Since SMC had often been dumped in fields near mushroom farms, some growers began experimenting with using this readily available material as a casing layer.

Wuest, who studied the reuse of SMC as a casing layer, reported many problems with its use (129, 130). He tried to identify the characteristic which caused some SMC to work well as a casing layer while other SMC worked poorly. He speculated that a toxic substance might be present, particularly if compost exposed to anaerobic conditions were used. Wuest (129) found that mushroom yields were higher when SMC which had weathered for two years was used than when SMC which had weathered for either one or three years was used. He examined many aspects of these samples of SMC and found many differences, but he was unable to find correlations between any of these differences and mushroom yields. While he found that zinc, copper, manganese, sodium, sulfur, ammonia, total nitrogen, nitrate nitrogen, soluble salts, cation exchange capacity, and water holding capacity all decreased as the SMC weathered, none of these could be used as an index for mushroom yield. To determine if a particular sample of aged SMC should be used as a casing layer, Wuest simply suggested experimenting with it first on a small tray of mushrooms.

Wuest discussed other problems which restrict the use of SMC as a casing soil (130). For the weathering process, the SMC must be placed in windrows. The size and spacing of these are important, because anaerobic conditions must be avoided. The SMC must be disked or roto-tilled once or twice a year. Wuest also pointed out that sufficient land must be available for the weathering process and that alternative uses for the land should be considered (129). He reminded growers that in comparing costs of alternative casing materials to the cost of using SMC, they should include the amount of income that could have been obtained if a crop had been grown on the land. Problems with liquid run-off from weathering SMC have also been noted. A final problem with using weathered SMC is that it must be resterilized before use. Steam sterilization of the material could result in the release of ammonia, which reduces mushroom spawn growth.

The Effects of Soluble Salts on Plant Growth

The problems of growing plants under saline conditions are well known. Several good books and reviews on the subject are available. The U.S. Salinity Laboratory staff's classic handbook (94), edited by Richards and published in 1954, presents a thorough treatment of the diagnosis and improvement of saline and sodic soils and includes very detailed methodology. In 1975 Bernstein reviewed the physiological responses of plants to saline and sodic conditions (9). A recent book by Bressler, McNeal, and Carter presents a good review of plant responses to saline and sodic soils and covers many other aspects of saline and sodic soils as well (15). It includes tables which show percentage reductions in growth which have been measured at specific salinity levels for many crops.

High levels of soluble salts in spent mushroom compost have been reported by various researchers (36, 49, 54, 91, 121). Some researchers did not report exact soluble salt levels, while some reported levels in 100% SMC, and others reported levels in mixtures containing SMC. The extraction method, which strongly influences the magnitude of the salinity values (21, 94, 119), was not always stated. While the precise levels measured by different workers cannot be compared, the levels appear to be well above those recommended for substrates for use in containers (21, 89, 120).

The problems associated with salinity can be divided into two general categories: those related to osmotic effects and those arising from specific ion toxicities (9, 15). As the salinity level in a soil solution increases, the osmotic potential decreases. Electrical conductivity has been used as a measure of osmotic potential, because the electrical conductivity of soil solutions has been correlated with osmotic potential and because it is easy to measure (9, 15, 94). As osmotic potential decreases, soil water becomes less available to plants, at least temporarily. Within a day or two, plants generally adjust to decreases in osmotic potential, but growth is still reduced (9). The extent to which decreases in osmotic potential result in reduced plant growth, or stunting, varies with different species and with different cultivars of the same species (9, 10, 15, 100, 102).

Specific ion toxicities also vary with the species of crop, the variety of the species, the specific ion, interactions with other ions, and growing conditions (9, 10, 15, 18, 21, 72). The complexities of the situation make generalizations difficult. For example, Bernstein showed that mature bean (*Phaseolus vulgaris*) plants were more damaged by calcium chloride than by sodium chloride (8), while LaHaye and Epstein showed that calcium sulfate could be used to overcome sodium chloride damage in seedling beans (72). Bernstein stated that calcium damaged beans while LaHaye and Epstein said that calcium enhanced the growth of beans; the growth responses are complex and may involve such additional factors as interactions with the stage of growth of the beans. Examples of some of the complex interactions which can occur when studying specific ion toxicities can be seen in the article by Bernstein, Francois, and Clark on interactions between salinity and fertility for various crops (10).

Ammonium Toxicity in Plants

One specific ion which can be very toxic to a variety of plants is the ammonium ion (7, 18, 21, 59, 80). As with other specific ion toxicities, plant responses can vary with different species, different varieties, the presence of other ions, and growing conditions (18, 48, 80, 87, 88). While actual damage to plants from ammonia is different from the damage due to ammonium ions (21), the two are usually not considered separately. Ammonium ions normally predominate under acid conditions and ammonia is formed under basic conditions. For those crops which are susceptible to ammonium ion toxicity, reduced growth, small lesions on the leaves, and reduced chlorophyll are typical symptoms of damage (7, 18, 21, 42, 47, 48, 57, 59, 79, 87, 97, 98, 124). Reduction in the levels of potassium, calcium, magnesium, and organic acids in plant tissue have been associated with ammonium toxicity (42, 57, 77, 88, 97, 124, 125).

The physiological basis for the damage from ammonium toxicity is not well understood, and some results seem contradictory (47). Wilcox, Mitchell, and Hoff reported reduced xylem exudate rates and reduced levels of calcium and magnesium in the exudate of tomatoes with ammonium nutrition (125). Potassium levels were not lower in the exudate, so they attributed reduced potassium in tomato tissue to the reduced exudate rate. Some of this work was later confirmed by Macklon and Sim (77). Schenk and Wehrmann showed that potassium uptake in cucumbers (Cucumis sativus) was reduced in the ammonium treated plants due to reduced permeability of the roots (97). They reported decreased respiration in cucumber roots. Matsumoto and Tamura measured increased rates of respiration in cucumber roots (79). Ikeda and Yamada showed that dark fixation of carbon dioxide was reduced (58) and respiration was increased (57) in the leaves of tomato plants grown in the presence of ammonia. Goyal, Huffaker, and Lorenz found that both dark and light fixation of carbon dioxide were reduced by ammonium in radishes (Raphanus sativus) (47).

Alleviation of the damage from ammonium has been reported for some crops. Maynard and Baker were able to eliminate damage in corn, bean, cucumber, and pea (Pisum sativum) plants by adding calcium carbonate to the nutrient solution (80). They suggested that calcium carbonate reduced damage by controlling the solution pH. While Pierpont and Minotti showed that calcium carbonate could reduce toxicity symptoms in tomatoes (87), Pill and Lambeth found that acidity control was not effective in increasing levels of potassium, phosphorus, calcium, or magnesium in ammonium fed tomatoes (88). Goyal, Lorenz, and Huffaker were unable to reduce ammonium toxicity in radishes by controlling pH, but found that adding nitrate was effective (48). In rice (Oryza sativa), Imai was able to minimize the effects of ammonium toxicity by increasing phosphate levels (59).

Steam Sterilization of Substrates

Most potting substrates or ingredients are sterilized before use to control soil borne diseases and insects (21, 78). Sterilization is commonly done with steam, but some growers use chemical means of sterilization (21, 29). Both beneficial and adverse effects following steam sterilization have been noted (78). Beneficial effects included increased growth due to the elimination of pathogens and increased growth due to release of nitrogen (29, 112). Problems following steam sterilization included reduced water retention, increased soluble salts, and aluminum, ammonium, manganese, or soluble organic compound toxicities (21, 78).

Problems with manganese and aluminum toxicities were generally associated with the sterilization of soils and with low acidity (21, 78). Liming of soils after sterilization reduced the solubility of the toxic ions (21, 78).

The dynamics of ammonia and nitrate production in soils following steam sterilization were presented and thoroughly discussed in a series of papers by Davies and Owen (29, 30, 31). They showed that ammonia production in sterilized soils continued for up to 16 weeks in undisturbed soils. Concentrations as high as 13 millimoles of ammonia per kg of dry soil were recorded. No nitrification occurred in those soils. They found that if they mixed the soil during sampling, the levels of ammonia dropped. Further experiments showed that digging the soil was effective in lowering levels of ammonia. Their results were largely explained in terms of recolonization of the steamed soils with nitrifying organisms.

Davies and Owens showed that reduction of ammonia levels in a steam sterilized soil could also be accomplished by transplanting plants into the soil (31). They assumed that the infected roots facilitated recontamination of the soil with nitrifying bacteria.

Problems with ammonium toxicity in potting media with high nitrogen contents were noted when these substrates were stored. The effect was also attributed to reductions in the populations of nitrifying bacteria, due to anaerobic conditions (21).

CHAPTER III

PHYSICAL AND CHEMICAL CHARACTERISTICS OF FRESH AND AGED SPENT MUSHROOM COMPOST

The horticultural industry has begun to search for cheap, alternative components for potting mixes (13, 28, 92, 93), because the cost of many of the ingredients commonly used in soilless potting mixes, such as peat and bark, has been rising, and because there is concern about the availability of these materials in the future (93). Some producers of container plants have become interested in the possibility of using spent mushroom compost (SMC), a by-product of the mushroom industry, in areas where it is locally available and inexpensive.

SMC, the organic mixture in which mushrooms have been grown, is commonly made from straw, horse manure, peat, limestone chips, gypsum, cottonseed meal, and urea. After the mushrooms have been harvested, the growing mix is resterilized, to control mushroom diseases and insects, and then it is dumped.

The use of SMC in various potting mixes has been investigated by White (121), Henny (54), and Rathier (91). These researchers all advised against using SMC directly from mushroom houses. They suggested that the material be aged before use, but they gave little information as to why or for how long it should age.

The purpose of this study was to characterize both fresh and aged SMC, to determine the possible uses of each in soilless potting mixes.

Materials and Methods

Shipments of SMC were obtained from the Ralston Purina Mushroom Farm in Loudon, Tennessee on five different dates in 1982. Samples were collected from each batch when each was received. Portions of the samples were analyzed immediately, while the remaining portions were placed in plastic bags and frozen for further analyses later. These samples will hereafter be referred to as "fresh".

Upon receipt, each batch of SMC was placed in four 200 liter drums for composting. The drums were kept in a greenhouse potting room where the average air temperature was 25 C. The temperature in the drums rose to 45 C during the first two weeks of composting, but remained below 35 C thereafter. To provide drainage and aeration, 17 holes, one centimeter (cm) in diameter each, were drilled in the bottom of each drum and each lid was left slightly ajar. To maintain aerobic conditions, the compost was turned by spading it into another drum every three days. Sufficient water was added as needed to maintain moisture at approximately 50% by weight, without leaching. This aging process was continued for five to six weeks, at which time samples were collected for analysis, and either used immediately or frozen for later analyses. This SMC, which was composted aerobically in the drums for five to six weeks, will hereafter be termed "aged".

Moisture content of each batch of fresh SMC was determined from weight measurements taken before and after air drying at 25-35 C.

Saturated pastes of all fresh and aged samples were prepared as described by Richards (94) and Bunt (21). Extracts were removed by using a Zero-Max vacuum extractor, model W4. The electrical conductivity (EC) and pH of an aliquot of these extracts were measured immediately on a Soilmoisture Equipment Corporation Salinity Bridge, number 5500, and an Orion Research Digital pH Meter, model 701, respectively.

Every three days, as the compost in drums was turned, a sample was collected and frozen for later analysis for ammonium and pH. The pH was measured using the procedure described previously. Ammonium ions were extracted using 2 M potassium chloride and ammonium levels in the extract were measured by distillation methods (14, 51, 116).

The rate at which salts could be leached was determined for samples of fresh and aged SMC and for samples of fresh and aged SMC mixed 1:1 with fine grade vermiculite (v/v). Plexiglass tubes that were 20 cm deep and 4 cm in diameter were covered with four layers of cheesecloth at the bottom and filled with SMC or mix that had been screened through a sieve with 2 millimeter (mm) openings. Each tube was dropped five times from a height of 2.5 cm, to evenly compact the medium. All tubes were filled to a depth of 16 cm. One volume (225 milliliters) of deionized water was slowly poured on the top of each column. The water that drained through was collected and will henceforth be referred to as the "leachate". After the excess water had drained, the tubes were capped to prevent excessive drying between leachings. Over a 6 week period, nine volumes of water were passed through each column. The EC and pH of all leachates were measured immediately after the samples were collected. The first three leachates were also analyzed for potassium, calcium, and magnesium.

At the end of this period, the final depth of the compost was measured and the percentage of shrinkage was calculated. The samples were then dried at 37 C, so that initial and final bulk densities could be calculated.

Samples of SMC were digested by the wet ashing technique described by Isaac and Johnson (61). Concentrations of potassium, calcium, magnesium, iron, manganese, zinc, molybdenum, aluminum, lead, nickel, copper, cadmium, and chromium were measured by atomic absorption spectrophotometry (2, 3, 60, 61) on a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. Phosphorus levels were measured on a Technicon Auto Analyzer by the vanadomolybdophosphoric yellow colorimetric test (24, 62). Total nitrogen concentration was measured on the Technicon Auto Analyzer by the indophenol colorimetric method after digestion with sulfuric acid and hydrogen peroxide (85, 113).

Slight modifications in the methods described by De Boodt and De Waele (32) and by De Boodt and Verdonck (33) were used to measure bulk density (BD), total pore space, percent air space, easily available water, and water buffering capacity. For BD, the compost was dried at 37 C, as recommended by Lockman (75), rather than at 105 C, as recommended by De Boodt and De Waele (32), because thermal decomposition of organic matter is likely at the higher temperature. Water suction was provided by the use of a tension table, as described by Brown and Emino (16).

Particle size distribution was measured for one sample of fresh and one sample of aged SMC. Three hundred grams of dry SMC were shaken and then washed through U. S. standard sieves. The material remaining in each sieve was dried in a forced air oven at 35 C until the weight stabilized (75). The percent of total dry weight was calculated. The specific gravities of three samples of fresh and aged SMC were determined using 50 cm^3 pycnometers. Each sample was subjected to a vacuum for 24 hours to remove air.

T-tests were used to compare fresh and aged SMC (74).

Results and Discussion

Because of its high moisture content, fresh SMC was more dense than peat. It had a mean of 47% water by weight with a standard deviation of 4%. The BD of the fresh material averaged 0.17 g/cm^3. After aerobic composting for five to six weeks, the BD rose slightly, to 0.21 g/cm^3 (significantly different from fresh at 1% level).

It is critical that the volume of a growth medium not be significantly reduced by decomposition or compaction over time. The reduction in volume that is tolerable depends on the container size and the time the plant is expected to remain in the container. The volume of the fresh SMC in the plexiglass tubes shrank 28% during the six week leaching experiment, while the aged shrank only 10% (different from fresh at 0.1% level). A shrinkage of 28% is excessive for most uses of potting mixes (83). When combined with 50% vermiculite (v/v), the shrinkage was only 10% with fresh SMC and 7% with aged.

The EC of a saturated paste extract from fresh SMC averaged as high as 22 decisiemens per meter (1 dS/m = 1 mmho/cm), while for aged SMC, the EC rose to 27 dS/m (significantly different at 1% level). This was probably due to the release of salts as the organic matter decomposed (109). These values for EC are excessive. Most vegetables can tolerate soils with levels up to 3 dS/m with little reduction in yield. At 4 dS/m, the yield of many vegetables will be reduced by 10-30% (15).

While the level of salts in SMC was quite high, these salts could be readily leached (Table 1). After leaching with 4 volumes of water, the EC had dropped below 3 for both the fresh and aged SMC. As expected, the level of salts in the substrates mixed with 50% vermiculite were more dilute.

Other researchers, including Bunt and Adams (22), have recommended using a calcium chloride suspension as the extractant when determining the pH of samples containing high levels of ammonia. Calcium chloride was not used for the determination of pH in this study, because preliminary studies showed that the pH of SMC measured with 1 N calcium chloride was the same as the pH determined with deionized water. This was probably due to the high levels of soluble salts already present in SMC.

The pH of fresh SMC was higher than that in aged SMC (Table 2). Bunt and Adams (22) showed that the pH of a soilless mix rose as the amount of water used to make the determination was increased above that required for a saturated paste. As expected, the pH of the leachates was higher than that of the saturated paste extracts. The pH of the leachates from mixes with aged SMC was relatively stable. For fresh mixes, it began high and dropped during the course of the experiment. This was probably caused by changes in ammonium ion concentrations, which will be discussed later.

Table 1. Electrical conductivity of successive leachates from fresh and aged spent mushroom composts, alone and mixed with 50% vermiculite by volume.

	Electrical conductivity (dS/m)			
	Fresh SMC		Aged SMC	
Successive leachates	100%	50%	100%	50%
0^z	22.1	11.1	27.4 **	13.7 *
1	14.5	5.9	22.8 ***	9.7 **
2	6.5	3.3	8.9 *	6.1 **
3	4.0	2.8	4.2	3.2 *
4	2.7	2.1	2.8	2.2
5	2.3	1.0	1.8 **	1.3
6	1.4	1.2	1.6	1.3
7	1.4	1.2	1.8 *	1.2
8	1.4	1.0	1.8 *	1.5 *
9	1.2	0.7	1.3	0.8

*,**,***Fresh SMC significantly different from aged at 5% (*), 1% (**), or 0.1% (***) level.

^{z}Level before leaching, based on saturated paste extract.

Table 2. The pH of successive leachates from fresh and aged spent mushroom composts, alone and mixed with 50% vermiculite by volume.

	pH			
	Fresh SMC		Aged SMC	
Successive leachates	100%	50%	100%	50%
0^z	7.3	7.4	6.7 **	6.3 ***
1	8.6	8.2	6.6 ***	6.3 ***
2	8.5	8.2	6.5 ***	6.3 ***
3	7.9	7.3	6.5 ***	6.3 ***
4	7.6	7.0	6.4 ***	6.2 ***
5	7.4	7.2	6.5 ***	6.2 ***
6	7.4	7.5	6.6 ***	6.7 ***
7	7.4	7.7	6.6 ***	6.4 ***
8	7.7	7.8	6.4 ***	6.5 ***
9	7.3	7.4	6.6 **	6.3 ***

,*Fresh SMC significantly different from aged at 1% (**) or 0.1% (***) level.

^{z}Level before leaching, based on saturated paste extracts.

The concentration of potassium in the first leachate was very high, and it dropped precipitously (Table 3). Monovalent cations should readily leach from organic matter (109). The levels of calcium and magnesium, divalent cations, were more constant in successive leachates. Phosphorus, various trace elements, and divalent cations should be less soluble, and thus less readily leached (109).

The relatively constant and high concentrations of calcium in the leachates (Table 3) might increase the salt tolerance of crops grown in SMC. In 1969, LaHaye and Epstein (72) showed that bean plants were not damaged by 50 millimoles per liter (mmoles/l) of sodium chloride when the nutrient solution contained a calcium concentration of 1 mmole/l or more. The highest concentration they tested was 10 mmoles/l. Approximately 10 mmoles/l of calcium was present in the leachates from SMC.

As expected, the total element concentrations in fresh and aged SMC were similar (Table 4). The compost contained approximately 2% nitrogen, 0.6% phosphorus, and 1.2% potassium. There was a trace of cobalt (less than 0.5 mmoles/kg), while the levels of cadmium, nickel, copper, lead, and chromium were too low to detect by the methods used.

The levels of extractable ammonium ions in the samples of SMC collected every three days, as the material was composting, were very dynamic (Figure 1). There were 8.9 mmoles of ammonium per kg of dry, fresh SMC (160 ppm). After aging for six weeks, the level dropped to 1.1 mmoles/kg (20 ppm). During the aging process, the level of ammonium rose to over 20 mmoles/kg (360 ppm). The change in the pH of the mix paralleled that of the ammonium (Figure 2).

Table 3. Concentrations of potassium, calcium, and magnesium in successive leachates from fresh and aged spent mushroom composts, alone and mixed with 50% vermiculite by volume.

		Fresh SMC		Aged SMC	
Element	Successive leachate	100%	50%	100%	50%
		(millimoles per liter leachate)			
Potassium	1	81	28	139 *	47 *
	2	30	9	39 *	19 *
	3	11	6	15	7
Calcium	1	7.9	5.0	12.3 **	8.2 **
	2	8.7	6.6	8.2	10.0 *
	3	9.5	7.8	8.8	7.8
Magnesium	1	7.3	2.8	12.0	4.8 *
	2	4.2	3.5	5.3	6.3 *
	3	3.9	3.9	4.5	4.2 *

*,** Fresh SMC significantly different from aged at 5% (*) or 1% (**) level.

Table 4. Total element concentrations in fresh and aged spent mushroom composts (SMC).

Element	Fresh SMC	Aged SMC
	(mmoles/kg dry weight)	
Nitrogen	1510 ± 170[z]	1580 ± 290
Phosphorus	180 ± 25	180 ± 30
Potassium	320 ± 45	305 ± 55
Calcium	740 ± 210	895 ± 105
Magnesium	275 ± 50	460 ± 60 **
Aluminum	180 ± 35	215 ± 10
Iron	67 ± 17	71 ± 5
Manganese	7.5 ± 2.3	7.1 ± 0.8
Zinc	1.7 ± 0.2	2.1 ± 0.1 *
Molybdenum	1.0 ± 0.2	1.4 ± 0.4

*,**Fresh SMC significantly different from aged at 5% (*) or 1% (**) level.
[z]± SD, based on 4 samples.

The observed fluctuation in the ammonium level was probably a result of the resterilization which the mushroom industry uses to control insects and diseases. Prior to disposing of the compost, it is steam sterilized to prevent the spread of mushroom insect and disease propagules. The bacteria which convert ammonium to nitrites and nitrates are killed by the heat, but the resting spores of some actinomycetes which convert organic nitrogen to ammonium are more resistant (21, 78). The populations of these ammonium producing organisms proliferate immediately. As they began to break down organic matter in the SMC, the level of ammonium rises. The pH also rises, probably because hydrogen ions are used to form the ammonium

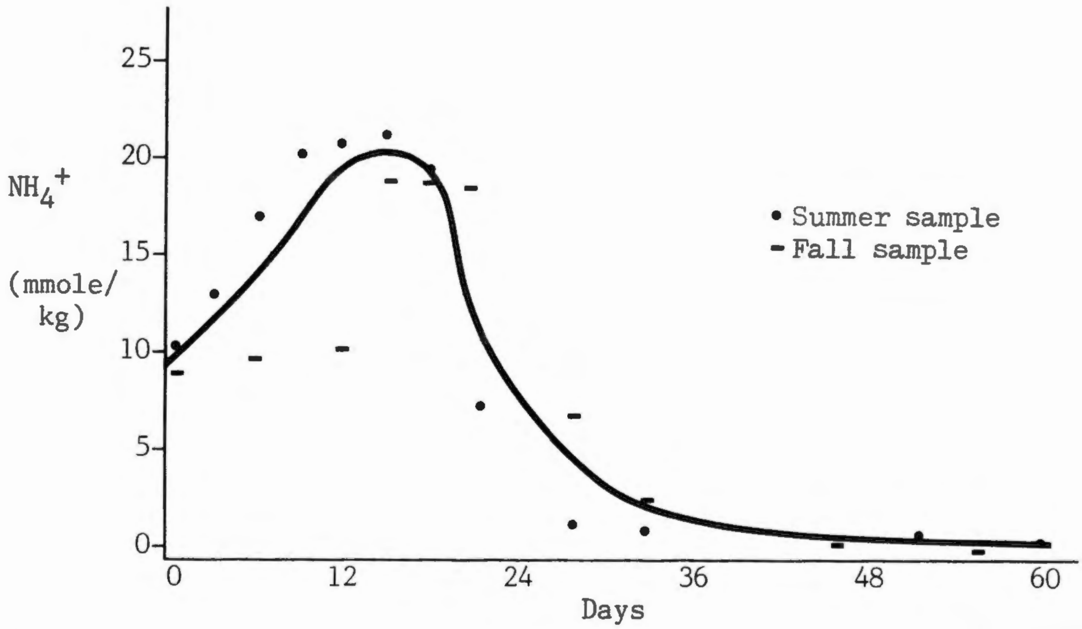

Figure 1. Changes in the level of ammonium in aerobically composted spent mushroom compost.

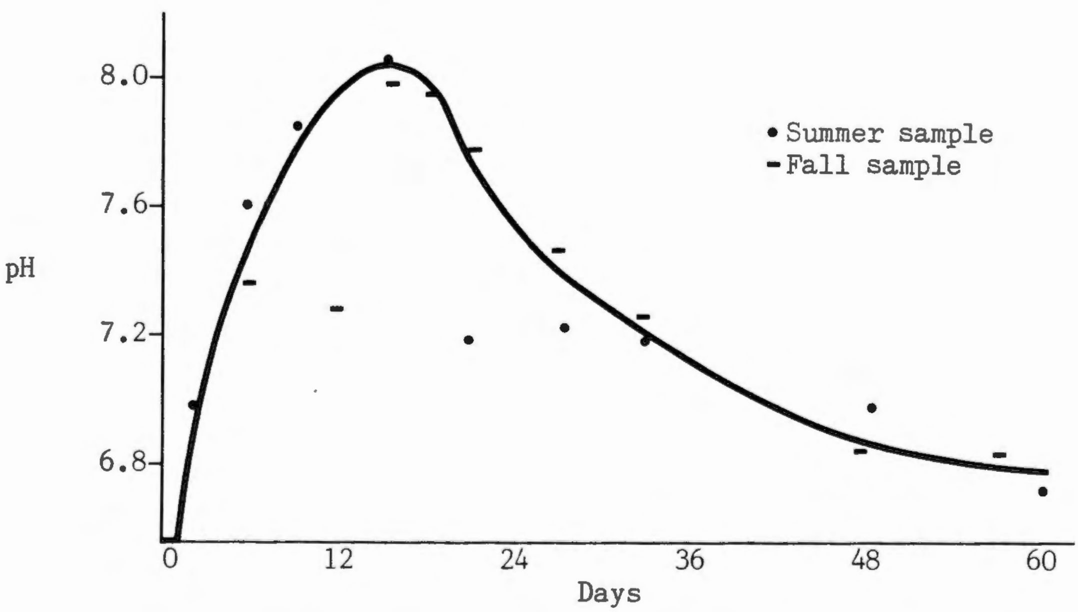

Figure 2. Changes in the pH level in aerobically composted spent mushroom compost over time.

and because ammonium hydroxide forms. Eventually, the Nitrosomonas and the Nitrobacter species, which convert ammonium to nitrites and nitrates, recolonize the compost. This leads to the subsequent drop and stabilization in the level of ammonium. Hydrogen ions are then released, as ammonium is converted to nitrites, thus causing the drop in pH. This is a common phenomenon seen after steam sterilization of potting media and when mixtures high in organic matter are not well aerated (21, 29, 30, 31, 78, 112).

The levels of ammonium in fresh SMC would probably be toxic to many crops. Ammonium has been found to reduce the growth of many crops including tomato (42, 57, 58, 124, 125), cucumber (79, 80, 97, 98), radish (47, 48), bean (80), rice (59),and sudangrass (Sorghum sudanensis) (7). After the six week composting process, the level of ammonium had dropped enough to no longer present a problem. Apparently, turning the SMC aging in drums and leaving the lids ajar allowed rapid recolonization with Nitrosomonas and Nitrobacter (29, 31).

Ideal characteristics for a potting medium are difficult to define because ideal characteristics depend on many factors. These factors include the crop to be grown, the size of the container, and even the habits of the grower in terms of frequency and quantity of waterings (4, 6, 45, 52). Generally, a potting mix should be sterile and light weight. It should also have good water holding capacity and a high percentage of air space. The physical characteristics of fresh and aged SMC are presented in Table 5. The characteristics of an ideal substrate as defined by De Boodt and De Waele (32) are included in Table 5, to serve as a general guide.

Table 5. Physical characteristics of fresh and aged spent mushroom composts (SMC) compared to an ideal substrate.

Physical characteristic	Substrate: Fresh SMC	Aged SMC	Ideal[z]
Total pore space (% by volume)	87.1	86.3	85.0
Total water at saturation (% by volume)	63.2	65.5	-
Air space (% by volume)	24.0	20.8	20-30
Easily available water (10-50 cm) (% by vol)	12.6	22.6 *	20-30
Water buffering capacity (50-100 cm)	1.9	2.1	6-10
Bulk density (g/cm^3)	.256	.293 *	.215
Specific gravity	2.05	2.12	-

*Fresh SMC significantly different from aged at 5% level.

[z]From: M. De Boodt and N. De Waele. 1968. Study on the physical properties of artificial soils and the growth of ornamental plants. Pedologie 18:275-300.

The total pore space in SMC was similar to that given as ideal (Table 5). The percent air space for both fresh and aged SMC was within the acceptable range. Percent air space is extremely important in container media (6). The small volume and depth of media in containers result in the retention of relatively large quantities of water (52). Plants in containers are susceptible to problems from lack of oxygen due to excess water, unless the percent air space is high.

Easily available water (EAW) and water buffering capacity (WBC) are terms used by researchers working with soilless mixes for containers. EAW is defined by De Boodt and De Waele (32) as the quantity of water released between 10 and 50 cm of water of suction, while WBC refers to that released between 50 and 100 cm. The amount of EAW is low for fresh SMC, but adequate for aged SMC. WBC is quite low for both fresh and aged SMC. This does not mean that SMC is unsuitable for potting mixes. Various researchers have shown that the physical properties of potting media can be controlled by varying the kind of ingredients and the ratios of those ingredients in a mix (5, 20, 50, 63, 103, 120, 122). Goh and Haynes (45) also showed that interactions among various physical properties are more related to plant growth than any single factor.

The changes which were measured in the physical characteristics of SMC as it aged (Table 5) were those which one would expect of a decomposing organic material. As an organic material decomposes, it becomes more dense, thus causing a rise in BD and a drop in percent air space. The changes observed with decomposing SMC were similar to those reported by De Boodt and coworkers between fresh and old pine leaf mold (32, 33).

Particle distribution was determined for one sample of fresh and one sample of aged SMC. These results give only an indication of the differences and similarities between the fresh and aged composts. The distributions (Table 6) of particles 1 mm in size and smaller appeared to be quite similar for fresh and aged SMC. There seemed to be differences in the distributions of the larger particles. The high percentage of aged SMC particles 5 mm or larger may have been due to a concentration effect. Those particles were predominately pebbles and small rocks, and therefore remained unchanged in size during the five to six week aging period, while the smaller particles of organic matter decomposed.

Table 6. Particle size distributions in fresh and aged spent mushroom composts (SMC).

Particle size (mm)	Fresh SMC (% of dry weight)	Aged SMC
> 5	10.0	16.3
2 - 5	35.4	31.0
1 - 2	21.4	16.5
.5 - 1	16.3	17.4
.25 - .5	6.7	8.4
.105 - .25	3.1	4.1
.062 -.105	0.7	1.1
< .062	6.4	5.2

Conclusions

Fresh spent mushroom compost, used immediately after it was received from the mushroom house, was found to be a poor quality component of soilless growth media. The levels of ammonium found in mushroom compost which recently had been steam sterilized would be toxic to many plants. The pH of fresh SMC was high when the level of ammonium was high. In addition, fresh SMC was found to be unsuitable, even for crops having high pH and high ammonium tolerance, due to excessive shrinking of the fresh material.

Spent mushroom compost which was aged aerobically for six weeks was found to be an acceptable component for some growing mixes. Toxic levels of ammonium were not present, and shrinkage was slight. Aged SMC generally had good physical properties. The pH was near neutral, so the addition of lime would be unnecessary for potting mixes containing aged SMC. Soluble salt levels were high. They represent a major potential problem for some crops, however the salts could be readily leached. The high concentrations of calcium present in solution may alleviate some of the salt problem.

CHAPTER IV

EFFECTS OF LEVEL, AGING, AND LEACHING ON THE USE OF SPENT MUSHROOM COMPOST AS A REPLACEMENT FOR PEAT IN STANDARD SOILLESS MEDIA FOR THE PRODUCTION OF TRANSPLANTS

Various researchers have advised against using spent mushroom compost (SMC) directly from mushroom houses (54, 91, 121). They recommended that the material be aged before use in potting media, but gave few or no details about why or how long it should be aged. Only Rathier (91) presented experimental results to substantiate the recommendation, but his results appeared inconclusive. Henny (54) showed that leaching of nine month old SMC was effective in lowering soluble salt levels, but the yield of foliage plants grown in the mixes suggested that leaching was unnecessary. White (121) grew Easter lilies in various levels of two to three year old SMC and concluded that mixes from 20 to 80% SMC were satisfactory.

The purpose of this study was to evaluate the effects of aging, leaching, and level of SMC, used as a replacement for peat in a standard soilless seedling mix for transplants. More specifically, the study was designed to (a) see how each factor influenced the growth of various species of transplants, and (b) examine the effects of interactions between the factors on the growth of these transplants.

Materials and Methods

Design

The experimental design was a randomized complete block with nine treatments and six blocks. The treatments consisted of a detached control group and factorial arrangement of three factors, each at two levels (Table 7). Results pertaining to the eight factorial treatments will be discussed here; comparisons to the control group will be presented in Chapters V and VI.

Four separate experiments were conducted, each on a different species. Seedlings of Sweet Slice Hybrid cucumber (*Cucumis sativus* L.), Orange Boy marigold (*Tagetes patula* L.), Black Seeded Simpson lettuce (*Lactuca sativa* L.), and Better Boy Hybrid tomato (*Lycopersicon esculentum* Mill.) were grown in treatment mixes in plastic cell packs, with six cells per pack. The six plants in each cell pack represented the experimental unit. The experiments were separated in

Table 7. Factors and levels of each factor which made up the eight treatments of the 2x2x2 factorial arrangement of treatments.

Factor	Level
Age of SMC	Fresh Aged
Level of SMC	25% 50%
Leaching	No Yes

the greenhouse, and each was surrounded by a guard row of cell packs which were planted and treated the same as the experimental plants. All treatments were randomized within a block, with each block and each species receiving separate randomizations. Randomizations were determined with the Plan procedure in SAS (53).

Procedures

SMC was received from the Ralston Purina Mushroom Farm in Loudon, Tennessee on August 25, 1982. This compost was placed in three 200 liter drums for aging. Each drum had 17 one cm holes drilled in the bottom to provide drainage and aeration. The drums were covered, with the lids left slightly ajar for additional aeration. The compost was turned every three days. Water was added as needed to maintain moisture at approximately 50% by weight, without leaching. The temperature in the drums rose to 45 C during the first two weeks of composting, but remained below 35 C thereafter.

On September 30, another shipment of SMC was received from the mushroom farm. This batch will be called "fresh". The batch of SMC which had been composting in drums for five weeks will be termed "aged".

On September 30, four potting mixes were prepared and thoroughly mixed by hand. They contained the following ingredients (v/v):

1. 25% fresh SMC, 25% peat, 50% vermiculite,
2. 50% fresh SMC, 50% vermiculite,
3. 25% aged SMC, 25% peat, 50% vermiculite,
4. 50% aged SMC, 50% vermiculite.

Canadian peat and fine grade vermiculite were used for this experiment. SMC and peat were screened through a one centimeter screen before use. Particles which did not pass the screen were discarded. The pH and electrical conductivities of the ingredients are shown in Table 8.

The six 4x6x6 cm cells of each cell pack were filled with a treatment medium. This was tamped down by stacking an empty cell pack on the surface of the medium and pressing it lightly. Four volumes of water were poured on the surface of each cell pack which represented a leached treatment. Cell packs were placed in flats in a greenhouse.

On September 24, 1982, seeds of Orange Boy marigold, Black Seeded Simpson lettuce, and Better Boy Hybrid tomato were started in seedling flats containing Terra-lite Redi-Earth Peat-lite, a commercially available, prepared mix, based on the Cornell mix of Canadian sphagnum peat moss and vermiculite with added nutrients (101). Seedling flats were placed in the greenhouse and watered as needed.

Table 8. Electrical conductivity and pH levels of the ingredients used in the treatment media.

Ingredient	pH^z	EC^z(dS/m)
Peat	4.1	0.7
Vermiculite	4.7	0.2
Fresh SMC	6.9	23.8
Aged SMC	7.3	30.3

^{z}Based on saturated paste extract.

On October 1, 1982, Sweet Slice Hybrid cucumber seeds were sown directly into the treatment mixes, at a rate of two seeds per cell. These were randomly thinned to one per cell as they germinated. Marigold, tomato, and lettuce seedlings were transplanted, one per cell, into the treatment mixes on October 2, 3, and 4, respectively.

Plants were grown by standard production practices (27, 101). All were fertilized weekly with Peter's Standard Trace Element Mixture and Peter's 20-20-20, at a rate of 35 millimoles of nitrogen per liter (500 ppm). All plants were grown for approximately five weeks.

The number of days from transplanting into treatment mixes until color was visible in the flower bud of at least one marigold plant per cell pack was recorded. Tomato, cucumber, lettuce, and marigold plants were harvested on October 28, November 1, November 2, and November 8, respectively. The six plants from each cell pack were cut off approximately 2 mm above the surface of the medium and immediately weighed. The height of each plant was measured by folding the leaves towards the apical bud and measuring the distance from the base of the stem to the tip of the highest leaf; heights for the six plants in each cell pack were averaged. Plants were then rinsed three times in distilled water and dried in a forced air oven at 60 C, as recommended by Lockman (75). The dry weights of the plants from each cell pack were recorded. Percent dry weight was calculated by dividing dry weight by fresh weight and multiplying the result by 100.

After harvest, treatment media were left in the cell packs in the greenhouse to dry. They were then collected and three of the six blocks were chosen at random to be analyzed. The EC and pH of saturated paste extracts were measured as described in Chapter III. EC and pH were also measured in the original mixes.

Statistical Analysis

Multivariate analysis of variance (68, 82) was used to simultaneously partition the variance in dry weight, height, and percent dry weight for cucumber, lettuce, and tomato. Variance in dry weight, height, percent dry weight, and bloom date were considered for marigolds. Univariate analysis of variance (74) was used to partition variance in EC and pH. Variance was partitioned by using orthogonal contrasts to test main effects and two and three way interactions within the eight treatments of the 2x2x2 factorial (66, 70, 73, 74). The analyses were run on the Manova program in SPSS (56). Cross validation of some results was run using the Manova statement in the General Linear Models (GLM) procedure in SAS (53).

Results and Discussion

Multivariate analysis of variance was used for this problem because multiple yield measures were taken. Dry weight, height, and percent dry weight were all interrelated and therefore should all be considered together when trying to isolate factors involved in the growth of transplants. Transplant growth cannot be totally defined by any single factor, such as dry weight, alone; other factors, such as height, are also important. Multivariate analysis allowed a group of related yield factors to be considered simultaneously (68). It more accurately reflected the total picture of treatment effects on transplant yield, and hence on the ultimate quality and marketablilty of the transplants.

A summary of the results of the multivariate procedure are presented in Table 9. Considering the variance in dry weight, height, and percent dry weight together (with bloom date, as well, for marigolds), there was a significant overall difference due to the age of SMC for each of the crops studied. Plants grown in fresh SMC generally were shorter, had much lower dry weights, and had less percent dry weight than those grown in aged SMC (Tables 10-13). Marigolds grown in fresh SMC took longer to bloom (Table 12).

This reduction in growth may have been caused by ammonium toxicity. Shortly after fresh SMC was received from the mushroom

Table 9. Multivariate partitioning of variance in dry weight, height, and percent dry weight into main effects and interactions by linear contrasts.

Linear contrast	Cucumber	Lettuce	Marigold[z]	Tomato
Fresh vs. aged	***	***	***	***
25% vs. 50%	***	***	***	***
Leaching effect	***	***	***	NS
Age of SMC x leach	NS	*	NS	***
Age of SMC x level	NS	***	*	***
Level of SMC x leach	**	*	**	*
Age x level x leach	NS	NS	NS	NS

NS,*,**,***Nonsignificant (NS) or significant at 5% (*), 1% (**), 0.1% (***) levels.
[z]Days to bloom also considered for marigolds.

Table 10. Cucumber dry weight, height, and percent dry weight means by treatment factors.

Factor	Dry weight (g)	Height (cm)	Percent dry weight	P[z]
Age of SMC:				***
Fresh SMC	1.82	31.9	6.78	
Aged SMC	2.61	35.5	6.97	
Level of SMC:				***
25% SMC	2.45	34.9	6.96	
50% SMC	1.97	32.5	6.77	
Leaching effect:				***
Unleached	2.09	32.7	6.60	
Leached	2.33	34.7	7.15	
Age of SMC x leach:				NS
Fresh-unleached	1.76	31.1	6.62	
Fresh-leached	1.88	32.8	6.95	
Aged-unleached	2.43	34.4	6.57	
Aged-leached	2.79	36.6	7.36	
Age of SMC x level:				NS
25% fresh	1.97	33.1	6.84	
50% fresh	1.66	30.8	6.72	
25% aged	2.93	36.8	7.08	
50% aged	2.28	34.3	6.81	
Level of SMC x leach:				**
25%-unleached	2.50	35.2	6.68	
25%-leached	2.40	34.7	7.26	
50%-unleached	1.68	30.3	6.51	
50%-leached	2.26	34.7	7.04	

NS,**,***Nonsignificant (NS) or significant at 1% (**), 0.1% (***) levels.

[z]Probability level, based on multivariate analysis, considering dry weight, height, and percent dry weight simultaneously.

Table 11. Lettuce dry weight, height, and percent dry weight means by treatment factors.

Factor	Dry weight (g)	Height (cm)	Percent dry weight	P^z
Age of SMC:				***
Fresh SMC	0.69	14.7	3.06	
Aged SMC	1.99	20.3	3.80	
Level of SMC:				***
25% SMC	1.58	19.2	3.52	
50% SMC	1.10	15.9	3.31	
Leaching effect:				***
Unleached	1.17	16.1	3.34	
Leached	1.50	18.8	3.48	
Age of SMC x leach:				*
Fresh-unleached	0.50	12.6	2.95	
Fresh-leached	0.88	16.7	3.19	
Aged-unleached	1.84	19.6	3.87	
Aged-leached	2.13	21.0	3.82	
Age of SMC x level:				***
25% fresh	0.92	17.0	3.23	
50% fresh	0.46	12.3	2.91	
25% aged	2.24	21.0	3.86	
50% aged	1.76	19.6	3.83	
Level of SMC x leach:				*
25%-unleached	1.51	18.5	3.47	
25%-leached	1.65	19.6	3.56	
50%-unleached	0.83	13.7	3.23	
50%-leached	1.36	18.1	3.39	

*,***Significant at 5% (*), 0.1% (***) levels.

^{z}Probability level, based on multivariate analysis, considering dry weight, height, and percent dry weight simultaneously.

Table 12. Marigold dry weight, height, percent dry weight, and bloom date means by treatment factors.

Factor	Dry weight (g)	Height (cm)	Percent dry weight	Days to Bloom	P^z
Age of SMC:					***
Fresh SMC	1.31	13.6	8.17	38	
Aged SMC	2.18	12.8	9.54	34	
Level of SMC:					***
25% SMC	2.08	13.7	8.94	35	
50% SMC	1.41	12.7	8.67	37	
Leaching effect:					***
Unleached	1.56	12.6	8.68	36	
Leached	1.93	13.9	8.95	36	
Age of SMC x leach:					NS
Fresh-unleached	1.12	12.8	7.96	37	
Fresh-leached	1.50	14.4	8.38	39	
Aged-unleached	2.01	12.3	9.49	34	
Aged-leached	2.36	13.3	9.60	34	
Age of SMC x level:					*
25% fresh	1.52	14.0	8.26	37	
50% fresh	1.10	13.2	8.07	38	
25% aged	2.64	13.4	9.74	34	
50% aged	1.73	12.2	9.35	35	
Level of SMC x leach:					**
25%-unleached	1.96	13.5	8.77	35	
25%-leached	2.20	14.0	9.12	36	
50%-unleached	1.16	11.7	8.55	36	
50%-leached	1.66	13.8	8.78	37	

NS,*,**,***Nonsignificant (NS) or significant at 5% (*), 1% (**), 0.1% (***) levels.

zProbability level, based on multivariate analysis, considering dry weight, height, percent dry weight, and days to bloom simultaneously.

Table 13. Tomato dry weight, height, and percent dry weight means by treatment factors.

Factor	Dry weight (g)	Height (cm)	Percent dry weight	P^z
Age of SMC:				***
Fresh SMC	0.76	19.4	6.86	
Aged SMC	2.00	25.1	8.98	
Level of SMC:				***
25% SMC	1.57	23.3	7.97	
50% SMC	1.19	21.1	7.59	
Leaching effect:				NS
Unleached	1.49	22.3	7.98	
Leached	1.33	22.1	7.58	
Age of SMC x leach:				***
Fresh-unleached	0.88	19.4	7.35	
Fresh-leached	0.65	19.3	6.43	
Aged-unleached	1.98	25.3	8.73	
Aged-leached	2.02	24.8	9.23	
Age of SMC x level:				***
25% fresh	0.96	21.5	7.02	
50% fresh	0.56	17.3	6.70	
25% aged	2.17	25.1	9.21	
50% aged	1.83	25.0	8.76	
Level of SMC x leach:				*
25%-unleached	1.73	23.9	8.26	
25%-leached	1.41	22.7	7.70	
50%-unleached	1.13	20.8	7.73	
50%-leached	1.26	21.5	7.46	

NS,*,***Nonsignificant (NS) or significant at 5% (*), 0.1% (***) levels.

zProbability level, based on multivariate analysis, considering dry weight, height, and percent dry weight simultaneously.

farm, the level of ammonium rose sharply (Figure 1, page 31). Many crops, specifically including tomato and cucumber, are sensitive to high levels of ammonium (7, 58, 59, 80, 98). Reduction in growth is one common symptom of ammonium toxicity (21, 80, 88). The change in acidity which accompanied the rise in ammonium (Figure 2, page 31) may also have contributed to the reduced growth in fresh SMC. The pH of all mixes containing fresh SMC was higher than for those prepared with aged SMC (Table 14).

As expected, there was a significant difference between the mixes containing the 25 and 50% levels of SMC for all crops (Table 9). The means for dry weight, height, and percent dry weight for the plants grown in 50% SMC were all lower than for plants grown in 25% SMC (Tables 10-13). Blossoming in marigolds was delayed in 50% SMC (Table 12). This may have been due to the higher level of soluble salts in the mixes with 50% SMC (Table 15). The pH of a mix with 50% SMC was also higher than for a comparable mix with 25% SMC (Table 14). Lucas and Davis (76) showed that in organic soils with pH levels between 7.0 and 8.0, phosphorus, manganese, and boron are relatively unavailable for plant uptake.

Considering dry weight, height, and percent dry weight simultaneously, the leaching effect was significant for all crops tested, except tomato (Table 9). The dry weight, height, and percent dry weight means for cucumber, lettuce, and marigold increased with leaching (Tables 10-12). The initial soluble salt level in all mixes was very high, and leaching was effective in reducing the salt levels in all mixes (Table 15). Plant tolerance to salinity varies with crop

Table 14. Final pH levels in media containing spent mushroom compost, by factors, based on saturated paste extracts.

	pH			
Treatment	After Cucumber	After Lettuce	After Marigold	After Tomato
Age of SMC:	***	***	***	***
Fresh SMC	7.3	7.3	7.2	7.3
Aged SMC	6.9	6.9	6.8	6.9
Level of SMC:	***	***	***	***
25% SMC	6.9	6.9	6.9	7.0
50% SMC	7.3	7.3	7.2	7.2
Leaching effect:	**			*
Unleached	7.1	7.1	7.0	7.1
Leached	7.2	7.1	7.1	7.2
Age of SMC x leach:	**			***
Fresh-unleached	7.3	7.2	7.2	7.4
Fresh-leached	7.4	7.3	7.2	7.4
Aged-unleached	6.8	6.9	6.8	6.8
Aged-leached	7.0	7.0	6.8	7.0
Age of SMC x level:	***	***	***	***
25% fresh	7.2	7.2	7.2	7.3
50% fresh	7.4	7.4	7.3	7.4
25% aged	6.6	6.6	6.6	6.6
50% aged	7.2	7.2	7.1	7.1
Level of SMC x leach:	**			
25%-unleached	6.8	6.8	6.8	6.9
25%-leached	7.0	6.9	6.9	7.0
50%-unleached	7.2	7.3	7.2	7.2
50%-leached	7.3	7.4	7.2	7.3

*,**,***Significant at 5% (*), 1% (**), 0.1% (***) levels.

Table 15. Final soluble salt levels in media containing spent mushroom compost, by factors, based on electrical conductivity of saturated paste extracts.

Treatment	Electrical conductivity (dS/m)			
	After Cucumber	After Lettuce	After Marigold	After Tomato
Age of SMC:	***		***	
Fresh SMC	4.2	5.7	6.0	6.2
Aged SMC	5.0	5.8	7.6	6.5
Level of SMC:	***	***	***	***
25% SMC	4.0	4.9	5.6	5.3
50% SMC	5.2	6.6	7.9	7.4
Leaching effect:	***	***	***	***
Unleached	5.6	6.7	7.9	8.1
Leached	3.6	4.8	5.6	4.6
Age of SMC x leach:				
Fresh-unleached	5.2	6.8	7.2	8.1
Fresh-leached	3.2	4.6	4.8	4.4
Aged-unleached	6.2	6.7	8.7	8.2
Aged-leached	4.0	4.8	6.5	4.8
Age of SMC x level:			*	
25% fresh	3.6	4.8	5.3	5.4
50% fresh	4.8	6.6	6.6	7.0
25% aged	4.5	5.0	6.0	5.3
50% aged	5.6	6.6	9.2	7.7
Level of SMC x leach:	*	*		**
25%-unleached	4.8	5.5	6.6	6.4
25%-leached	3.2	4.2	4.8	4.2
50%-unleached	6.4	8.0	9.3	9.8
50%-leached	4.0	5.2	6.5	5.0

*,**,***Significant at 5% (*), 1% (**), 0.1% (***) levels.

species, growing conditions, and specific ions present (9, 10, 15, 72). Generally it is recommended that only crops with moderate or high salt tolerance, such as geranium (Pelargonium) or broccoli (Brassica oleracea var. italica), be grown in media with an EC of 4 dS/m (4 mmoles/cm) or higher (15, 21). The crops grown in this experiment are all moderately salt sensitive (15, 21). Of the vegetables used, tomato is the least sensitive and lettuce the most sensitive (15). According to Bressler, McNeal, and Carter (15), a 20% reduction in yield is likely for lettuce at a level lower than 3 dS/m, for cucumber at approximately 4 dS/m, and for tomato at 4.5 dS/m.

Three-way interactions among the age of SMC, the level of SMC, and leaching were not significant for any of the crops studied (Table 9). Many of the two-way interactions, however, were significant.

The interaction between the level of SMC and leaching was significant for all crops. Leaching at both the 25 and 50% levels of SMC resulted in increased dry weight, height, and percent dry weight in marigolds and lettuce, but the increase was much greater for those plants grown in 50% SMC compared to those in 25% SMC (Tables 11, 12). Leaching also resulted in increased growth for cucumbers grown in 50% SMC, but leaching did not improve their growth in 25% SMC (Table 10). There was little difference in the growth of tomato as a result of leaching at the 50% level of SMC, and leaching actually resulted in slightly reduced growth for tomato grown in 25% SMC (Table 13). The effects of salinity on plant growth probably account for these differences.

The interaction between the age of SMC and its level was significant for all crops except cucumber (Table 9). As the level of SMC was increased from 25 to 50%, the means for dry weight, height, and percent dry weight dropped for all crops (Tables 10-13). This reduction in growth at 50% SMC was greater for marigold, lettuce, and tomato plants grown in fresh SMC than for those grown in aged SMC, resulting in the significant interactions. As the level of SMC changed from 25 to 50%, the level of salts in the media and the pH rose, but the rise in pH was very slight in fresh SMC compared to aged SMC (Tables 14, 15).

The interaction between the age of SMC and leaching (Table 9) was not significant for cucumber or marigold. It was significant at the 5% level for lettuce and significant at the 0.1% level for tomato. Leaching increased the average growth of cucumber, marigold, and lettuce (Tables 10-12). This increase was much greater for lettuce grown in fresh SMC than for lettuce grown in aged SMC (Table 11). Leaching generally did not improve the growth of tomato, and leaching actually resulted in reduced growth when tomato plants were grown in fresh SMC (Table 13). Generally, the leaching of media containing SMC would be expected to improve plant growth by reducing the high soluble salt levels in SMC. Because the EC was greater in aged SMC than in fresh SMC, the leaching response might have been expected to be greater for aged than fresh SMC. This was not found to be true, perhaps because the difference in the salinity levels was not very large. One would not expect leaching to have much effect on the level of ammonium in fresh SMC, because the rise in ammonium levels occurs over time (Figure 1, page 31), while the leaching was only done at the beginning of the experiment.

Conclusions

The age of spent mushroom compost (SMC), the level of SMC, and the leaching of SMC all influenced the growth of bedding plant transplants. The nature of the crop response varied with the specific crop and with the specific levels of the factors.

There were no significant three-way interactions among age of SMC, level of SMC, and leaching. While most of the two-way interactions were significant, the direction of the response on any one factor usually did not change; the change in the magnitude of that response was responsible for the interactions. For this reason, discussions of the responses to the main factors alone were meaningful in most cases.

Plants grown in fresh SMC were generally much smaller than those grown in aged SMC. This reduction in growth was evidently not a result of soluble salt levels, because the EC was generally higher in aged SMC than in fresh SMC. Some reduction in growth was probably caused by ammonium toxicity.

Plants grown in 50% SMC were smaller than those grown in 25% SMC. This reduction in growth was probably caused by the higher salinity level at the higher rate of SMC. Higher pH may also have contributed to this response.

Leaching improved plant growth, except for tomato. Leaching reduced salt levels in the mix, so improved growth was expected.

Tomato plants are slightly more tolerant of salt than are cucumbers or lettuce.

These results clearly showed that fresh SMC should not be recommended for general use in potting mixes. They also showed that after only five weeks of aerobic composting, the characteristics of SMC had changed sufficiently to result in improved plant growth. There may be no need to age SMC for two to three years as recommended by White (121), or even for nine months as was done by Henny (54).

CHAPTER V

COMPARISONS BETWEEN TRANSPLANTS GROWN IN A HIGH QUALITY PEAT-VERMICULITE MEDIUM AND TRANSPLANTS GROWN IN MEDIA CONTAINING SPENT MUSHROOM COMPOST AS A REPLACEMENT FOR PEAT

With the rise in the cost of peat moss, a major ingredient in many soilless potting mixes (21, 101), came the search for inexpensive and locally available alternative substrates for container grown crops (28, 33, 105, 128). Concern about the future availability of peat and of bark, a common peat substitute, also fostered research in this area (13, 92).

This study was designed to examine the uses of spent mushroom compost (SMC), a by-product of the mushroom industry, as a replacement for peat in a standard soilless medium. Various transplants were grown in mixes containing SMC which was either fresh or aged, leached or unleached, and at levels of 25% or 50% by volume. These transplants were compared to transplants grown in a high quality, commercially available, peat-vermiculite medium.

Materials and Methods

Design

The details of the experimental design were presented in Chapter IV, page 38. Four randomized complete block design experiments with nine treatments and six blocks were conducted, each on a separate crop. The treatments included a detached control group containing no

SMC and a 2x2x2 factorial arrangement of treatments containing SMC (Table 7, page 38). "Detached control group" does not mean that the control group was removed from the other treatments during the experiment. Rather, it refers to the fact that it was not part of the full factorial. A full factorial was not appropriate in this experiment, because it would require redundant treatments. The inclusion of the control group as part of the full factorial would result in one treatment called 0% fresh SMC and another called 0% aged SMC, but they would be the same treatment. All treatments were randomized within each block.

Procedures

Procedures for the preparation of media containing spent mushroom compost and procedures for the production of the transplants were detailed in Chapter IV, pages 39-42. Control plants were grown in Terra-lite Redi-Earth Peat-lite, a commercially available, prepared mix based on the Cornell mix of 50% Canadian sphagnum peat and 50% vermiculite (v/v) with added nutrients (101). This mix was chosen because of its reputation for being capable of producing superior quality plants (101).

Just prior to harvesting, a quality rating for consumer acceptability (89), based on a scale from 1 to 5, was recorded for each cell pack. On the quality rating scale, plants in a cell pack receiving a score of 1 were so poor that a consumer would not buy them. A quality rating of 2 was used for plants which the consumer would buy only if they were on sale. Average salable cell packs received a rating of 3. Cell packs receiving ratings of 4 and 5 contained uniform plants of good and exceptional quality, respectively. The single-blind rating scores were assigned by the author, based on training gained from working in commercial greenhouses for two years. While the rating score may have included unconscious experimenter bias, it was used because it represented a composite of many factors which could not be readily measured by more objective means and which were important in making comparisons to control plants. These factors included uniformity, stockiness, color, shape, and damage.

Statistical Analysis

Multivariate analysis of variance (68, 82) was used to simultaneously partition the variance in dry weight, height, and quality rating. Variance in bloom date was also considered for marigolds. Univariate analysis of variance was used to partition variance in medium pH and EC. Nonorthogonal contrasts were used to compare each treatment group to the control (66, 69). The analysis was run on the Manova program in SPSS (56).

Results and Discussion

A multivariate approach was used for this analysis to consider different yield variables at the same time. This approach more accurately reflects what occurs in consumers' minds as they consider purchases. Many factors are considered simultaneously before a selection is made. Consumers would not, for example, choose a plant based on height alone, but would consider color, stockiness, insect damage, and other factors as well.

This part of the experiment was done in order to determine if plants comparable to high quality, control plants could be grown in mixes containing SMC. Successful use of SMC would result in the production of transplants which were not significantly different from control plants. In contrast to most experiments, treatments which were found to be significantly different from the control were undesirable treatments.

In this experiment, the consequences of reporting that a treatment was not different from the control, when in fact it was, were considered to be more serious than the consequences of reporting that a treatment was inferior to the control, when in fact it was not. For example, concluding that a treatment containing SMC was as good as the control treatment might lead a grower to use the treatment. If a Type II error (55, 66) had occurred, then the conclusion would be wrong, and the grower utilizing SMC might lose valuable bench space, time, and money (4). On the other hand, concluding that a treatment containing SMC was not as good as the control, when in fact it was (Type I error) would only result in less usage of SMC by the transplant industry. For these reasons, reducing the possibility of Type II statistical errors was considered very important; of Type I errors were considered less important.

To reduce the possibility of a Type II error, the alpha level for significance was changed from the commonly accepted value of 0.05 to 0.20. This meant that if the probability of a greater F statistics for any treatment was 0.20 or less, that treatment would be considered undesirable. It also meant that, on the average over time, 20% of the treatments would be considered different from the control, when in fact they were not.

The four treatments containing fresh SMC and the treatments containing 50% aged SMC were all clearly different from the control for all crops tested (Table 16). The mean dry weights of plants grown in each of these treatment mixes were much lower than for the control plants (Tables 17-20). The same generally held true for the heights and quality ratings as well. Marigolds grown in these mixes were not always shorter than the control plants, but the mean number of days to bloom was longer for these plants than for the controls (Table 19).

Table 16. Multivariate partitioning of variance in dry weight, height, and quality rating by simple linear contrasts comparing plants grown in spent mushroom compost (SMC) to control plants.

SMC Treatment	Cucumber	Lettuce	Marigold[z]	Tomato
25% Fresh-unleached	***	***	***	***
25% Fresh-leached	***	***	***	***
50% Fresh-unleached	***	***	***	***
50% Fresh-leached	***	***	***	***
25% Aged-unleached	NS	NS	**	NS
25% Aged-leached	NS	NS	NS	.
50% Aged-unleached	***	***	***	***
50% Aged-leached	.	.	***	*

NS,.,*,**,***Nonsignificant (NS) or significant at 20% (·), 5% (*), 1% (**), 0.1% (***) levels.

[z]Days to bloom also considered for marigolds.

Table 17. Comparison of dry weight, height, and quality rating means of cucumbers grown in spent mushroom compost (SMC) to means of control plants grown in peat-vermiculite.

SMC Treatment	Dry weight (g)	Height (cm)	Quality rating[y]	P[z]
25% Fresh-unleached	2.02	33.0	3.0	***
25% Fresh-leached	1.93	33.2	3.0	***
50% Fresh-unleached	1.50	29.2	2.3	***
50% Fresh-leached	1.82	32.4	2.8	***
25% Aged-unleached	2.99	37.4	3.3	NS
25% Aged-leached	2.87	36.2	3.5	NS
50% Aged-unleached	1.86	31.4	3.0	***
50% Aged-leached	2.70	37.1	3.3	·
Control	3.04	37.4	3.5	

[NS,·,***]Nonsignificant (NS) or significant at 20% (·), 0.1% (***) levels.

[z]Probability level, based on multivariate analysis, considering dry weight, height, and quality rating simultaneously.

[y]Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.

Table 18. Comparison of dry weight, height, and quality rating means of lettuce grown in spent mushroom compost (SMC) to means of control plants grown in peat-vermiculite.

SMC Treatment	Dry weight (g)	Height (cm)	Quality rating[y]	P[z]
25% Fresh-unleached	0.81	16.1	2.7	***
25% Fresh-leached	1.04	18.0	2.8	***
50% Fresh-unleached	0.19	9.2	1.5	***
50% Fresh-leached	0.72	15.3	2.2	***
25% Aged-unleached	2.22	20.9	4.7	NS
25% Aged-leached	2.26	21.1	4.3	NS
50% Aged-unleached	1.47	18.3	3.5	***
50% Aged-leached	2.00	20.9	4.0	.
Control	2.43	21.6	4.7	

NS,.,***Nonsignificant (NS) or significant at 20% (·), 0.1% (***) levels.

[z]Probability level, based on multivariate analysis, considering dry weight, height, and quality rating simultaneously.

[y]Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.

Table 19. Comparison of dry weight, height, quality rating, and days to bloom means of marigolds grown in spent mushroom compost (SMC) to means of control plants grown in peat-vermiculite.

SMC Treatment	Dry weight (g)	Height (cm)	Quality rating^y	Days to bloom	P^z
25% Fresh-unleached	1.39	13.5	2.8	35	***
25% Fresh-leached	1.65	14.5	3.3	39	***
50% Fresh-unleached	0.84	12.1	2.2	38	***
50% Fresh-leached	1.35	14.3	3.2	39	***
25% Aged-unleached	2.53	13.4	4.3	34	**
25% Aged-leached	2.75	13.5	4.7	34	NS
50% Aged-unleached	1.48	11.3	3.2	35	***
50% Aged-leached	1.97	13.2	4.0	35	**
Control	3.01	13.9	4.9	33	

NS,**,***Nonsignificant (NS) or significant at 1% (**), 0.1% (***) levels.

^{z}Probability level, based on multivariate analysis, considering dry weight, height, quality rating, and days to bloom simultaneously.

^{y}Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.

Table 20. Comparison of dry weight, height, and quality rating means of tomatoes grown in spent mushroom compost (SMC) to means of control plants grown in peat-vermiculite.

SMC Treatment	Dry weight (g)	Height (cm)	Quality rating[y]	P[z]
25% Fresh-unleached	1.16	22.3	3.2	***
25% Fresh-leached	0.76	20.7	2.3	***
50% Fresh-unleached	0.59	16.5	2.2	***
50% Fresh-leached	0.53	18.0	2.2	***
25% Aged-unleached	2.29	25.5	4.3	NS
25% Aged-leached	2.05	24.8	4.7	•
50% Aged-unleached	1.67	25.1	3.7	***
50% Aged-leached	1.98	24.9	4.7	*
Control	2.32	25.1	4.8	

NS,•,*,*** Nonsignificant (NS) or significant at 20% (•), 5% (*), 0.1% (***) levels.

[z] Probability level, based on multivariate analysis, considering dry weight, height, and quality rating simultaneously.

[y] Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.

Most of the crops grown in 25% aged SMC were not significantly different from those in the control mix (Table 16). That is, plants grown in 25% aged SMC usually appeared to be as good as high quality, control plants. The means for dry weight, height, and quality rating for cucumber and lettuce grown in leached and unleached 25% SMC were similar to the means for the controls (Tables 17, 18). The means for marigolds in leached 25% aged SMC and tomatoes in unleached 25% aged SMC were also similar to those for the controls (Tables 19, 20).

While plants produced in the leached 50% aged SMC treatments were not as good as the high quality, control plants, they were still marketable. For example, lettuce and marigolds in leached 50% aged SMC received a mean quality rating score of 4.0 (Tables 18, 19). A quality rating of 4.0 indicated uniform plants of good quality. Based on these results, growers should not use leached medium containing 50% aged SMC and expect to produce high quality plants. They might, however, consider using this medium with the expectation of slightly lower prices for the crop. The lower return should be weighed against the differences in cost among various potting mixes.

The results presented in this chapter can largely be explained by the age, level, and leaching factors involved in the SMC treatments. The effects of these factors and the effects of the interactions among these factors were discussed in Chapter IV.

While there was variation among treatments, overall, the pH and electrical conductivity levels for all treatment media were higher than for the control medium (Tables 21, 22). The high salinity levels generally did not represent as great a problem as might have been

Table 21. Comparison of pH levels in media containing spent mushroom compost (SMC) and a standard peat-vermiculite control, before and after growing crops, based on pH of saturated paste extracts.

	pH				
SMC Treatment	Before	After Cucumber	After Lettuce	After Marigold	After Tomato
25% Fresh-unleached	5.8	7.2 ***	7.1 ***	7.2 ***	7.3 ***
25% Fresh-leached		7.3 ***	7.2 ***	7.2 ***	7.3 ***
50% Fresh-unleached	6.3	7.4 ***	7.4 ***	7.3 ***	7.4 ***
50% Fresh-leached		7.4 ***	7.4 ***	7.3 ***	7.4 ***
25% Aged-unleached	6.3	6.5 ***	6.6 ***	6.5 ***	6.6 ***
25% Aged-leached		6.8 ***	6.6 ***	6.6 ***	6.7 ***
50% Aged-unleached	7.0	7.1 ***	7.2 ***	7.1 ***	7.0 ***
50% Aged-leached		7.2 ***	7.3 ***	7.1 ***	7.2 ***
Control	5.6	6.1	5.7	5.7	5.8

***Significant at 0.1% level.

Table 22. Comparison of electrical conductivities in media containing spent mushroom compost (SMC) and a standard peat-vermiculite control, before and after growing crops, based on electrical conductivity of saturated paste extracts.

	Electrical conductivity (dS/m)				
SMC Treatment	Before	After Cucumber	After Lettuce	After Marigold	After Tomato
25% Fresh-unleached	7.1	4.4 ***	5.4 ***	6.3 ***	6.7 ***
25% Fresh-leached		2.7 **	4.1 *	4.3	4.0
50% Fresh-unleached	10.7	5.9 ***	8.1 ***	8.0 ***	9.4 ***
50% Fresh-leached		3.7 ***	5.2 ***	5.2 **	4.7 *
25% Aged-unleached	8.5	5.3 ***	5.6 ***	6.8 ***	6.2 ***
25% Aged-leached		3.7 ***	4.4 **	5.2 **	4.4 *
50% Aged-unleached	13.9	7.0 ***	7.8 ***	10.6 ***	10.2 ***
50% Aged-leached		4.2 ***	5.3 ***	7.8 ***	5.2 **
Control	4.5	1.7	2.8	3.4	3.1

*,**,*** Significant at 5% (*), 1% (**), or 0.1% (***) levels.

expected, based on the EC readings alone. For example, the mean dry weight for tomatoes grown in unleached 25% aged SMC was 99% of the mean dry weight for those grown in the control mix (Table 20). Tables presented in Bressler, McNeal, and Carter (15) predicted that a 30% reduction in yield would occur at 6 dS/m, the level present in the 25% aged SMC mix with tomatoes, compared to 3 dS/m, the level present in the tomato control mix. Differing conditions in the field compared to those in a cell pack might account for this discrepancy.

Conclusions

Plants that were similar to high quality, control plants were produced in potting mixes containing 25% aged spent mushroom compost with 25% peat and 50% vermiculite. For all crops except tomatoes, plants similar to high quality, control plants were produced in leached 25% aged SMC. For all crops except marigolds, plants similar to high quality, control plants were produced in the 25% aged SMC without leaching. Because the leaching process is cumbersome, time consuming, and a potential source of pollution, the use of unleached mixes is generally preferable.

Plants grown in leached 50% aged SMC were not as good as the high quality, control plants, however, these plants were generally still of marketable quality.

Plants grown in fresh SMC were very different from the control plants. The generally low quality ratings of the plants grown in fresh SMC indicated that mixes containing fresh SMC should not be used, at least for those crops studied.

CHAPTER VI

EFFECTS OF LEVEL, AGING, AND LEACHING ON ELEMENT CONCENTRATIONS IN TRANSPLANTS GROWN IN SOILLESS MEDIA CONTAINING SPENT MUSHROOM COMPOST AS A REPLACEMENT FOR PEAT

The effects of level, aging, and leaching of spent mushroom compost (SMC) on the dry weight, height, and percent dry weight of transplants grown in media containing SMC were reported (Chapter IV). The dry weight, height, and overall quality of transplants grown in media containing SMC as a replacement for peat have been compared to those of transplants grown in a standard, high quality, peat-vermiculite medium (Chapter V). Generally, plants grown in 25% aged SMC were found to be similar to the control plants in appearance.

This study examined the effect of level, aging, and leaching of SMC on the concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in transplants grown in media containing SMC, and compared the element levels in those plants to the levels in plants grown in a control mix.

Materials and Methods

Design

Four experiments were conducted, each on a separate crop, as discussed in Chapters IV and V. The experimental design for each was a randomized complete block with nine treatments (2x2x2 factorial plus a detached control) with six blocks. Three blocks were sampled at random for element concentration.

Procedures

Plant tissue harvested from the previously discussed experiments (Chapters IV and V) was used for this study. Tissue which had been rinsed and oven-dried (60 C) was ground in a cyclone mill to pass a one mm screen. Ground tissue was collected in plastic bags, sealed, and frozen until the analyses were run. Samples were digested by the wet ashing technique described by Isaac and Johnson (61). Potassium, calcium, and magnesium were measured by atomic absorption spectrophotometry (2, 3, 60, 61) on a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. Phosphorus was measured on a Technicon Auto Analyzer by the vanadomolybdophosphoric yellow colorimetric test (24, 62). Total nitrogen concentration was measured on the Technicon Auto Analyzer by the indophenol colorimetric method, after digestion with sulfuric acid and hydrogen peroxide (85, 113).

Statistical Analysis

Multivariate analysis of variance (68 ,82) was used to simultaneously partition the variance in nitrogen, phosphorus, potassium, calcium, and magnesium. Univariate analyses (74) were also performed for each element separately. Orthogonal contrasts were used to test main effects and interactions within the eight treatments of the 2x2x2 factorial (66, 70, 73, 74). Nonorthogonal contrasts were used to compare each treatment to the control (66, 69). Analyses were run on the Manova program in SPSS (56).

Results and Discussion

Comparisons To Control Plants

For all four crops, the results of the multivariate analysis of variance showed that, when nitrogen, phosphorus, potassium, calcium, and magnesium were considered simultaneously, all treatments containing SMC were significantly different from the control treatments (probability < 0.001). An examination of the univariate results (Tables 23-26) aids the interpretation of these data.

The concentrations of calcium in transplants grown in the media containing SMC were significantly higher than the concentration of calcium in the control plants (Tables 23-26). Potassium was also higher than in control plants, but the differences were not always significant. In all treatments, potassium in tomato tissue was significantly higher than in the control. Widders and Lorenz showed that young tomatoes were very efficient in potassium uptake (123). The high concentrations of potassium and calcium found in SMC (Table 4, page 30) could account for the high concentrations found in the tissue of plants grown in it.

The concentrations of magnesium in the tissue of plants grown in media containing SMC were usually significantly lower than in control plants. While there were also high concentrations of magnesium in SMC, other researchers have reported that high calcium and potassium may reduce the uptake of magnesium (84, 99, 126).

Nitrogen in the tissue of plants grown in SMC was generally not significantly different from that in control plants (Tables 23-26).

Table 23. Comparison of mean element concentrations in cucumbers grown in spent mushroom compost (SMC) to that in control plants grown in peat-vermiculite.

SMC Treatment	N	P	K	Ca	Mg
	(millimoles per kilogram of dry tissue)				
25% Fresh-unleached	2960	228 ***	1870 ***	630 ***	309 ***
25% Fresh-leached	2880	293	1740 ***	604 ***	267 ***
50% Fresh-unleached	3150	151 ***	2020 ***	545 ***	319 ***
50% Fresh-leached	2810	252 **	1830 ***	611 ***	253 ***
25% Aged-unleached	3370	303	1790 ***	666 ***	351 ***
25% Aged-leached	2690	333	1540	621 ***	290 ***
50% Aged-unleached	3690 *	220 ***	1790 ***	730 ***	403 ***
50% Aged-leached	2880	265 **	1740 ***	718 ***	313 ***
Control	3000	345	1420	433	520

*,**,*** Significant at 5% (*), 1% (**), 0.1% (***) levels.

Table 24. Comparison of mean element concentrations in lettuce grown in spent mushroom compost (SMC) to that in control plants grown in peat-vermiculite.

SMC Treatment	N	P	K	Ca	Mg
	(millimoles per kilogram of dry tissue)				
25% Fresh-unleached	4190	308	2300	344 ***	185 ***
25% Fresh-leached	4220	324	2240	327 ***	153 ***
50% Fresh-unleached	4660 **	236 **	2190	272 ***	167 ***
50% Fresh-leached	4160	263 **	2190	318 ***	153 ***
25% Aged-unleached	4190	320	2390 *	292 ***	197 ***
25% Aged-leached	3430	340	2360	270 **	172 ***
50% Aged-unleached	4070	275 **	2440 *	311 ***	229
50% Aged-leached	3980	271 **	2490 **	316 ***	199 ***
Control	3550	366	2080	225	259

*,**,***Significant at 5% (*), 1% (**), 0.1% (***) levels.

Table 25. Comparison of mean element concentrations in marigolds grown in spent mushroom compost (SMC) to that in control plants grown in peat-vermiculite.

SMC Treatment	N	P	K	Ca	Mg
	(millimoles per kilogram of dry tissue)				
25% Fresh-unleached	3270	223 **	1410 ***	442 ***	238 ***
25% Fresh-leached	3250	176 ***	1300 **	455 ***	217 ***
50% Fresh-unleached	3700 *	159 ***	1690 ***	438 ***	255 ***
50% Fresh-leached	3430	175 ***	1460 ***	460 ***	204 ***
25% Aged-unleached	3390	282	1250 *	483 ***	294 **
25% Aged-leached	2740	275	1240	482 ***	256 ***
50% Aged-unleached	3190	238 *	1270 *	457 ***	303 *
50% Aged-leached	3400	210 **	1350 ***	537 ***	281 ***
Control	3190	312	1120	309	346

*,**,***Significant 5% (*), 1% (**), 0.1% (***) levels.

Table 26. Comparison of mean element concentrations in tomatoes grown in spent mushroom compost (SMC) to that in control plants grown in peat-vermiculite.

SMC Treatment	N	P	K	Ca	Mg
	(millimoles per kilogram of dry tissue)				
25% Fresh-unleached	2880	153 **	1840 ***	586 ***	316 **
25% Fresh-leached	3570	191	1940 ***	638 ***	282 ***
50% Fresh-unleached	3870	113 ***	1870 ***	536 ***	360
50% Fresh-leached	3730	166 *	1800 ***	685 ***	295 ***
25% Aged-unleached	3590	215	1640 ***	531 ***	373
25% Aged-leached	2420	254	1610 **	567 ***	269 ***
50% Aged-unleached	3710	195	1870 ***	604 ***	448
50% Aged-leached	3340	159 **	1580 **	633 ***	336 *
Control	3010	235	1260	346	394

*,**,***Significant at 5% (*), 1% (**), 0.1% (***) levels.

Phosphorus were generally reduced by the use of SMC, and the reductions from the concentrations in control tissue were often significant. Some of the plants grown in SMC had the appearance of a slight phosphorus deficiency; slight stunting and reddish-purple coloring on the stems and leaves of tomatoes and marigolds were frequently observed. This caused the leaves to appear dark green, and is a symptom which others have reported in association with phosphorus deficiency (23). Dark green foliage has also been associated with high salinity (9, 15). Regardless of the cause, the plants looked very good, because they were relatively compact and deep green in color.

Effects Of Level, Aging, and Leaching of SMC

Using multivariate analysis, all of the main effects (level of SMC, age of SMC, and leaching) were found to be significant for all crops tested, except for the leaching effect for lettuce (Tables 27-30). Of the 16 possible two- and three-way interactions examined, only those interactions between the level of SMC and leaching for marigold and between the level and age of SMC for lettuce were found to be significant (probability < 0.05). Only the main effects will be discussed.

Cucumbers grown in fresh SMC contained significantly lower concentrations of phosphorus, calcium, and magnesium and significantly higher concentrations of potassium than cucumbers grown in SMC which had been aged aerobically for five weeks (Table 27). The concentrations of magnesium in fresh and aged SMC (Table 4, page 30) might

Table 27. Mean cucumber element concentrations by treatment factors.

Factor	N	P	K	Ca	Mg	Multivariate probability
	(mmoles per kg of dry tissue)					
Age of SMC:		**[y]	***	***	***	***[z]
Fresh SMC	2950	231	1870	598	287	
Aged SMC	3160	280	1720	684	339	
Level of SMC:		***	**			*
25% SMC	2980	289	1740	630	304	
50% SMC	3130	222	1840	651	322	
Leaching effect:	**	***	***		***	***
Unleached	3290	225	1870	643	346	
Leached	2820	285	1710	638	281	

*,*** Significant at 5% (*), 0.1% (***) levels.

[z] Probability based on multivariate analysis, considering all elements simultaneously.

[y] Probability based on univariate analysis, considering each element separately.

Table 28. Mean marigold element concentrations by treatment factors.

Factor	N	P	K	Ca	Mg	Multivariate probability
	(mmoles per kg of dry tissue)					
Age of SMC:		**[y]	***	*	***	**[z]
Fresh SMC	3410	183	1460	449	228	
Aged SMC	3180	251	1280	490	283	
Level of SMC:		*	***			*
25% SMC	3160	239	1300	465	251	
50% SMC	3430	196	1440	473	260	
Leaching effect:					**	***
Unleached	3390	226	1400	455	272	
Leached	3200	209	1340	484	239	

*,**,***Significant at 5% (*), 1% (**), 0.1% (***) levels.

[z]Probability based on multivariate analysis, considering all elements simultaneously.

[y]Probability based on univariate analysis, considering each element separately.

Table 29. Mean tomato element concentrations by treatment factors.

Factor	N	P	K	Ca	Mg	Multivariate probability
	(mmoles per kg of dry tissue)					
Age of SMC:		**y	**		*	***z
Fresh SMC	3510	156	1860	611	313	
Aged SMC	3270	206	1670	584	356	
Level of SMC:	*	**			*	**
25% SMC	3110	203	1760	581	310	
50% SMC	3660	159	1780	614	360	
Leaching effect:				**	***	***
Unleached	3510	169	1800	564	374	
Leached	3270	193	1730	631	295	

*,***Significant at 5% (*), 0.1% (***) levels.
zProbability based on multivariate analysis, considering all elements simultaneously.
yProbability based on univariate analysis, considering each element separately.

Table 30. Mean lettuce element concentrations by treatment factors.

Factor	N	P	K	Ca	Mg	Multivariate probability
	(mmoles per kg of dry tissue)					
Age of SMC:			*y	*	**	***z
Fresh SMC	4310	283	2230	315	165	
Aged SMC	3920	301	2420	297	199	
Level of SMC:		*				**
25% SMC	4010	323	2320	308	177	
50% SMC	4220	261	2330	304	187	
Leaching effect:					*	NS
Unleached	4280	285	2330	305	195	
Leached	3950	299	2320	308	169	

NS,*,**,***Nonsignificant (NS) or significant at 5% (*), 1% (**), 0.1% (***) levels.

zProbability based on multivariate analysis, considering all elements simultaneously.

yProbability based on univariate analysis, considering each element separately.

explain the reduced concentrations of magnesium in the tissue of plants grown in fresh SMC. Other differences seen in cucumber tissue content may have been caused by the response of cucumbers to ammonium. Fresh SMC has been shown to have high levels of ammonium (Chapter 3). Schenk and Wehrmann (98) found reduced uptake of both potassium and phosphorus associated with ammonia treatments in cucumbers. They suggested that the phosphorus response was caused both by a direct effect of ammonia toxicity and an indirect effect from the increase in pH associated with higher levels of ammonia. At the conclusion of this experiment, the average pH in media containing fresh SMC was higher than in media containing aged SMC (Table 31). The reason for the increased potassium in the tissue of cucumbers grown in fresh SMC was unclear.

Table 31. Average final pH and electrical conductivities of treatment mixes containing spent mushroom compost (SMC) by main factors.

Treatment	pH^z	EC^z (dS/m)
Age of SMC:		
Fresh SMC	7.3	5.5
Aged SMC	6.9	6.2
Level of SMC:		
25% SMC	6.9	5.0
50% SMC	7.3	6.7
Leaching effect:		
Unleached	7.1	7.1
Leached	7.1	4.6

^{z}Based on saturated paste extract.

Like cucumbers, marigolds grown in fresh SMC had significantly less phosphorus, calcium, and magnesium and significantly more potassium than marigolds grown in aged SMC (Table 28).

Differences in phosphorus, potassium, and magnesium concentrations in tomatoes grown in fresh and aged SMC (Table 29), were similar to those for cucumbers and marigolds. There was no difference between the calcium concentration in tomatoes grown in fresh and that in those grown in aged SMC. Wallihan and others (117) reported higher concentrations of potassium and lower concentrations of phosphorus and calcium in tomatoes grown in basic solutions. Reduced calcium and magnesium have been associated with ammonium fertilization in tomatoes grown in sand culture (126). The reason why no difference was found in the calcium concentrations in this study is unclear. As a growth medium, SMC is much more complex than sand. Many factors changed as SMC aged. While ammonium level seemed to be the most important difference between fresh and aged SMC, salinity, acidity, bulk density, and easily available water also differed (Chapter III). As Kenworthy pointed out, soil variation can often lead to problems in the interpretation of plant tissue data (64).

Lettuce transplants grown in fresh SMC contained significantly lower concentrations of potassium and magnesium and significantly higher concentrations of calcium than those grown in aged SMC (Table 30). While the average concentration of phosphorus was lower in the tissue of all crops grown in fresh SMC than in those grown in aged SMC, the difference was not significant in lettuce. The concentrations of phosphorus in all lettuce treatments were well above the diagnostic level for phosphorus deficiency in lettuce seedling tops, tentatively set by Berry (11) at the equivalent of about 30 mmoles per kg of tissue (1000 ppm). The concentrations of potassium, phosphorus, calcium, and magnesium were similar to the base-line levels for seedling lettuce, established by Berry and others (12).

All crops tested had significantly lower concentrations of phosphorus in their tissues when they were grown in 50% SMC than when grown in only 25% SMC (Tables 27-30). This was consistent with White's findings for phosphorus concentrations in the tissue of Easter lilies grown in increasing levels of SMC (121). This reduction in phosphorus levels may have been due to the effect of pH on phosphorus availability (76). At the conclusion of the experiment, the average pH of the 50% SMC mixes was higher than that for the 25% SMC mixes (Table 31).

Crops grown in 50% SMC had higher concentrations of nitrogen and magnesium in their tissue than crops grown in 25% SMC, however, the difference was only significant for tomato (Table 29). Potassium was significantly higher in cucumber and marigold plants grown in 50% SMC than in those grown in 25% SMC (Tables 27, 28). White also reported potassium increases in Easter lily tissue as levels of SMC in the potting mix were increased (121). No differences in calcium concentrations in plants grown in 25 and 50% SMC were observed in this study.

As expected, the electrical conductivities in the leached mixes were much lower than those in the unleached treatment mixes (Table 31). Leaching of these mixes resulted in significantly reduced concentrations of magnesium in the tissue of all crops tested. Salinity studies have shown that high concentrations of either potassium or calcium salts alone can reduce magnesium concentrations in plant tissue, but high concentrations of potassium and calcium salts together may not reduce magnesium levels (8). The interactions among potassium, calcium, and magnesium in SMC are complex. Potassium, a monovalent ion, should have been readily reduced in SMC by leaching (109). Significantly lower concentrations of potassium were seen in cucumber tissue after leaching (Table 27). Calcium tissue concentrations in tomato were significantly increased by leaching (Table 29).

Conclusions

The use of SMC as a replacement for peat in standard soilless potting media for transplants generally resulted in crops with higher concentrations of calcium and potassium and lower magnesium than in control plants. Large differences in elemental analysis at this stage of growth often have little effect on the final yield of crops (71).

Phosphorus concentrations in plants grown in SMC tended to be lower than in plants grown in the control mix. Reduced phosphorus may have caused a delay in flowering, as was seen in marigolds (Table 19, page 62), and could represent a problem in the production of flowering annuals. Root development could also be hindered (21). The reduced phosphorus, however, probably caused the overall improved visual appearance of tomatoes and marigolds, which were generally more compact and darker green than the control plants.

Transplants grown in fresh SMC had reduced concentrations of magnesium and phosphorus in comparison to those grown in aged SMC. Ammonium levels in fresh SMC probably account for this difference both from its directly toxic effects and from its effect on pH. Plants grown in 50% SMC had lower concentrations of phosphorus than plants grown in only 25% SMC, probably as a result of the higher pH at 50% SMC. Leaching reduced the concentrations of magnesium in all crops tested.

CHAPTER VII

GROWTH RESPONSES OF TRANSPLANTS GROWN IN VARYING DOSES OF FRESH AND AGED SPENT MUSHROOM COMPOST

The responses of transplants to varying levels of fresh and aged spent mushroom compost (SMC) have not been thoroughly studied. In his work on the production of transplants, Rathier used a fixed level of 33% by volume of fresh SMC or SMC which had aged 6 to 12 weeks, in combinations with perlite and peat moss or soil (91). He produced plants which were superior to those grown in a low fertility control mix. An editor's note to Rathier's article reported that 10-15% SMC was being used successfully by greenhouse operators. In research discussed previously in this dissertation, the effect of 0, 25, and 50% fresh SMC or SMC which had aged for five weeks, in combination with vermiculite and peat was presented (Chapters IV-VI). Generally, transplants grown in 25% SMC were larger than those grown in 50% SMC. Henny was able to produce quality foliage plants in 50, 67, and 100% SMC which was nine months old, in combinations with pine bark (54). White experimented with a full range of levels of two to three year old SMC, by using increments of 10% from 0 to 100% in combination with peat to grow Easter lilies, and recommended using rates of SMC from 20 to 80% (121).

In this study, the responses of broccoli, lettuce, marigold, and tomato transplants to 0%, 12.5%, 25%, 37.5%, and 50% fresh SMC or SMC aged for six weeks were investigated.

Materials and Methods

Design

The experimental design was a randomized complete block with five treatments and five blocks. The treatments consisted of 0, 12.5, 25, 37.5, and 50% SMC. Separate experiments were conducted using fresh SMC and using aged SMC.

Four crops were grown from seed in treatment mixes in plastic cell packs, with six 4x6x6 cm cells per pack. The six plants in each cell pack represented the experimental unit.

All experiments were conducted in the spring of 1982 and were repeated in the summer of the same year.

Procedures

On March 26 and on May 7, 1982, treatment mixes were prepared using fresh SMC and using SMC which had aged for six weeks, as described in Chapter IV, page 39. All mixes contained 50% (by volume) horticultural grade vermiculite and 0, 12.5, 25, 37.5, or 50% SMC, with Canadian peat comprising any remaining portion. To obtain pH levels between 6 and 7, approximately 3 kg of dolomitic limestone were added to each cubic meter of mix containing 0% SMC, 50% peat, 50% vermiculite. Three kg of aluminum sulfate were added per cubic meter of mix containing 37.5% SMC, 12.5% peat, 50% vermiculite. Four kg aluminum sulfate were added per cubic meter of mix of 50% SMC, 50% vermiculite. There were no additions to the mixes containing 12.5 or 25% SMC. All potting media were thoroughly mixed by hand. The medium in each cell pack was tamped down by stacking an empty cell pack on the surface of the mix and pressing down lightly. Cell packs were placed in flats in a greenhouse.

The following cultivars were used in this experiment: Premium Crop Hybrid broccoli (*Brassica oleracea* L. var. *italica*), Black Seeded Simpson lettuce (*Lactuca sativa* L.), Orange Boy marigold (*Tagetes patula* L.), and Walter tomato (*Lycopersicon esculentum* Mill.). Five seeds were sown in each cell of each cell pack. These were later thinned randomly to one seedling per cell. Plants were grown by standard production methods (27, 101). After germination, seedlings were fertilized weekly with Peter's 20-20-20, at a rate of 35 mmoles of nitrogen per liter (500 ppm). Peter's Standard Trace Element Mixture was applied with the early fertilizations.

Plants from the first run were harvested on May 6. Plants from the second run were harvested on June 23. Quality ratings, heights, dry weights, and percent dry weights were measured as described in Chapters IV and V. Media pH and EC were also measured as previously described.

Statistical Analysis

Multivariate analysis of variance (68, 82) was used to simultaneously partition the variation in dry weight, height, and percent dry weight. Dose response to treatment effect was partitioned into single degree of freedom contrasts to test for linear and quadratic components, as suggested by Little (73). The analysis was run using the polynomial contrast statement in the Manova program of SPSS (56). While there were some seasonal differences, the overall trends for the spring and summer runs were similar. Only the results from a combined analysis will be presented. Data from the spring and summer runs were combined and analyzed, with blocks nested within runs, as suggested by McIntosh (81).

Results and Discussion

The average, initial electrical conductivity in the control mix was low (Table 32). Only lime had been added during the preparation of the mix. Due to liquid fertilization during the experiment, the final EC of the mix was within the range considered appropriate for a well fertilized mix for non-salt tolerant crops (21, 96). The soluble

Table 32. Electrical conductivity and pH levels in media containing various levels of fresh or aged spent mushroom compost (SMC), before and after growing transplants.

		EC^z (dS/m)		pH^z	
Percent of SMC		Before	After	Before	After
Fresh:	0.0	0.9	1.6	5.7	6.7
	12.5	4.6	3.8	6.2	6.0
	25.0	6.4	5.6	6.3	6.5
	37.5	9.9	6.4	6.2	6.4
	50.0	11.6	7.1	6.4	6.6
Aged:	0.0	0.9	1.6	5.7	6.7
	12.5	4.4	4.7	6.2	6.0
	25.0	6.7	6.0	6.1	6.3
	37.5	11.0	7.2	6.2	6.5
	50.0	13.6	7.7	6.3	6.4

^{z}Based on saturated paste extract.

salt levels in the mixes, both before and after the growth of crops, increased linearly with the level of SMC. The initial and final pH levels in the mixes were quite similar, except for the control mix (Table 32). The pH of the control mix increased by one unit during the experiment.

Average crop yields are presented in Tables 33-36. The linear and quadratic responses to the level of SMC were significant for all crops. Generally, the percent dry weight decreased linearly as the level of SMC rose. Increased succulence is a commonly reported response of vegetable crops to increased salinity (102). The values for dry weight, height, and quality rating initially rose, but then dropped as the level of SMC increased.

The peak values for these plant growth indexes generally occurred at lower levels when plants were grown in fresh SMC than when they were grown in aged SMC. The mean dry weight of plants grown in 50% aged SMC was higher than the mean dry weight for control plants, but the mean dry weight of plants grown in 50% fresh SMC was lower than that for the controls. This difference between plants grown in fresh and aged SMC was most extreme in lettuce (Table 34), where very little growth occurred at the 37.5% or 50% levels of fresh SMC. The differing growth responses in fresh and aged SMC were similar to those observed in the previously described experiments (Chapters IV, VI) and to those briefly mentioned by Rathier (91). This was probably caused by the ammonium in fresh SMC (discussed in Chapter III). It could not be due to salinity alone, because the electrical conductivity was high in both the fresh and aged SMC mixes.

Table 33. Broccoli dry weight, percent dry weight, height, and quality rating means by level of fresh or aged spent mushroom compost (SMC).

Percent of SMC	Dry weight (g)	Percent dry weight	Height (cm)	Quality rating[z]
Fresh:[y]				
0.0	1.29	14.4	14.5	3.1
12.5	1.40	13.1	16.1	3.7
25.0	1.63	13.1	16.7	3.8
37.5	1.60	12.7	16.3	3.7
50.0	1.18	12.0	15.0	3.0
Aged:[y]				
0.0	1.24	13.2	15.8	3.1
12.5	1.80	14.4	17.3	3.6
25.0	1.89	13.7	17.3	3.5
37.5	2.18	12.6	18.7	3.7
50.0	1.88	11.7	17.3	2.8

[z]Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.
[y]Linear and quadratic trends significant at 0.1% level, based on multivariate analysis of dry weight, percent dry weight, and height.

Table 34. Lettuce dry weight, percent dry weight, height, and quality rating means by level of fresh or aged spent mushroom compost (SMC).

Percent of SMC	Dry weight (g)	Percent dry weight	Height (cm)	Quality rating[z]
Fresh:[y]				
0.0	2.18	7.4	16.2	3.5
12.5	2.51	6.9	16.7	4.0
25.0	2.41	7.1	16.1	3.9
37.5	0.83	5.6	11.9	1.9
50.0	0.22	5.5	7.6	1.0
Aged:[y]				
0.0	1.82	6.6	17.9	3.0
12.5	2.86	6.9	19.4	3.5
25.0	2.96	6.9	20.5	3.8
37.5	1.88	5.8	19.5	3.2
50.0	1.90	5.9	18.9	3.0

[z]Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.
[y]Linear and quadratic trends significant at 0.1% level, based on multivariate analysis of dry weight, percent dry weight, and height.

Table 35. Marigold dry weight, percent dry weight, height, and quality rating means by level of fresh or aged spent mushroom compost (SMC).

Percent of SMC	Dry weight (g)	Percent dry weight	Height (cm)	Quality rating[z]
Fresh:[y]				
0.0	1.41	11.8	14.8	3.5
12.5	1.72	10.9	16.0	4.5
25.0	1.63	10.6	15.5	4.5
37.5	1.47	10.8	13.8	3.9
50.0	1.22	10.3	13.1	3.1
Aged:[x]				
0.0	1.32	10.4	16.1	3.3
12.5	1.50	10.3	15.7	3.7
25.0	1.82	10.4	16.4	4.3
37.5	1.62	9.7	15.4	4.1
50.0	1.46	9.8	14.7	3.7

[z]Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.
[y]Linear and quadratic trends significant at 0.1% level, based on multivariate analysis of dry weight, percent dry weight, and height.
[x]Linear and quadratic trends significant at 0.1% and 1% levels, respectively, based on multivariate analysis of dry weight, percent dry weight, and height.

Table 36. Tomato dry weight, percent dry weight, height, and quality rating means by level of fresh or aged spent mushroom compost (SMC).

Percent of SMC	Dry weight (g)	Percent dry weight	Height (cm)	Quality rating[z]
Fresh:[y]				
0.0	1.89	12.6	23.3	3.0
12.5	2.35	12.2	24.0	3.7
25.0	2.66	12.3	24.7	4.2
37.5	1.99	11.2	21.3	3.1
50.0	1.21	9.4	18.6	2.2
Aged:[y]				
0.0	2.35	12.9	24.5	3.0
12.5	2.76	11.1	27.8	3.6
25.0	3.34	11.5	28.3	3.9
37.5	3.03	9.8	29.9	4.5
50.0	2.47	8.4	28.9	3.9

[z]Based on a scale from 1 to 5, 1 = poor quality, 5 = excellent.
[y]Linear and quadratic trends significant at 0.1% level, based on multivariate analysis of dry weight, percent dry weight, and height.

All crops seemed to grow better with at least 12.5% SMC in the mix than they did in the average quality control mix (Tables 33-36). The mean quality ratings for control plants were lower than the mean quality ratings for all treatments except lettuce in 37.5% fresh SMC, broccoli in 50% aged SMC, and all crops in 50% fresh SMC. The SMC appeared to act as an additional source of fertilizer, and thus improve growth.

The control mix used in the previously described experiments (Chapters IV-VI) contained added nutrients, while the control mix used in this experiment relied solely on liquid fertilizations for nutrients. High quality control plants were produced in the earlier experiments, and average quality plants were produced in these experiments. The peat-vermiculite control media used in this experiment was similar to media used by some growers and to control treatments used by other researchers (127). The variability which can occur in crops grown in various standard media has been well documented by Brown and Emino (16), and these research findings should be interpreted in light of this fact.

The mean dry weights of tomato, marigold, and lettuce transplants were highest when they were grown in 25% aged SMC (Tables 33-36). The mean dry weight of broccoli was highest in 37.5% aged SMC. This difference was probably due to their differing sensitivities to salinity. Tomato, marigold, and lettuce are moderately sensitive to salts, while broccoli is moderately tolerant of salts (15, 21).

Conclusions

Crop responses to both fresh and aged SMC had significant linear and quadratic trends. Generally, percent dry weight decreased linearly with increasing SMC, while dry weight, height, and quality rating rose initially and then dropped as the level of SMC in the growing mix increased. The previously observed response of reduced growth in fresh compared to aged SMC, reported in Chapter IV, was also observed here. This response was most pronounced for lettuce.

Lettuce, marigolds, and tomatoes, the moderately salt sensitive crops, grew best in 25% aged SMC, while broccoli, the moderately salt tolerant crop, grew best at 37.5% aged SMC. Crops grown in these mixes were taller, had higher dry weights, and had higher quality ratings than crops grown in the average quality control mix, probably because the SMC supplied additional nutrients.

CHAPTER VIII

GENERAL DISCUSSION

General Recommendations and Conclusions

Spent mushroom compost (SMC) can be successfully used as a partial replacement for peat in a soilless potting mix for the production of transplants. It supplies high levels of calcium and potassium to plants. The amounts of aeration porosity and easily available water in aged SMC are within the range considered adequate for substrates used in containers. The potential problems with the use of SMC in potting media include its high soluble salt levels, its rate of shrinkage, the high ammonium and pH levels when fresh, and the low level of phosphorus uptake by plants grown in it. A mix of 25% aged SMC, 25% peat, and 50% vermiculite can be recommended for the production of some transplants, but it should be used with caution.

In these studies, the problems resulting from high levels of soluble salts were not as severe as expected. The salinity problems could be overcome in three ways. SMC, or the potting mixes containing SMC, could be leached before use, as the salts could be readily leached. Leaching, however, can be a cumbersome, time-consuming process, and can represent a potential pollution source (129). Another way to overcome the salt problem would be to dilute its effect by using small proportions of SMC in a potting mix. For example, some growers in Connecticut routinely use only 10 to 15% SMC in their mixes (91). Finally, the use of SMC could be restricted to salt tolerant crops, such as broccoli.

Shrinkage of a potting medium, due to compaction or decomposition, is less of a problem in the production of transplants than it is in the production of foliage or nursery stock, because the transplants are in the growing medium for a shorter period of time. Shrinkage was not a major problem in these experiments; the highest rate of SMC used was 50%, and crops were harvested within seven weeks. If SMC were to be used for slow growing transplants, shrinkage might be a problem. The problem could be overcome by using small proportions of SMC in the mix, or by composting SMC before use.

The level of ammonium in fresh SMC was high. Ammonium is potentially damaging to many crops (21, 59, 80). Crops for transplanting are often grown in winter or early spring, so they will be ready for planting in spring and early summer. Research has shown that crops can be more susceptible to ammonium injury in the winter, when light intensity and plant carbohydrate supplies are low (18, 21). The aerobic composting and turning of SMC for five weeks eliminated the ammonium problem in this study.

Stockpiling SMC for five weeks would probably not be effective in eliminating the toxic levels of ammonium. The problem is apparently eliminated by the recolonization of the SMC by Nitrosomonas and Nitrobacter, which convert the ammonium to nitrites and nitrates (78). Davies and Owen showed that ammonia levels in steam sterilized soils which were left undisturbed remained high, even after 16 weeks (29). They showed that little aerial contamination from nitrifying bacteria occurred at the surface of the sterilized, undisturbed soil (30). Digging in the soil and planting of crops were both effective in inducing recolonization of the soil by nitrifying bacteria (30, 31). The aerobic composting method used in this experiment involved transferring the composting SMC from one 200 liter drum to another every three days. This method allowed ample mixing of the compost, and apparently was effective in distributing nitrifying bacteria throughout the aging compost, because ammonium levels dropped dramatically within three weeks (Figure 1, page 31).

In addition to the directly toxic effect of ammonium on crops, ammonium can also cause problems indirectly due to an increase in pH. In sterilized or anaerobic situations, ammonium production is associated with increased pH (21). Ammonium fertilization is usually associated with a decrease in pH. The Nitrosomonas normally present convert the ammonium to nitrites and hydrogen ions are released in the process. Sterilization and anaerobic conditions prevent the conversion of ammonium to nitrite. If the ammonium level in SMC is reduced, the extreme pH problem in SMC will be eliminated. The pH of SMC will then normally be near neutral.

Because SMC is a source of organic matter that resembles peat in some ways, uninformed people have assumed that its characteristics are similar to those of peat, which is generally acidic. The pH of SMC, even after the reduction in the level of ammonium, is too high for SMC to be useful with acid-loving plants, such as azaleas.

The level of phosphorus in the tissues of plants grown in SMC may be inadequate. Levels low enough to cause visible deficiency symptoms are likely if fresh SMC is used, because phosphorus is less available at the higher pH. The pH of fresh SMC may also cause micronutrient deficiencies. Lucas and Davis (76) showed that manganese, boron, and zinc are much less available between pH 7 and 8. In some experiments, temporary symptoms of micronutrient deficiencies were seen in some crops. If composted SMC is used in the potting mix, there should be little problem from these deficiencies.

Because the level of ammonium in SMC is closely associated with the pH, monitoring of the pH of SMC as it ages might be a simple way to track the general ammonium level. It might be used as a way to determine when SMC was sufficiently recolonized with nitrifying bacteria to be used in potting media, however, no such simple test was effective in determining when aging SMC was suitable for use as a casing layer to grow mushrooms (129).

Future Work

Ammonium was presented in this study as a cause of the reduced plant growth which was associated with fresh SMC, but definitive proof of this was not presented. The ammonium levels observed in SMC composting in drums were extremely high. Ammonium in the medium in which the plants were actually growing was not directly monitored. The growth patterns of the plants strongly suggested that the concentration of ammonium in the fresh growth media paralleled those in the drums. Further work would be needed to prove this to be the case.

The changes in the levels of ammonium in SMC were assumed to be caused by changes in the populations of microorganisms, as reported by other researchers in similar situations (21, 29, 30, 31). Fordyce (39) examined microbial populations in mushroom compost up to the time of the final sterilization. He showed that thermophyllic actinomycetes do survive the initial pasteurization process, so it is reasonable to assume they also survive the final sterilization process. Population counts of these organisms and of Nitrosomonas and Nitrobacter would be needed to prove that the predicted changes actually occurred.

Calcium carbonate and nitrate have been shown to overcome ammonium toxicity in some crops (48, 80). The high levels of calcium which were measured in SMC are at least partly due to the gypsum (calcium sulfate) added to mushroom compost. The levels of carbonate in SMC were not measured. It would be interesting to measure levels of nitrites and nitrates in fresh SMC and in composting SMC both to see if nitrate levels are sufficient to overcome ammonium toxicity in some crops and to see their relationship to the mechanisms which have been proposed to account for changes in the ammonium levels.

While the dynamics of ammonium explained many of the problems seen in the use of SMC, they do not preclude the possibility that other undiscovered problems also exist. Some of the common symptoms of ammonium toxicity, such as reduction in growth, were seen in this experiment. Others, such as epinasty (21), were not seen. Perhaps other toxic compounds are also present. Flaig and others have shown that various phenolic compounds are formed from the decomposition of lignin and from microbial synthesis in straw (38). While phenolic compounds generally increase plant yields, through indirect effects on soil properties and through direct effects on plant metabolism (37, 67), some can act as growth inhibitors (67, 110, 111, 133).

De Roo examined the effect of fermentation residues (raw mycelial wastes) on the growth of various crops, including tomatoes (34). Some reduction in growth was seen, and De Roo showed that it was not due to the high levels of gypsum or zinc in the residues (34, 35). Perhaps a biotoxin was produced by the fungi which were grown in the material. Perhaps a biotoxin is produced by the fungi which were grown in the mushroom compost as well. Comparing the growth of plants in potting mixes containing steam sterilized SMC with that in unsterilized SMC might help answer this question.

The yield of plants in SMC which had been composted aerobically for five weeks was shown to be higher than the yield of plants in fresh SMC. The benefits of further composting were not examined. Further composting would result in continued decomposition of the material, which might result in increased problems due to high salt concentrations, but fewer problems due to shrinkage. Wuest showed that two year old SMC was better than one year old compost for use as a casing layer for mushroom growth, but he was unable to determine why (129, 130). Perhaps further composting would also lead to improved plant yields for unknown reasons.

The responses of crops to salinity vary with the species and cultivar of crop and with the specific ions present (9, 10, 15, 72, 100). Further studies, including testing the growth of other crops and different cultivars of the same crops in SMC, could be of value. Differences in plant growth due to container size and type have been reported (101, 105). Studies to test for interactions between SMC and container size or type might also be of economic benefit.

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