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I am submitting herewith a dissertation written by Hsiao-lei Sherry Wang entitled "Spent Mushroom Compost as a Soil Amendment for Vegetables." 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 AS A SOIL
AMENDMENT FOR VEGETABLES

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Hsiao-lei Sherry Wang
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DEDICATION

To my respectful parents,
Professors Fong-chi Wang and Yuan-hua Yin,
without whom I would not be here.

To my loving husband,
Kriengkrai Aphinyanaphongs,
without whom this task could not have become a reality.

To my dear son,
Yindalon,
without whom this undertaking would not be worthwhile.

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ABSTRACT

Spent mushroom compost (SMC) was obtained from Ralston Purina Mushroom Plant in Loudon, Tennessee to determine its effects as a soil amendment for growing vegetables under field conditions. Four rates (0, 2, 10, and 20 kg/m²) of SMC were applied to a Sequatchie fine sandy loam in 1981 and 1982. Yields of cabbage, cucumber, mustard, onion, radish, snap bean, spinach, and tomato were evaluated.

Spent mushroom compost application decreased the bulk density, increased the percentage of small pore space, pH, and electrical conductivity. Within the year of 1981 or 1982, the difference in the response of vegetable yield to SMC application was probably due to the difference in ability of each vegetable species to tolerate salinity. Difference in the yield response of the same vegetable species to SMC application between the two years of test period was perhaps because of the combined effects of salinity, climatic conditions, and the residual effect from the first year's application of SMC. All vegetables tested in both years had significantly increased potassium concentration, but decreased magnesium concentration in leaf tissue.

Under greenhouse conditions with adequate watering and leaching, snap bean, cucumber, radish, spinach, and tomato were grown from seed in soils amended with 0, 10, 20, 30 and 50% of SMC. The percentage of seedling emergence was not affected while the rate of

seedling emergence was delayed by the addition of SMC. Optimum seedling growth was observed at 30% or 50% of SMC. The elemental content in seedling tissue indicated a potassium and calcium and/or magnesium antagonism in ion uptake. Under greenhouse conditions with a non-leached system, vegetables grown at 50% of SMC exhibited some stunting. The increased plant growth and yield were obtained with addition of 20% to 30% of SMC.

In general, using SMC as a soil amendment was beneficial to some vegetables, but its high soluble salt content could make excessive rates or long term use harmful to plants that are sensitive to salinity.

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CHAPTER I

INTRODUCTION

Soil fertility and crop yield are interrelated. Plant nutrients in the soil become available during the process of mineral weathering and organic matter mineralization. In many soils the rate of removal of plant nutrients by crop uptake, leaching, volatilization, and immobilization exceeds the rate of release of nutrients by weathering and mineralization. A negative nutrient balance thus results unless nutrients are supplied in the form of fertilizer, organic or inorganic, to make up the difference (73). Generally the more intensive the cropping system and the higher the yields, the greater the amount of nutrients that must be applied to the soil in order to maintain soil fertility.

Organic wastes are by-products which can be cycled through soils to supply plant nutrients (99). Elevated costs of commercial inorganic fertilizer have made the application of organic wastes to cropland increasingly attractive. The application of organic materials increases the content of organic matter in the soil and thus has beneficial effects on soil physical and chemical properties. It is well documented that the incorporation of organic residues contributes increased humus content, water holding capacity, water infiltration, aeration porosity, soil aggregation; decreased soil crusting, runoff, and bulk density (4,22,33,36,48,49,68,88,113); improved soil cation exchange capacity, nutritional status, and

tilth (50,51,52,63,68,71,76). These effects are more pronounced on sandy soils than on finer textured soils. The extent of these changes is a function of the amount and nature of the organic wastes being added. Incorporation of massive amounts of organic materials will produce profound changes. Since these changes are related to plant growth and yield, directly or indirectly, they should be evaluated carefully.

Mushroom compost is a product derived from mushroom beds. After the mushrooms are harvested, the compost is unsuitable for further mushroom cultivation and is then termed "spent" (35). Spent mushroom compost is made from wheat straw composted with horse manure, peat, limestone chips, gypsum, cottonseed meal, urea, and fungal mycelia. The Ralston Purina Mushroom Plant in Lenoir City, Tennessee produces approximately 780,000 kilograms of mushrooms annually, and disposes of about 120,000 cubic meters of spent mushroom compost (60). The utilization of this locally produced waste product appears to be a promising way to improve soil properties and increase nutrient resources for vegetable crop production.

A study was conducted to determine the effects of using spent mushroom compost as a soil amendment for growing vegetable crops under field conditions. A broad category of vegetable species, two root crops (onion and radish), three leaf-stem crops (cabbage, mustard, and spinach), and three seed-fruit crops (snap bean, cucumber, and tomato) were evaluated. Spent mushroom compost was applied at four rates. The influence on soil physical and chemical

properties, plant yield responses, and elemental concentrations of plant tissue were compared among various rates of spent mushroom addition to determine potential of this waste material as a soil amendment.

Greenhouse experiments were conducted to further determine if spent mushroom compost could be used as a soil fertilizer amendment. The objectives of these studies were to determine the effects of high levels of soluble salts in spent mushroom compost on vegetable seedling emergence and growth, plant growth and development, and plant elemental uptake in a controlled environment.

CHAPTER II

REVIEW OF LITERATURE

Application of Wastes to Cropland for Disposal and Recycling Nutrients

Wastes are resources which are out of place; are by-products which are not fully utilized within the confines of production. Organic wastes are natural by-products which can be recycled in the natural cycle (99). The increasing cost of commercial inorganic fertilizers and foreseeable regulation controlling pollution from farms and industries have made waste management more important than ever.

Researchers worldwide have studied the effects of the use of various organic wastes on cropland for growing many kinds of vegetables. For example, animal manures have been used in studies with beans (87), beets (50,111,112), Chinese cabbage (18), kale (4), potatoes (4,111,112), raspberries (17), and strawberries (1). The effects of municipal wastes or refuse compost on the growth of bean (30,82), cabbage (81,115), lettuce (82), pea (82), potato (82,102), radish (45), and sugar beet (102) have been examined. Sewage sludge application has been studied in experiments with bean (14,54,58), cole crops (26,29,96,114,115), eggplant (29), lettuce (26), muskmelon (96), pepper (26,29), sweet corn (26,27,72), tomato (14,96,105,109), turnip, spinach, and pea (26). Crop residues such as leaf compost were used for container-grown plants (89). Rice straw, rice husks,

sugarcane trash, pineapple pulp, and coconut shells have been intensively studied in Asia (54).

From studies such as these, some generalizations about the effects of organic wastes can be made. The beneficial effects of organic wastes on soil physical properties include increased water infiltration, water holding capacity, water content, aeration, and permeability. Organic wastes also promote stable soil aggregates and increase rooting depth, resulting in better soil tilth and increased crop yields. Soil crusting, surface runoff, and bulk density are decreased (78) by organic waste application. After organic wastes are incorporated into the soil, the microbial decomposition results in the formation of humus. Humus provides long-range benefits such as maintaining good soil structure and increasing soil cation exchange, pH buffering and water holding capacities (13).

It is generally known that soils lacking organic matter are more likely to suffer problems arising from poor structure. This is because soil organic matter binds soil particles together into aggregates between which there are large (non-capillary) pore spaces through which air can penetrate into the soil and through which surplus water can drain away. The smaller pores (capillary) between individual soil particles are more or less filled with water when the soil is moist and air does not move freely in them (98). Capillary porosity is the sum of the volume of small pores that hold water by capillary force. These spaces are responsible for the water holding

capacity of soil. Non-capillary porosity is the sum of the volume of the large pores, which do not hold water tightly. Sandy soils and soils with low clay content frequently suffer structural problems when organic matter is below 3% (36). Soils treated with organic matter have more stable aggregates and smaller bulk density, leading to greater porosity (22,33,36,48).

Magdoff and Amadon (68) reported that the increased soil organic matter from manure application improved soil structure and porosity. Salter and Williams (88) found that organically treated soil held more available water in the surface 30cm than did untreated soil. Johnston et al. (49,51,52) reported that improvements in the physical properties of soil by the addition of farm yard manure had the largest effects on seedlings and on short-season crops when comparing many vegetable crops. They observed that organic treatment improved seedling emergence and vegetable growth, because of improved water holding capacity and diminished resistance to root growth.

Normally, improvements in soil structure are more permanent in clay soils than in sands. Johnston (50) found that organic manuring did not improve the stability of a loamy-sand at the Rothamsted Experiment Station, England. However, Williams (113) reported that long term application of farm yard manure contributed to particle stability, increased water holding capacity and decreased bulk density on a Woburn sandy soil. The large application of manure and sludge increased the cation exchange capacity of

soil (63). The use of manure as a soil amendment was also thoroughly studied in the United States by Azevedo and Stout (4). They concluded that under California's warm climate even large additions of manure can decompose rapidly, but residual organic matter derived from manures increased soil reserves of organic matter and nutrients. They also demonstrated that manure application increased soil aggregation, aggregate stability, permeability, hydraulic conductivity, water holding capacity, and provided a higher proportion of large pores in the soil.

Not only does manure affect physical changes in soil, it has supplemental benefits in improving soil chemical properties. Lund and Olson (63,76) showed that the addition of manure increased soil pH, N, P, K, Ca, and Mg. A nine year field study conducted by Meek and Donovan (71) indicated that the application of high rates of manure increased soil organic matter, soil P and K content, and water infiltration rates. Magdoff and Amadon (68) reported increased soil pH, organic matter, P, K, and Ca after 11 years of manure applications. Since animal feeds are derived from plants, an entire complement of essential plant nutrients is contained in animal manures. Therefore, manure application can affect nutrient availability, solubility, and retention in soil. Nutrients bound to the organic fractions of animal manure and residual humus can resist leaching but still be available for plant uptake. These retentive properties of organic matter are of more obvious value in soils of low clay content and low natural ion-exchange capacity (4).

In both classic Rothamsted and Woburn organic manure experiments, the long term continuous treatment with farm yard manure resulted in larger dry matter yield of sugarbeet and potatoes than could be obtained with fertilizer only (113). Johnston and Brooks (52) reported substantially increased yields of saleable produce and total dry matter for beets, carrots, potatoes and beans by the annual addition of 8, 55, 110 and 165 t/ha of peat dry matter to the soil over 15 years. A four year field experiment showed that the annual application of 35 and 70 t/ha farm yard manure increased raspberry fruit production by 11% and 20%, respectively (17). Municipal waste compost application increased yield of sweet corn (30). Increased yields of potato tubers and pea pods were also obtained by the application of municipal compost at rates of 50 to 100 tons/ha (82). A two year field study showed that sweet corn yield was increased with the application of incinerated sewage sludge (72). Plant height, shoot weight, and fruit yield of blueberries were increased by incorporation of peatmoss (94). Evidence from long term tests clearly showed that organic wastes such as animal manures can give larger yields than can be obtained with fertilizer only (68).

The application of organic wastes on cropland is not totally advantageous. Two major hazards to plants encountered from the application of organic wastes to cropland are (i) the accumulation of excess total salts such as Na, K, and NH_4 derived from manure (4) or (ii) specific microelement toxicities from elements such as

Zn, Cu, Ni, Mn, or B in sewage sludge (16,82). Additionally, certain potentially toxic microelements, such as Cd, Pb, Hg, contained in some wastes are of concern because of their hazard to animal health. The incorporation of sugarcane trash into soil under field conditions resulted in Mn toxicity in Hawaii (2).

As a result of his experience with sludge application, Haan (34) made general comments on the organic value of sludge. He stated that the most interesting effects of sewage sludge is not the direct or short term fertilizer effects, but the so-called "organic matter effect." The long term negative organic matter effects appear because of high levels of heavy metals in sewage sludge. High heavy metal contents of Cd, Mn and Zn were observed in pot grown cabbage tissue when refuse compost and sewage sludge were added (30,114). Inferior or inhibited growth and excess uptake of Zn in greenhouse grown cabbage and tomato leaves from plants grown in sewage sludge amended soil have also been reported (104,115). Multiple application of heavy rates of municipal compost has caused accumulation of potentially toxic Zn (21,70). A four year field study on the growth and metal uptake of snap beans grown on sewage sludge amended soil showed that the Cu and Zn concentration in edible tissue increased as the rates of sludge application increased from 0 to 450 mT/ha (20,30). In a greenhouse study, leaf samples from bean and tomato treated with sewage sludge extract contained toxic levels of B and excessive levels of Cu, Mo, Ni, Co, Pb, and Cd (14). Boron toxicity symptoms have also been reported in pot grown

radishes by Purves (81) and in field grown potatoes by Bergmann (5). A three year study on the effect of municipal compost at rates of 50 to 100 tons/ha on uptake of Cu, Zn and B by garden vegetables showed that bean leaves had increased levels of Cu and Zn; the increased B content caused stunting in the bean plant. Leafy vegetables, such as lettuce and spinach were found to absorb high concentrations of Cd when grown on sludge-amended pot soils (16). Because of the high uptake of heavy metals in sludge-grown vegetables, Cheung and Wong (18) suggested that sewage sludge should be used as a soil additive only for non-edible crops.

Recently Sterrett (96) and Wootten (116) both showed that sewage sludge compost of low metal content was safe to use for vegetables. Wells and Whitton (109) in New Zealand used digested sewage sludge at 0, 25, 50, 75, and 100% by volume for growing tomato and stated that content of heavy metals such as Mo, Zn, Cu, Ni, Mn, and Fe was not a significant factor affecting fruit for human consumption.

It is, therefore, the properties of the waste, the rates of their application, and the times and methods of their application that determine the beneficial or risk aspects of those wastes. The proper management of organic wastes on land is essential for protecting soils from wind and water erosion, and for preventing nutrient losses through runoff. Parr and Wilson (78) stated that efficient and effective use of waste materials renders one of the best means for maintaining soil productivity by recycling plant nutrients and by improving soil physical properties.

Spent Mushroom Compost as a Soil Amendment

One of the few available sources of "manure" in some regions today is spent mushroom compost (41). Mushroom compost is "a product derived from mushroom beds unsuitable for further mushroom cultivation" (35). After the mushrooms are harvested, the compost is termed "spent" (40).

Spent mushroom compost produced today is a well-rotted manure with about the same nutrient content as farm yard manure (12). The spent mushroom compost used in this study was made from wheat straw composted with horse manure, peat, limestone chips, gypsum, cottonseed meal, urea and fungal mycelia. It was produced at the Ralston Purina mushroom plant in Lenoir City, Tennessee, which produces approximately 780,000 kilograms of mushroom per year, and disposes of about 120,000 cubic meters of spent mushroom compost (60). The chemical analysis of spent mushroom compost from Ralston Purina Mushroom Plant in Tennessee showed that the calcium content was three times above the desired level for plant growth. Magnesium was about two times higher, potassium was about 15 times higher, and the soluble salts were about four times higher than desired level for plant growth. The value for pH was about one and one-half units too high for optimum growth of most plants (110). Therefore, in the case of salt sensitive crops, the application of large amounts of spent mushroom compost has the potential to be hazardous.

In greenhouse studies, Sprague and Marrero (95) were the first researchers to test the effect of using spent mushroom soil, which was largely composed of silt and clay, as an organic material on the physical properties of soils and plant growth. They concluded that the spent mushroom soil reduced the pore spaces and water percolation, but increased the available water holding capacity of sandy soil. In a field experiment Wang (108) reported that corn yield was increased by using 10 and 20 ton/ha of spent mushroom compost as an organic matter additive to soils in Taiwan. While he found no evidence of a difference in bulk density, he did measure a slight increase in aggregate stability and in the moisture holding capacity at 1/3 bar tension. Moisture content and percentage of organic matter were found to be the highest in 20 ton/ha waste mushroom compost treatment. Wang concluded that the increased corn yield resulted from the added nutrients of the mushroom compost.

Salinity Characteristics of Waste and Their Effect on Soil

Wastes vary greatly in salt content. The basic principles of salinity management must be considered to alleviate salinity hazards associated with applying wastes to cropland. The two hazards most often encountered in waste application to cropland are excess total salts and high levels of Na or K (22). Stewart and Meek (97) indicated that soluble salts leach more rapidly from organic wastes which have a small particle size. Monovalent cations, K and Na, are highly soluble and can be readily leached;

however, the divalent cations, Ca and Mg, are less soluble and migrate more slowly and, therefore are less rapidly leached (1,63, 97). Sewage sludge is usually low in soluble salts because many of the salts have been removed with the sewage effluent. Calcium and Mg in organic wastes are not soluble initially but are released during the decomposition process (97).

Common diagnostic criteria of saline conditions have normally been based upon the electrical conductivity (EC) of extracts from saturated soil pastes. The EC measurement takes into account the moisture retention properties as well as the soluble salt content of the soil. This measure is based upon the principle that the amount of electrical current transmitted by a salt solution under standardized conditions will increase as the salt concentration of the solution increases. The relationship between electrical conductivity and osmotic potential is described (11,107) by this approximate expression: $\text{osmotic potential (bars)} \approx -0.36 \times \text{EC (dS/m)}$. Total dissolved solids (TDS) are related to EC by the following approximation: $\text{TDS (mg/l)} \approx 0.64 \times 10^3 \times \text{EC (dS/m)}$. In general, the sum of extractable Na, K, Ca, and Mg equals approximately half of total salt content.

Solid organic waste materials usually have a good balance between monovalent and divalent ions and usually do not cause deterioration of the physical properties of the soil (97). However, an excess or unbalanced distribution of monovalent ions such as Na or K can cause the dispersion of soil particles and

therefore have an adverse effect on the soil physical properties. The effect of salts on soil properties are dependent upon soil texture. Salt addition influences the EC of sandy soil more than that of clay soils. Salts, however, are more easily leached from sandy soils. This results in a greater buildup of salinity on fine textured soils than on sandy soils from repeated annual applications of organic waste materials (97).

Effect of Salinity on Seed Germination, Emergence, and Plant Growth

Salinity, defined simply as the presence of an excessive concentration of soluble salts, suppresses plant growth (107). The most common salinity effect is a general stunting of plant growth (9,31,65,86). As salt concentration increases above a threshold level, both the growth rate and size of most plant species progressively decrease. Even though roots, which are directly exposed to salinity, absorb and retain more ions than are translocated to shoots, root growth is generally less affected by salinity than is top growth. In addition to the general stunting of plant growth, in certain plants, salinity causes specific morphological changes, including fewer and smaller leaves, darker leaves, thicker leaf cuticles, more surface wax, and earlier lignification of roots (61,65). Thicker layers of leaf surface wax cause a bluish-green cast on the leaves of crucifers. Some salt affected plants may appear normal and show no distinctive symptoms (9). Occasionally, nutritional imbalances caused by salinity can produce specific

nutrient deficiency symptoms, for example, blossom end rot of tomato caused by calcium deficiency (28).

A prime requisite for obtaining satisfactory crop yields is a full and uniform stand of plants, thus it is desirable that all seeds emerge simultaneously and as early as possible after planting. Ayers (3) first noted that a crop growing on saline soil was frequently characterized by an uneven stand and the prevalence of barren areas. He also observed that if the development of the crop was followed from the time of seeding, it was often apparent that the spotty pattern in the stand, so evident during the later stages of growth, was actually initiated at the time of germination and seedling emergence. In 1954, Richards (84) reported that accumulation of salts on the soil surface and in the upper part of the soil profile where seed germination took place could have inhibited germination and retarded emergence; the consequence was a reduced plant population and subsequently a lowered yield. Shumel and Goldberg (92) again stated that one of the problems related to salinity was retarded germination. Under field conditions any delay in the germination rate results in a reduced plant population. Salinity usually varies greatly in a salt affected fields. The variation of salinity may be so high in spots as to inhibit germination completely and cause bare spots or uneven growth of annual plants (9).

Plant sensitivity to salinity often varies with the plant growth stage (65,67). Salinity affects plants at all stages of development. Corn and rice were shown to be more sensitive during

the emergence and early seedling growth stage than during either germination or the late growth stages, including grain development (3,53,67,79). In contrast, sugar beet and safflower were shown to be relatively sensitive during germination (23,24). The salinity response of field grown tomato during germination was studied by Shalhevet and Yaron (90). They reported that in the range of 0 to about 6 mmhos/cm EC the tolerance of tomato during germination was similar to its tolerance during subsequent growth, a 25% reduction was noted at 6.4 mmhos/cm. At higher levels, about 7 mmhos/cm, tomato appeared more tolerant during germination than during subsequent growth: a 50% reduction in germination was found at 13.3 mmhos/cm as compared to a 50% yield reduction at 8 mmhos/cm.

The yield of a crop may be considered in biological as well as agricultural terms (73). Biological yield has been defined as the total production of plant material by a crop, whereas the economic yield or commercial yield takes into account only those plant organs for which particular crops are cultivated and harvested (44). Very often vegetative growth response to salinity is not a reliable guide for predicting fruit or seed production. Grain yields of rice and corn may be greatly reduced without appreciably affecting straw yield, but, seed or fiber yields of grass, barley, wheat, and cotton are decreased proportionately less than vegetative growth. For root crops, storage-root yields may be decreased much more than that of tops or fibrous roots (65).

In general, crop yields are not decreased significantly until the EC exceeds a specific critical value for each crop. This specific critical value is known as the threshold salinity level, or threshold EC, for that crop (15,65). Above the threshold level, the decreases of crop yield can be classified into three basic patterns. In the first pattern, crop yields decreased linearly with increasing EC; Francois and West (25) reported a near perfect linear decline of relative yield of celery with increasing salinity above the threshold EC of 1.8 dS/m. In the second pattern, yields approach zero asymptotically above the threshold EC; bean, onion, and pepper fall into this group. In the final basic pattern, yields decrease linearly at a rather gradual slope to a point above which the plants died and yields dropped sharply to zero (65). Relative yield can be calculated from the relation of $Y=100-Bx(EC-A)$ in which Y =relative yield, A =salinity threshold in dS/m or mmhos/cm, and B =% yield decrease per unit salinity increase (or slope). Maas and Hoffman (65) classified crop tolerance to salinity as sensitive, moderately sensitive, moderately tolerant, and tolerant. According to their classification, bean and onion are salt sensitive crops, and cabbage, cucumber, radish, spinach, and tomato are all moderately salt sensitive crops.

Most U.S. Salinity Laboratory data of plant tolerance to salinity were obtained from artificial, uniform salinity treatments imposed after seedlings were established in nonsaline plots. Their studies do not necessarily apply to germination and early seedling

growth or to crops grown under conditions of nonuniform salt distribution. The distribution of salt in the soil usually varies greatly. Salinity profiles in field soil may be rather uniform or may be highly nonuniform. Therefore, applying the data obtained from uniform salt concentration to field conditions where salinity distribution is neither uniform nor constant, requires the knowledge of plant responses to salinity that vary with space. It is believed that plants can tolerate excessive salinity levels if an adequate part of the root zone is relatively salt free (65). Popadopoulos and Rendig (80) conducted a study on greenhouse grown tomato plants to evaluate the effects of uniform and nonuniform salinization in space on plant growth and yield. They found that plants with their root systems divided and growing in containers with differentially salinized soil were less severely affected than plants with undivided root systems. In their split-root system, the reduction of root growth in the compartments with high salinity levels was compensated for by more growth of those portions of the root system in the less saline environment.

Physiological Effects of Salinity

In 1952, Ayers (3) proposed two possibilities for the effect of soil salinity on the germination of seeds: either by decreasing the ease of water uptake by seeds or by facilitating the entry of ions in sufficient amounts to be toxic resulting in a slower rate of emergence of those seeds that germinate and a subsequent decrease

in the percentage of germination. He showed that the effect of salinity in diminishing emergence percentage is most severe at a low level of soil moisture. He also found that emergence was significantly delayed by both high salinity and low soil moisture. Ayres believed that the germination and emergence responses could be explained at least in part by soil moisture stresses. The increased soil salinity caused increased soil moisture stress and resulted in longer emergence times and lower germination percentages.

Recently, Taylor et al. (100,101) proposed that the water sensitive phase of germination occurred just prior to radical emergence. They showed that tomato emergence was not affected by sowing "germinated" seed in a drying soil; but sowing dry seed under the same conditions resulted in a decrease in emergence. It was demonstrated by Harivandi (38) that as long as the soil was kept sufficiently moist, some grass seeds could be successfully germinated in sandy soils using water with high salt content. They stated that the eventual germination of seeds sown in sand after a portion of the salt was leached suggested that germination in highly saline conditions was inhibited partially by osmotic stress. Therefore, it seems reasonable to believe that salinity induced water stress can greatly affect germination.

Two possible causes of plant growth suppression by salinity are: (i) specific ion effects, and (ii) the osmotic adjustment process or low osmotic potential per se (7,9,37,55,56,66). Specific ion effects are a consequence of specific individual ions

whereas the osmotic effect are results of the decreased osmotic potential of saline root media which is dependent simply upon the concentrations of ions in solution, not specific ions.

Osmoregulation or osmotic adjustment is a process by which turgor pressure in the plant is maintained while water potential decreases. Cell growth is the most sensitive process affected by water stress, therefore maintenance of turgor or pressure potential is mandatory for cell growth. Taylor et al. (100) reported that osmotic regulation in germinated tomato seedlings appeared to be an adaptive feature during periods of water stress. They demonstrated that as water stress increased, osmotic adjustment occurred in the roots which accounted for the maintenance of turgor and growth. Abrupt decreases in osmotic potentials of root media decreased the osmotic gradient for water uptake, but such effects did not persist. After a day or two, the osmotic potentials of plant organs decreased to match the decrease in osmotic potential of the medium, and osmotic gradients are therefore not affected.

Mechanisms for osmotic adjustment vary among plant species. Plants that accumulate salts in affecting osmotic adjustment are known as euhalophytes. Plants that accumulate organic solutes rather than salts are called glycohalophytes. For example, in carrot roots, increased sucrose concentration under saline conditions provided a major component for osmotic adjustment, but in sugar beet it was salt rather than sugar concentration which increased (9). The synthesis and accumulation of organic acids is

also known as a means for osmotic adjustment (66). It is apparent that osmotic adjustment involves both the uptake and accumulation of ions and the synthesis or accumulation of organic solutes. Bernstein (6,7) reported that plants tolerant to salinity must be capable of adjusting to osmotic stress. He reported that plants could adjust to decreased osmotic potential without losing turgor. Rates of osmotic adjustment were about 1 bar/day. Since rates of uptake differ among ions, therefore affecting ionic balance, the readily absorbed monovalent cations contribute more to osmotic adjustment than divalent cations or anions.

Although mechanisms for osmotic adjustment vary among plant species, such adjustment are always made at the expense of plant growth. Thus, osmotic effects are manifested through reduced plant growth and lowered productivity (15). The growth of salt affected plants usually is impaired despite the complete osmotic adjustment and the maintenance of full turgor. Reduction in growth may be regarded as a result of the requirement for osmotic adjustment. Bernstein (9) indicated that perhaps as much respiratory activity was needed to retain the solute concentrations required for osmotic adjustment as was needed to increase them to affect osmotic adjustment. The term "salt-respiration" was used by Lundegardh (64) to describe the observed increase in respiration as salt in the medium was increased. In the presence of salt, plants reflected a change in the partitioning of energy as observed by the rise in respiration (64,83,85). Succulence was also often related to high

salinity (19,61,83). The response of plants to saline conditions is to expend energy to maintain a favorable water balance and to maintain a relatively stable ionic environment. The plant may then become energy deficient and no longer be able to supply energy for accumulating salt. The plant literally works itself to death.

Specific ion effects can result from an excess of specific ions which may be toxic to various plant physiological processes, and also from an excess concentration of specific ions which may cause nutritional disorders (15). It has been recognized since the early days of plant physiology that in saline environments the adverse effect of low external osmotic potential can be remedied by uptake of electrolytes. This uptake, however, also creates the danger of "ion excess," which has been noted, for example in boron, sodium, and chloride toxicities (32).

The major nutritional effects of salinity are associated with cation nutrition. Although imbalances in cation nutrition tend to be corrected when mixed salts are present, imbalances sometimes do occur. For example, salinity induced calcium deficiency causes blossom end rot of tomato and bell pepper, blackheart of celery, and internal browning of lettuce (28). Proportions of calcium in the medium that are adequate under nonsaline conditions become inadequate under saline conditions (9). Calcium is known to have a role in maintaining the integrity of plant cell membranes, therefore, it plays a crucial role in the regulation of the salt economy of plants and specifically in the selective transport or exclusion of

other mineral ions by plant cell membranes (57). Increasing the level of salts in the medium surrounding the roots of plants results in greater demands on the salt regulating process of plants. Therefore the role of calcium becomes even more important as the system becomes increasingly saline. Rains (83) concluded that calcium was extremely important in saline environments and influenced the response of plants to salinity. LaHaye and Epstein (57) demonstrated a definite role of calcium in increasing the tolerance of bean, a salt sensitive crop, to high salt.

Potassium has an active uptake mechanism. Of all the essential mineral cation species, potassium is the only one which can be transported against an electrochemical gradient into plant cells. The high uptake rate of potassium makes it a strong competitor with the uptake of other cation species (73). For example, as the concentration of potassium increases, the contents of sodium in barley (39), magnesium in fruit trees (74), and calcium in tomato (28) decreases.

Apparent salt tolerance may vary with soil fertility. The types of salinity-fertility interactions have been thoroughly illustrated by Bernstein (8). Crops grown on infertile soils generally have high apparent salt tolerance as compared with crops grown on fertile soils. The U.S. Salinity Laboratory lists for crop salt tolerance were obtained under optimum fertility for nonsaline conditions (65). Environmental factors such as climate also may significantly influence plant response to salinity

(42,65,75). Many crops seem less salt tolerant when grown under hot, dry conditions than under cool, humid ones. Magistad (69) found that relative yields of bean, beet, carrot, onion, and tomato were depressed more in warm than in cool climates. Hoffman and Rawling (43) also found that the salt tolerances of radish, onion, and bean plants are significantly higher when grown in cool climate than when grown under hot conditions.

CHAPTER III

MATERIALS AND METHODS

Field Experiments

Experiments were conducted in 1981 and 1982 at the Plant Science Field Laboratory, Knoxville, Tennessee, on a Sequatchie fine sandy loam. The experimental design was a randomized complete block with four treatments and three replications with individual plot size of 6M by 6M. The spent mushroom compost was applied each spring to the same plots at rates of 0, 2, 10, and 20 kg/m² (0, 10, 50, and 100 T/A). Plots did not receive supplemental irrigation in either of the two test years. Compost received from the Ralston Purina Mushroom Farm in Loudon, Tennessee was surface applied, spread evenly on plots with rakes, and then incorporated into the soil by disking. Prior to the compost application, 3.4, 3.0, and 5.6 g/m² of nitrogen, phosphorus, and potassium, respectively, were added to each plot.

Subsamples (100 g) of spent mushroom compost were weighed upon arrival, then air-dried. The moisture content of the compost was measured as the difference between weight changes before and after air-drying. Air-dried spent mushroom compost was digested by the wet ashing technique for total element content (46). Potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), molybdenum (Mo), aluminum (Al), lead (Pb), nickel (Ni), copper (Cu), and cadmium (Cd) were measured by atomic absorption

spectrophotometry with a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. Phosphorus (P) was determined on a Technicon Auto Analyzer by the molybdate-vanadate colorimetric test (47). Total nitrogen (N) content was measured on the Technicon Auto Analyzer by the indophenol colorimetric method after digestion with sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) (103).

Soil samples (0-40cm) were taken periodically each season from each treatment plot. Soil samples were taken randomly across the area of the plot, were air-dried, and were crushed with a ceramic pestle in the laboratory. Saturated paste extracts were prepared by adding deionized water to 250 g of air-dried soil (11). The pastes were allowed to equilibrate overnight, and then vacuum-filtered through Whatman No. 42 filter paper. The filtrate was analyzed for electrical conductivity (EC) by using a Soil Moisture Equipment Corporation Salinity Bridge, number 550, for pH by using an Orion Research Digital pH meter, model 701, and for Ca, Mg, and K by atomic absorption spectroscopy. Soil pore size distribution and bulk density were determined yearly on two undisturbed soil core samples per plot by the tension-table method (11).

Vegetables evaluated in 1981 were 'Scarlet Knight' radish (Raphanus sativus), 'Poinsett 76' cucumber (Cucumis sativus), 'Early Gallatin' snap bean (Phaseolus vulgaris), 'Better Boy' tomato (Lycopersicon esculentum), 'Supermarket hybrid' cabbage (Brassica oleracea var. vapitata), and 'Ebenezer' onion (Allium cepa). In 1982 'Dark Green Bloomsdale' spinach (Spinacia oleracea) and

'Tendergreen' mustard (Brassica hirta) were added as fall crops. Onions were grown from sets. Cabbages and tomatoes were grown from transplants. Radishes were planted at 50 seeds per meter of row in both spring and fall of each year. Snap beans and spinach were directly seeded at 25 seeds per meter of row. Mustards were sown at a rate of 35 seeds per meter of row. One row of each species was planted. Between row spacings were 75cm for radish, spinach, mustard, onion, cabbage, and snap bean; and 100cm for cucumber and tomato. Within row spacings were 40cm for cabbage, tomato, and cucumber; 5cm for onion, spinach, and mustard; and 3cm for radish. Recommended cultural practices were followed for each vegetable. Each crop was harvested at market maturity. Yields were taken from 5 meters of row.

Following the guidelines provided by Knott's Handbook for Vegetable Growers (62), the following plant tissue samples were collected for elemental analyses: young mature trifoliate leaves of snap bean prior to bloom, wrapper leaves of cabbage at heading, young mature leaves and petioles of tomato and cucumber at early fruit set. Plant samples were dried in a forced air oven at 60C and ground in a stainless steel Wiley Mill to pass a 2-mm mesh screen. The ground samples were stored in polyvinyl plastic bags until analyzed. Subsamples of ground tissue (1.0g) were digested with $\text{HNO}_3\text{-HClO}_4$ (46). Phosphorus was assayed by a colorimetric molybdate-vanadate method (47). Calcium, K, and Mg were analyzed by air-acetylene flame atomic absorption. Ground tissue samples

(0.5g) were digested by H_2SO_4 and H_2O_2 for N analysis via the colorimetric indophenol method (103).

The Statistical Analysis System (SAS) was used for the analysis of variance. The partitioning of treatment effects was conducted by orthogonal polynomial single degree of freedom contrast comparisons (59) to determine the linear and quadratic trends of yield responses and tissue elemental contents.

Greenhouse Experiments

Greenhouse experiments were conducted in the spring and fall of 1982. The experimental design was a randomized complete block with five treatments and three replications. The five treatments consisted of methyl bromide sterilized Sequatchie silt loam surface soil amended with fresh spent mushroom compost at 0, 10, 20, 30, and 50% by volume. Spent mushroom compost was thoroughly mixed with soil. No fertilizer was added. The treatment soil mixture was either placed in seedling flats for the emergence and young seedling growth experiment or potted in plastic pots (lined with polyethylene bags to prevent leaching) for the plant growth experiment. Each flat or pot was watered to approximate field capacity (12% moisture) before the seeding of vegetables.

The five vegetables evaluated were 'Scarlet Knight' radish, 'Poinsett 76' cucumber, 'Early Gallatin' snap bean, 'Dark Green Bloomsdale' spinach, and 'Better Boy' tomato. On March 26 (spring experiment) and October 8 (fall experiment) of 1982, 50 seeds each

of snap bean or cucumber, or 100 seeds each of radish, spinach, or tomato were directly sown in flats (26cm x 26cm x 5.5cm). Seedling flats were placed in a greenhouse and watered as needed. The number of emerged seedlings was recorded. A seedling was considered to have emerged when the cotyledons appeared above the soil surface. Four weeks after seeding of snap bean, cucumber, radish, and tomato, 5 weeks after seeding of spinach, all seedlings were cut off at the soil line and immediately weighed. Plant height was determined by folding the leaves upward and measuring the distance from the base of soil line to the tip of the highest leaf. The plants were rinsed consecutively three times with deionized water, dried in a forced air oven at 60C, and weighed. Oven-dried plant tissue was ground in a stainless steel Wiley Mill to pass a 2-mm mesh screen. One gram subsamples of ground plant tissue were digested by wet ashing techniques (46). Potassium, Ca, and Mg were analyzed by air-acetylene flame atomic absorption; phosphorus was assayed by the colorimetric molybdate-vanadate method (47). Half gram subsamples of ground plant tissue were digested with H_2SO_4 and H_2O_2 for N analysis by the colorimetric indophenol method (103).

On March 26 and October 8 of 1982, soil in polyethylene lined plastic pots was planted with 10 snap bean or 20 cucumber, radish, spinach, or tomato seeds each. Seeds were planted to a depth of about twice the average size of the seed. A pot of 22cm diameter and 20cm height (3 gallon size pot) was used for growing tomatoes; a pot of 19cm diameter and 17cm height (2 gallon size pot) was used

for growing cucumber; and a pot of 16cm diameter by 17cm height (1 gallon size pot) was used for growing spinach, bean, or radish. Pots were placed in the greenhouse and watered as needed. Three weeks after sowing, the emerged seedlings were thinned to four plants per pot of radish or spinach; one plant per pot of snap bean, cucumber or tomato. Plants were harvested at maturity.

After termination of the experiments, soil from each seedling flat or pot was air dried in the greenhouse and crushed with a pestle in the laboratory. The electrical conductivity, pH, K, Ca, and Mg concentrations of saturated paste extracts were determined as described previously.

The Statistical Analysis System (SAS) was used for the analysis of variance. The partitioning of treatment effects was conducted by orthogonal polynomial single degree of freedom contrast comparisons (59) to determine the linear and quadratic trends of yield responses and tissue element contents.

CHAPTER IV

RESULTS AND DISCUSSION OF FIELD EXPERIMENTS

Spent Mushroom Compost Analysis

Spent mushroom compost (SMC) obtained from the Ralston Purina Mushroom Farm in Loudon, Tennessee consisted of wheat straw, horse manure, peat, limestone chips, gypsum, cottonseed meal, urea, and residual fungal mycelia. The moisture contents were $46\pm 3\%$ and $41\pm 4\%$, respectively, for 1981 and 1982. Table 1 shows that the total elements in SMC were in descending order of concentration: N, Ca, K, Mg, and P, whereas the water extractable elements were, in descending order of concentration: K, Ca, and Mg. The concentration of the potentially toxic elements, Pb, Ni, Cu, Cd, and Cr, were too low to be detected by flame atomic absorption. There was a trace of Co (less than 0.5 micromoles per gram). As indicated in Table 1, the saturated paste extracts of SMC were pH of 7.4 with an electrical conductivity (EC) of 21 deciSiemen per meter (dS/m), indicating a high soluble salts content in this waste material. Traditionally, units of millimhos per centimeter (mmhos/cm) have been used to express EC; however, in order to comply with the International System of Units, the measurement of deciSiemens per meter (dS/m) will be used to express EC in this research. One dS/m equals 1 mmho/cm, which is the electrical conductivity of a solution containing approximately 640ppm total dissolved salts (11,65,107). Calculations based on these references indicated that the sum of K,

Table 1. Chemical composition of spent mushroom compost from the Ralston Purina Mushroom Farm in Loudon, Tennessee.

Element	mmol/kg Dry Weight	
	Total HNO ₃ -HClO ₄ Digested	Extractable (Saturated Paste)
Nitrogen	1,586	---
Phosphorus	168	---
Potassium	312	171
Calcium	855	45
Magnesium	280	3
EC (dS/m)	---	21
pH	---	7.4

Ca, and Mg concentrations in saturated paste extracts of SMC approximately accounted for 80-90% of soluble salt content in the extracts with EC of 21 dS/m.

Chemical and Physical Properties of Spent Mushroom Compost Amended Soil

Sequatchie fine sandy loam used in this experiment contained 1% organic matter, 62% sand, 6% coarse silt, 16% silt, and 16% clay. It had a specific gravity of 2.7 g/cm^3 and a bulk density of 1.45 g/cm^3 . The total porosity was 42% and the available water holding capacity was 0.15cm of water per cm of soil. After the incorporation of spent mushroom compost (SMC), the soil salinity (EC) in saturated paste extracts increased as the rate of SMC increased (Table 2). The average EC increased from the control plot average of 0.7 dS/m to 1.1, 3.9, and 4.8 dS/m in 1981 and to 3.1, 5.2, and 6.2 dS/m in 1982 after the incorporation of 2, 10, and 20 kg/m² of SMC, respectively. It was suggested by Albregts and Howard (1) that plants in the field were usually grown at a moisture content less than field capacity, therefore, the soil-soluble salts level in the field would have averaged more than double that found in saturated paste extracts. According to Bernstein (7), yields of many vegetables are restricted between 4-8 mmhos/cm (dS/m) of salinity. Thus, when the SMC application rate exceeded 10 kg/m² (EC then was above 4), the increased salinity could be expected to affect seed germination, emergence, and growth of salt sensitive vegetables.

Table 2. Electrical conductivity (EC) of soil saturated paste extracts as influenced by rates of spent mushroom compost, 1981 and 1982.

SMC Rate kg/m ²	Electrical Conductivity (EC) dS/m								
	1981				1982				1983
	26 Mar ^a	23 Apr ^b	25 Jun ^c	17 Aug ^d	22 Apr ^a	13 May ^b	9 Jun ^c	19 Aug ^d	15 Apr ^a
00	0.5	0.7	0.5	0.5	0.3	0.7	0.6	0.3	0.5
02	0.7	1.1	1.0	0.6	0.4	3.1	1.7	0.7	0.3
10	0.5	3.9	2.7	2.2	0.6	5.2	4.3	2.6	0.4
20	0.6	4.8	4.0	3.9	0.7	6.2	5.2	3.3	0.5

^aBefore application of spent mushroom compost.

^bAfter spent mushroom compost was incorporated into soil.

^cMidway between the spring and summer crops.

^dAt end of growing season or at seeding of fall crops.

Leaching of nutrients during and between cropping seasons was extensive (Table 2). Electrical conductivity (EC) decreased with time as the dynamics of salt uptake by plant roots and of leaching by rainfall occurred. By the end of each growing season (or before fall crop seeding), the EC value dropped considerably to levels which can be tolerated by most plants. Since the field soil was a fine sandy loam, a high rate of infiltration from rain occurred. The low levels of soluble salts in soils from SMC treated plots obtained yearly after winter rainfall (in April 1982 and 1983) indicated that the leaching had removed most soluble salts.

The increased EC in saturated paste extracts resulting from SMC application indicated the increasing total soluble salts concentration. Thus, concentrations of salts such as K, Ca, and Mg in the saturated paste extracts were expected to increase with increasing SMC rates. A significant relationship exists among K (monovalent cation), Ca, and Mg (divalent cations) in the soil (93). Since the uptake of each nutrient by plants is known to be influenced by the relative amount of other nutrients, balanced cation nutrition is important. In order to express the relationship among these three ions in soil solution, it was decided in this research to use the ratio of mmol/kg concentration of K to (Ca+Mg) which takes into account not only the absolute amount of these three elements but also the relationship among them. A high $K/(Ca+Mg)$ ratio indicates a relatively high proportion of K to Ca and Mg content, while a low $K/(Ca+Mg)$ ratio implies a relatively low proportion of K to Ca and Mg content.

The ratio of $K/(Ca+Mg)$ in the saturated paste extracts from all treatment plots was similar prior to the first application of SMC, $K/(Ca+Mg)$ averaged 0.09 (Table 3). The ratio of $K/(Ca+Mg)$ in saturated paste extracts from soil with 0, 2, 10, and 20 kg/m² SMC was 0.12, 0.22, 0.67, and 1.1 after the April 1981 application of SMC and 0.12, 0.13, 0.35, and 0.52 after the May 1982 addition of SMC, respectively. In general, the value of $K/(Ca+Mg)$ after application of SMC application was higher in 1981 than 1982 from all treatment levels. Perhaps the large amount of total calcium added in limestone chips was not water soluble in first growing season since limestone chips would dissolve only slowly. Calcium ions may also be absorbed by soil colloids or soil organisms and temporarily immobilized (93). Perhaps the decomposition of organic compounds such as wheat straw and manure in spent mushroom compost also made some calcium soluble in the second year, resulting in a greater concentration of soluble calcium being measured in the saturated paste extracts after the 1982 application of SMC. Although K and/or Mg concentration also increased in the second year, proportionally, the increase in Ca was much more evident than the increase in K and/or Mg resulting in the overall decrease of $K/(Ca+Mg)$ ratio in 1982 (Table 3).

Over the two year period, the application of SMC raised the pH of saturated paste extracts from an average of 7.2 to 7.7, 7.9, and 8.0 for 2, 10, and 20 kg/m² of SMC, respectively (Table 4). The simple liming effect from limestone chips in SMC may be the

Table 3. The K/(Ca+Mg) ratio of soil saturated paste extracts as influenced by rates of spent mushroom compost, 1981 and 1982.

SMC Rate kg/m ²	K/(Ca+Mg)					
	1981			1982		
	26 Mar ^a	23 Apr ^b	17 Aug ^c	22 Apr ^a	13 May ^b	19 Aug ^c
00	0.09	0.12	0.11	0.08	0.12	0.11
02	0.10	0.22	0.18	0.10	0.13	0.11
10	0.09	0.67	0.26	0.20	0.35	0.23
20	0.09	1.10	0.46	0.32	0.52	0.32

^aBefore application of spent mushroom compost.

^bAfter spent mushroom compost was incorporated into soil.

^cAt end of growing season or the seeding of fall crops.

Table 4. The pH of soil saturated paste extracts as influenced by rates of spent mushroom compost, 1981 and 1982.

SMC Rate kg/m ²	pH						
	1981			1982			1983
	26 Mar ^a	23 Apr ^b	17 Aug ^c	22 Apr ^a	13 May ^b	19 Aug ^c	15 Apr ^a
00	7.2	7.0	7.3	7.2	7.0	7.3	7.3
02	7.1	7.2	7.4	7.3	7.4	7.5	7.7
10	7.2	7.3	7.5	7.6	7.7	7.8	7.9
20	7.2	7.5	7.6	7.6	7.7	7.9	8.0

^aBefore application of spent mushroom compost.

^bAfter spent mushroom compost was incorporated into soil.

^cAt end of growing season or the seeding of fall crops.

cause of the increasing pH. Both Albregts and Lund (1,63) reported that Ca accumulated to a greater extent in the top 30 to 60cm of soil than did K after three annual applications of manure. The increased soil pH was attributed to the action of displacing cations, such as Ca, which caused the leaching of acid forming constituents in the soil profile. In agreement with their results, perhaps the high levels of K in spent mushroom compost were easily leached while Ca stayed in the soil system and served as the displacing cation, thus causing the increase of pH over the two years of this study.

To examine the possible changes in soil bulk density and pore size distribution from SMC application, undisturbed soil core samples were taken in March of 1982 and 1983. The straw-like property of SMC made the collection of undisturbed soil core samples immediately after the SMC was incorporated into the soil very difficult. During the growing season, the plant root distribution also could have disturbed the soil system. Thus, it was decided to collect the soil core samples after the over wintering of the SMC from one season and before the application of SMC for the coming season.

The results from the soil core sampling appear in Table 5. To increase the power of test statistics, a single degree of freedom linear contrast was used to compare the control plot with the SMC added treatment plots. The percentage of small pore space and total pore space increased with increasing rates of SMC after

Table 5. Effect of spent mushroom compost application rates on bulk density and pore size distribution of field soil.

SMC Rate kg/m ²	Bulk Density (g/cm ³)	Large Pore Space (%)	Small Pore Space (%)	Total Pore Space (%)
After 1981 SMC Application ^a				
00	1.54	10.6	31.7	42.3
02	1.55	10.7	32.2	42.8
10	1.52	11.0	33.4	44.4
20	1.49	12.3	34.5	46.8
control vs others ^c	.	NS	.	.
After 1982 SMC Application ^b				
00	1.48	9.8	31.2	41.0
02	1.48	9.4	32.7	42.1
10	1.44	8.9	33.7	42.2
20	1.43	9.2	33.8	43.0
control vs others ^c	.	NS	..	.

^aSoil core samples were collected in March 1982.

^bSoil core samples were collected in March 1983.

^cSignificant at 10% (..), 20% (.), or non-significant (NS).

the SMC applications in both 1981 and 1982. Decreased bulk density was found after the addition of SMC in both years. The change in percentage of large pore space was not significant. Decreased bulk density and increased pore space both are well noted advantages from application of organic waste material to sandy soil (4,49,51,52, 68,113). As the rate of SMC increased above 10 kg/m², the bulk density decreased. Treatment with the highest rate (20 kg/m²) of SMC clearly resulted in the lowest bulk density in both years. Bulk density decreased from the 1.54 g/cm³ in soil of the control plot to 1.49 g/cm³ after the 1981 addition of 20 kg/m² SMC, and decreased from 1.48 g/cm³ to 1.43 g/cm³ after the 1982 addition of 20 kg/m² SMC. Percentage of small pore space increased significantly from 31.7% to 34.5% and from 31.2% to 33.8% after 1981 and 1982 additions of 20 kg/m² SMC, respectively. Spent mushroom compost may be decomposed rapidly after being mixed into the soil and probably released most of the plant nutrients during the first two years. After decomposition, the residue or humus left in soil may stabilize the soil aggregates. The reduction in bulk density occurred as a result of the increase in small pore space.

To summarize, the SMC application improved some soil physical conditions. Bulk density was decreased slightly, perhaps making conditions more favorable for root growth than those present in untreated soil. The percentage of small pore space was increased significantly, therefore, the water holding capacity was increased from the capability of small pores to retain water.

The improved soil water holding capacity on SMC treated plot would be advantageous to plant growth during periods of moisture stress.

Vegetable Crop Yield Response

The data on the fresh weight yield of vegetable crops, presented in Table 6, indicate varied responses to the rates of SMC application. The cabbage yield was not significantly affected by the addition of SMC in either 1981 or 1982. Yields of onion decreased significantly with increasing rates of SMC application, while the reverse occurred with the yield of cucumber in both 1981 and 1982. Tomato yield was not significantly affected in 1981, but a significant quadratic trend was seen in 1982. The yield responses of snap bean were completely opposite in 1981 and 1982; in 1981, snap bean pod yield increased as the rates of SMC increased, however, in 1982, the yield decreased linearly as the rates of SMC increased. The equations for the regression of SMC rates on the significantly affected vegetable yield were listed in Table 7.

The yield responses may be partially explained by the salinity or EC changes following the addition of SMC. In general, cole crops such as broccoli and cabbage are more tolerant to salinity effects than other vegetable crops (7). The cabbage yield data (Table 6) is consistent with and supports that idea, since the yield was not significantly affected, even at the highest level of SMC in either year.

According to U.S. Department of Commerce local climatological data (106), 1981 was a drier and hotter year than 1982. The average

Table 6. Effect of spent mushroom compost application rates on fresh weight yield of snap bean, cabbage, cucumber, onion, and tomato in 1981 and 1982.

Year	SMC Rate kg/m ²	Fresh Weight Yield (kg) ^a				
		Snap Bean	Cabbage	Onion	Cucumber	Tomato
1981	00	0.84	7.56	7.80	16.62	12.43
	02	1.67	7.32	7.64	13.82	13.27
	10	4.01	7.6	7.26	26.86	13.04
	20	4.28	5.3	5.09	26.77	13.40
	Linear ^b	***	NS	*	*	NS
	Quadratic ^b	**	NS	NS	NS	NS
1982	00	5.50	6.24	5.33	24.59	29.19
	02	4.42	8.43	5.10	34.09	38.84
	10	3.52	7.02	5.10	42.97	49.54
	20	1.38	6.77	2.72	51.92	36.41
	Linear ^b	***	NS	***	***	NS
	Quadratic ^b	NS	NS	*	NS	***

^aBased on 5 meters of row.

^bSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

Table 7. Regression equations and coefficients of determination (r^2) for spent mushroom compost (SMC) addition to soil on vegetable yield in 1981 and 1982.

Vegetable	Equation	r^2
Snap bean 81	$0.83 + 0.463(\text{SMC}) - 0.0145(\text{SMC})^2$	0.881
Onion 81	$7.7 - 0.1(\text{SMC})$	0.567
Cucumber 81	$15.88 + 0.64(\text{SMC})$	0.489
Fall radish 81	$0.39 + 0.166(\text{SMC}) - 0.00638(\text{SMC})^2$	0.743
Snap bean 82	$5.21 - 0.18(\text{SMC})$	0.848
Onion 82	$5.17 + 0.0997(\text{SMC}) - 0.011(\text{SMC})^2$	0.877
Cucumber 82	$28.5 + 1.24(\text{SMC})$	0.812
Tomato 82	$28.6 + 3.65(\text{SMC}) - 0.168(\text{SMC})^2$	0.852
Fall radish 82	$1.0 + 0.189(\text{SMC}) - 0.00756(\text{SMC})^2$	0.739

SMC rate, 0, 2, 10, and 20 kg/m².

Yield unit, kg per 5 meters of row.

yearly precipitation for 1981 was 111.2cm (43.79 inches) while for 1982 it was 138.9cm (54.7 inches). From March to August of 1981, the average temperature was 20.3C (68.5F) and the precipitation was 55.2cm (21.72 inches); from March to August of 1982, the average temperature was 19.7C (67.4F) and the precipitation was 72.0cm (28.35 inches). It is well documented that salinity effects are more severe in a dry and hot climate than in a moist and cool environment (43,65,69,75). Therefore, the weather differences between 1981 and 1982 may explain the overall higher yield of tomato and cucumber in 1982 than in 1981 (Table 6). The yield of tomato was not significantly affected in 1981. The relationship between tomato fruit yield and SMC rate was a quadratic type of response in 1982; as the rate of SMC increased to 10 kg/m² the tomato fruit yield increased up to 49.54 kg, but, at 20 kg/m² of SMC rate, the yield decreased to 36.41 kg.

Onion and snap beans are salt sensitive vegetable crops; yield decreased of up to 50% have been reported at EC of 4 dS/m (9,15,65). High total soluble salts concentration, indicated by the high EC readings during growing season (Table 2, page 34), probably was the limiting factor on the yield of onion in both 1981 and 1982. SMC addition also had a negative effect on the yield of snap beans and spring grown radish (Table 8) in 1982. The decreased yield of snap bean in 1982 may be attributed to decreased plant stands (Table 8). In 1981 SMC was applied on March 23 and snap bean seeds were planted on May 1. There were

Table 8. Effect of spent mushroom compost application rates on fresh weight yield and plant stand of snap bean, cucumber, spring and fall grown radishes, spinach, and mustard in 1981 and 1982.

SMC Rate kg/m ²	1982 Snap Bean	1981 Cucum- ber	1982 Cucum- ber	1981 Spring Radish	1981 Fall Radish	1982 Spring Radish	1982 Fall Radish	1982 Spinach	1982 Mustard
Fresh Weight Yield (kg) ^a									
00	5.50	16.6	24.6	1.52	0.21	1.56	0.91	0.02	0.41
02	4.42	13.8	34.0	1.46	0.44	2.19	1.67	0.08	1.05
10	3.52	26.9	43.0	1.53	1.00	1.56	2.09	0.52	2.34
20	1.38	26.8	52.0	1.35	0.95	0.40	2.00	0.52	2.55
Linear ^b	***	*	***	NS	*	**	*	*	***
Quadratic ^b	NS	NS	NS	NS	*	NS	*	*	*
Plant Stand ^a									
00	71	13	12	80	76	72	100	03	22
02	54	18	17	71	99	93	122	07	23
10	59	42	18	70	121	58	140	19	43
20	34	44	16	62	120	20	151	16	29
Linear ^b	*	***	NS	NS	**	***	**	*	NS
Quadratic ^b	NS	*	NS	NS	NS	NS	NS	*	*

^aBased on 5 meters of row.

^bSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

15.4cm (6.07 inches) of precipitation in the period from March 23 to May 1, 1981, therefore, a considerable amount of soluble salts would have been leached out by May, when the snap bean seeds were sown into the soil. In addition, there were 1.96cm (0.77 inch) accumulated rainfall for the following 10 days, during which the seed germination and emergence took place. In 1982, SMC was applied on April 23 and snap beans were seeded on May 3. The total accumulated precipitation was only 4cm (1.68 inches), therefore, not as much soluble salts could have been leached out at this time as had been in 1981. The accumulated rainfall for the 10 days after sowing the snap bean seed was only 1.2cm (0.51 inch) in 1982. It was obvious that the environmental conditions under which the snap bean seeds were germinating and emerging were more favorable in 1981 than 1982. Even though the overall climatic conditions during the growing season were hotter and drier in 1981 than in 1982, the specific periods of time during which snap bean seeds germinated, emerged, and developed were different. In addition, the salinity in the saturated paste extracts after the addition of SMC was higher in 1982 than 1981 as indicated in Table 2, page 34). This higher initial EC and the dry weather conditions may have played an important role in inhibiting the snap bean seedling germination and emergence or in damaging the seedling development. This led to decreased plant stands, and consequently decreased yields. The 1982 spring planted radishes also responded in this pattern; increasing the rate of SMC beyond 2 kg/m² significantly decreased plant stands, and therefore decreased yields.

Cucumber stands increased significantly as the rates of SMC increased in 1981, however, no significant response occurred in 1982 (Table 8). In spite of the differences in the plant stands, cucumber fruit yield increased significantly in both years with increased levels of SMC. This clearly indicated that for cucumber, the number of plants did not influence the final marketable fruit yield. In 1981, SMC application may have decreased bulk density, increased nutritional content, available water holding capacity, and organic matter content to the soil system, and therefore enhanced seedling emergence and growth. Even though the cucumber stands were the same for all treatments in 1982, the total yield potential was increased as the rates of SMC increased.

The fall planted radishes, spinach and mustard, all showed the quadratic type of response (Table 8). Although the fresh weight yields of fall planted vegetables were somewhat low, the yield response to the rates of SMC addition was positive. The positive yield response of fall planted crops may be attributed to the residual effects resulting from the spring application of SMC.

To summarize, in 1981, the yields of cabbage, spring planted radish, and tomato were not significantly affected by the addition of SMC. Yield of onions was gradually decreased as the rate of SMC reached 20 kg/m^2 . Yields of cucumber and snap bean were significantly increased as the SMC rate increased.

In 1982, salinity effects prevailed, especially at the highest level of SMC application of 20 kg/m^2 . Salt sensitive

plants, such as snap bean, onion, and spring planted radish, suffered severely decreased plant stands and consequently decreased yields. Cabbage, a more salt tolerant crop, was not significantly affected by SMC addition. Within the range of SMC tested, tomato fruit yield reached a peak at 10 kg/m² of SMC, then declined as the SMC rate increased to 20 kg/m². The yield response of fall planted radishes, spinach, and mustard were similar to the quadratic trend of tomato yield. Yield of cucumber was increased linearly as the rate of SMC increased.

It seemed that within the year of 1981 or 1982, the difference in the response of vegetable yield to SMC application was mainly due to the difference in ability of each vegetable species to tolerate salinity. Difference in the yield response of the same vegetable species to SMC application between the two years of test period was probably because of the combined effects of salinity (EC), climatic conditions, and the possible residual effect from the first year's application of SMC.

Elemental Concentration in Leaf Tissue

Nutrient availability from SMC application was evaluated by analysis of N, P, K, Ca, and Mg concentrations in leaf tissue. One main feature of K is its high rate of uptake by plant tissue. Potassium, a monovalent cation, is taken up actively and is favored in comparison to other cation species such as Mg and Ca. The uptake rate of Ca is usually slower than that of K. The rate of uptake

also depends on the concentration of the individual ion species in the soil solution. It is a general rule therefore that increasing the supply of one cation species results in lowering the concentration of other cation species. This relationship is known as cation antagonism (73,74).

In 1981, for all four crops shown (Table 9), the concentration of K was significantly increased by the addition of SMC, while the concentration of Ca was not. The Mg concentration was significantly decreased in cabbage, cucumber, and snap beans. For tomato, the trend of decreasing Mg concentration could be seen but was not statistically significant. The reason for the decreased Mg concentration as the rate of SMC increased was probably an example of the classic antagonism between K and Mg. The data in Table 3, page 37, indicated the increased $K/(Ca+Mg)$ ratio in the 1981 soil saturated paste extracts as the rate of SMC increased. It is therefore reasonable to expect that the relatively high concentration of K in soil solution facilitated the uptake of K by the roots and increased the transport of K to the leaves, consequently the Mg concentration was depressed in leaf tissue resulting from the antagonism effect. The concentration of phosphorus was unaffected by the SMC application in 1981, except in cabbage.

In 1981, the incidence of blossom end rot on tomato fruit was high from plants in the plots where 20 kg/m^2 SMC was applied, even though Ca concentration in leaf tissue was not significantly affected by SMC application. In Table 3, page 37, the high $K/(Ca+Mg)$

Table 9. Effect of spent mushroom compost application rates on elemental concentration in leaf tissue of snap bean, cabbage, cucumber, and tomato in 1981 and 1982.

Vegetable	SMC Rate kg/m ²	mmol/kg									
		1981					1982				
		P	K	Ca	Mg	N	P	K	Ca	Mg	
Snap bean	00	57	478	366	169	2293	84	433	510	254	
	02	62	577	350	138	2450	81	754	608	225	
	10	71	877	328	133	2729	103	1005	738	233	
	20	84	1038	343	122	2743	116	1218	785	213	
	Linear ^a	NS	***	NS	**	**	NS	***	**	NS	
	Quadratic ^a	NS	*	NS	NS	*	NS	NS	NS	NS	
Cabbage	00	59	513	873	275	2586	106	785	728	263	
	02	68	708	760	229	3071	142	997	635	179	
	10	74	879	920	217	4193	152	1064	735	183	
	20	81	867	923	183	4050	158	1190	733	163	
	Linear ^a	**	**	NS	**	NS	**	***	NS	*	
	Quadratic ^a	NS	*	NS	NS	NS	*	NS	NS	NS	
Cucumber	00	58	174	985	796	3150	126	595	798	529	
	02	48	210	968	725	3107	145	818	820	425	
	10	52	262	945	592	3657	174	1097	815	304	
	20	52	374	935	508	3400	174	1179	830	263	
	Linear ^a	NS	***	NS	***	NS	***	***	NS	***	
	Quadratic ^a	NS	NS	NS	NS	NS	*	**	NS	*	
Tomato	00	36	431	483	216	3079	110	818	525	225	
	02	29	492	468	200	3071	132	923	465	200	
	10	29	613	473	196	3443	142	1013	415	167	
	20	36	708	460	192	3271	155	1044	433	163	
	Linear ^a	NS	***	NS	NS	NS	***	**	NS	***	
	Quadratic ^a	NS	NS	NS	NS	NS	NS	NS	NS	**	

^aSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

ratio of 1.10 in 20 kg/m² SMC treated plots in April 1981 indicated a high soluble K concentration in soil solution relative to that of Ca and Mg. Since Ca is immobilized in the leaf, the translocation can not take place from leaf to fruit (28). The resulting antagonistic effect between K and Ca, as well as the dry and hot weather, could have decreased the availability of Ca during the fruit development stage. Blossom end rot symptoms thus developed due to the deficiency of Ca that is known to be essential for stabilizing membrane integrity. On the other hand, although the EC or salinity was higher in 1982 than 1981, the K/(Ca+Mg) ratio was lower due to the proportionally higher concentration of soluble Ca in saturated paste extracts in 1982 than 1981 (Table 3, page 37). In addition to the extra soluble Ca present, the cool and wet weather in 1982 could have helped to alleviate the tomato blossom end rot problem, and therefore tomato fruit yield was increased in 1982.

In 1982, the overall trends were similar to those of 1981. Potassium concentration was significantly increased in all four crops (Table 9). With the exception of snap beans, the level of Ca in leaf tissue was not significantly affected. The increased level of Ca in the 1982 snap bean leaf tissue may be due to the proportionally higher soil solution concentration of Ca (or the lower K/(Ca+Mg) ratio as shown in Table 3, page 37) in 1982 than in 1981. The phosphorus concentration was significantly increased as the rates SMC increased in 1982. The only significant increase in nitrogen concentration was found in snap bean. The possible residual effect

of 1981 SMC application may explain the increased P and N concentration. Perhaps more P and N were available in 1982 than 1981.

To summarize, all vegetable crops tested in both 1981 and 1982 had a significantly increased potassium concentration in leaf tissue as the level of SMC increased. Magnesium content in leaf tissue decreased due to the antagonistic effect between the K and Mg uptake. The concentration of calcium and nitrogen increased significantly only in the 1982 grown snap beans.

CHAPTER V

RESULTS AND DISCUSSION OF GREENHOUSE EXPERIMENTS

Chemical Characteristics of Spent Mushroom Compost Amended Soil

The chemical composition of saturated paste extracts from greenhouse soil as affected by the addition of spent mushroom compost ranging from 0 to 50%, by volume, appears in Table 10. The pH, electrical conductivity, K, Ca, and Mg concentrations all increased as the level of SMC increased.

An interesting relationship among K, Ca, and Mg in saturated paste extracts appears in Table 10. Below 20% SMC, Ca was the predominant ion followed by Mg and K. As SMC level increased beyond 20%, the relationship among these three cations began to change, but Ca still was the dominant ion, until the level of SMC approached 50%. At 50% SMC, potassium became the predominant ion, followed by Ca; magnesium was the least of all three ions. It is generally known that the Ca concentration of the soil solution is about ten times higher than that of K (73). The control soil that had no SMC added had a Ca concentration about thirty times greater than the K concentration in saturated paste extracts (Table 10). The relationship among K, Ca, and Mg changed drastically due to the addition of SMC. Since a significant relationship exists among K, Ca, and Mg in the soil (93), an overabundance of any one or two of these ions may cause them to compete with others for uptake by plants or to exchange with others and accelerate leaching of the exchanged ions.

Table 10. The chemical characteristics of soil saturated paste extracts as influenced by various levels of spent mushroom compost addition in the greenhouse.

SMC (%)	pH	EC ^a dS/m	mmol/kg			K/(Ca+Mg)
			K	Ca	Mg	
00	6.0	0.2	0.18	5.30	1.46	0.03
10	6.3	4.9	1.92	18.35	5.13	0.09
20	6.6	8.7	7.44	29.10	8.79	0.21
30	6.7	11.3	16.10	35.05	12.04	0.37
50	7.1	17.3	50.33	39.10	16.88	1.00

^aElectrical conductivity (EC).

Seedling Emergence

Spent mushroom compost was composed of organic materials (straw, manure, etc.) and inorganic compounds (salts). The addition of organic matter to soil has been demonstrated to be beneficial to seedling emergence by improving the soil physical properties, for example decreasing bulk density, and increasing water holding capacity (48,49,52,113). However the high salt content of SMC can delay or retard seedling emergence by increasing the osmotic potential of the soil medium. Furthermore, high salts per se may also be harmful or toxic and can cause nutritional imbalances, and hence, inhibit or retard seedling growth and development. The effects of SMC levels on the seedling emergence of snap bean, cucumber, radish, tomato, and spinach appear in Table 11.

Of the five vegetable species studied, only cucumber responded differently to the addition of SMC. The initial seedling emergence percentage increased in a quadratic manner as the levels of SMC increased. From day 4 to day 7, the highest percentage of seedling emergence was observed at 20% SMC; further increases of SMC to 30% and 50% decreased the percentage of seedling emergence. As indicated in Table 11, at day 7, cucumber seedling emergence was 27, 30, 61, 48, and 34% at SMC levels of 0, 10, 20, 30, and 50%, respectively. The increased percentage and rate of cucumber emergence may be due to improved soil physical conditions such as decreased bulk density, increased aeration porosity, and increased

Table 11. Effect of level of spent mushroom compost on seedling emergence of snap bean, radish, tomato, cucumber, and spinach in the greenhouse.

SMC (%)	Emergence (%)							
	Days from Seeding							
	4	6	7	11	13	15	18	26
Snap Bean								
00	11	71	84	88	88	88	88	87
10	12	70	74	90	91	92	92	95
20	12	25	68	83	85	88	88	88
30	12	21	48	89	89	88	88	86
50	02	05	24	78	90	92	92	92
Cucumber								
00	00	03	27	73	78	83	84	82
10	13	16	30	73	79	88	89	91
20	22	42	61	78	79	80	80	82
30	10	24	48	76	79	77	76	77
50	06	10	34	76	80	83	84	82
Radish								
00	64	78	87	90	91	91	91	91
10	61	72	80	84	85	86	86	86
20	70	82	86	87	89	89	87	87
30	43	74	84	85	85	85	84	84
50	34	67	77	86	86	86	86	85
Spinach								
00	01	14	46	81	82	86	83	84
10	00	03	20	72	75	78	80	84
20	00	02	12	77	78	83	82	82
30	00	03	10	59	56	63	68	84
50	00	00	02	42	44	56	65	79
Tomato								
00	00	25	60	85	88	88	86	86
10	00	20	65	86	90	91	91	91
20	00	18	71	90	90	90	90	90
30	00	00	50	90	90	91	91	91
50	00	00	12	85	90	90	90	90

available water holding capacity, resulting from the addition of this organic compost material. It appeared that the addition of SMC at or below the level of 20% was beneficial to cucumber seedling emergence. However, above 20% SMC, the increased salinity may have played a dominate role in the retardation of cucumber seedling emergence.

With snap bean, tomato, radish, and spinach (Table 11), the addition of SMC decreased the percentage of seedling emergence during the first 7 days after seeding and therefore delayed the rate of germination. As the levels of SMC increased, the percentage of seedling emergence decreased. For example, snap bean seedling emergence at 6 days after seeding decreased from 71% to 5% when SMC levels increased from 0% to 50%. The higher the SMC level, the lower the percentage of seedling emergence.

Although the rate of seedling emergence was delayed in snap bean, tomato, radish, and spinach, it was accelerated and then delayed in cucumber by increasing SMC level, the final percentage of seedling emergence was essentially unaffected by SMC addition up to 50%. As indicated in Table 11, 13 days after seeds of snap bean, tomato, radish, or cucumber were sown and 26 days after spinach seeds were sown, the percentages of seedling emergence were unaffected by levels of SMC.

Seedling Growth

The criteria selected for measuring seedling growth response to the addition of SMC were height, fresh weight, dry weight, and

tissue elemental content. Since the control soil (no SMC added) was not fertilized, the SMC in the other treatments may have behaved as a fertilizer as well as a soil amendment. The fertilizer amendment properties of SMC were therefore examined.

As indicated previously, the percentage of final seedling emergence was not affected by SMC addition, therefore, it would be assumed that the total seedling stands in each seedling flat would also not be significantly affected by SMC addition (Table 12).

Although the numbers of seedlings that finally emerged were not affected, the heights of seedlings were significantly affected by the levels of SMC added (Table 13). Seedling heights of radish, spinach, and tomato increased linearly as the level of SMC increased to 50%. Snap bean and cucumber responded in a quadratic manner to the addition of SMC. The seedling heights increased as the SMC increased up to 30%, further increments of SMC to 50% reduced the seedling heights. Up to 30%, the application of SMC probably supplied additional nutrients and organic matter, which in turn improved soil physical conditions favoring seedling growth, thus, the positive growth response was obtained. However, with the addition of SMC beyond this level, the soil salinity increased to a point that was inhibitory to seedling growth, therefore the salinity effect overcame the fertilizer effect.

Seedling fresh weights of radish and spinach increased significantly as the level of SMC increased up to 50%. Those of snap bean, cucumber, and tomato increased significantly up to 30%, then

Table 12. Seedling stand of snap bean, cucumber, radish, spinach, and tomato as influenced by various levels of spent mushroom compost in the greenhouse.

SMC (%)	Numbers/Seedling Flat				
	Snap Bean ^a	Cucumber ^a	Radish ^a	Spinach ^b	Tomato ^a
00	46	94	82	78	93
10	45	93	93	85	90
20	47	94	83	84	92
30	45	93	87	80	94
50	45	92	86	77	85
Linear ^c	NS	NS	NS	NS	NS
Quadratic ^c	NS	NS	NS	NS	NS

^aTwenty-eight days after seeding.

^bThirty-five days after seeding.

^cNon-significant (NS).

Table 13. Seedling height, fresh weight, dry weight, and fresh weight to dry weight ratio of snap bean, cucumber, radish, spinach, and tomato as influenced by various levels of spent mushroom compost in the greenhouse.

SMC (%)	Snap Bean	Cucumber	Radish	Spinach	Tomato
Height (cm)					
00	36.0	15.3	6.8	4.4	11.3
10	38.0	22.7	8.0	6.8	15.8
20	39.5	22.8	7.8	7.0	16.9
30	41.0	27.3	8.5	9.5	20.5
50	37.0	24.0	13.5	9.8	23.3
Linear ^a	NS	*	***	*	***
Quadratic ^a	*	*	NS	NS	NS
Fresh Weight (g/Seedling)					
00	2.60	0.98	0.32	0.15	0.38
10	3.75	1.53	0.49	0.44	0.91
20	3.81	1.65	0.54	0.44	1.01
30	4.28	1.91	0.93	0.69	1.42
50	3.24	1.78	1.33	0.77	1.31
Linear ^a	NS	***	***	***	***
Quadratic ^a	**	***	NS	NS	**
Dry Weight (mg/Seedling)					
00	327	83	65	29	58
10	391	105	83	69	133
20	423	116	87	66	134
30	454	128	127	95	174
50	304	114	145	101	123
Linear ^a	NS	***	**	**	**
Quadratic ^a	***	***	NS	NS	**
Fresh Weight to Dry Weight Ratio (g Fresh Weight/g Dry Weight)					
00	7.9	11.8	4.9	5.4	6.6
10	9.6	14.5	6.0	6.3	6.9
20	9.0	14.4	6.2	6.7	7.7
30	9.4	15.1	7.3	7.3	8.2
50	10.7	15.7	9.1	7.6	10.7
Linear ^a	*	**	***	***	***
Quadratic ^a	NS	NS	NS	NS	NS

^aSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

decreased at 50%. The dry weights of seedlings reflected the same trend as did the fresh weights (Table 13).

As shown in Table 13, with all five vegetables tested, there was a significant linear response of the fresh weight to dry weight ratio to the levels of SMC. As the levels of SMC increased from 0 to 50%, there was a corresponding increase in the fresh weight to dry weight ratio. The increased fresh weight to dry weight ratio (or the decreased percentage of dry weight) implied an increase in succulence. Increased succulence, or decreased dry matter production, is often related to increasing salinity (19,61,80,83). Under saline conditions, plant turgor pressure is maintained through an osmotic adjustment process. Osmotic adjustment usually occurs at the expense of growth; the decreased dry matter production may have resulted from the expenditure of energy for maintaining a stable ionic environment (15).

Elemental Concentrations in Seedlings

Nitrogen, P, K, Ca, and Mg concentrations in seedlings were evaluated to determine the effect of SMC addition on the nutritional content of vegetables. The increase in nitrogen content of seedlings grown on SMC suggested that it is a good source of nitrogen (Table 14). With the exception of spinach, the concentration of nitrogen in seedling tissue of all species increased as the level of SMC increased. This was probably due to the state of decomposition and the readily available N in this compost material.

Table 14. Nitrogen, phosphorus, potassium, calcium, and magnesium concentrations in seedlings of snap bean, cucumber, radish, spinach, and tomato as influenced by various levels of spent mushroom compost in the greenhouse.

SMC (%)	Snap Bean	Cucumber	Radish	Spinach	Tomato
Nitrogen (mmol/kg)					
00	1743	1171	921	2000	985
10	1657	1128	950	1136	679
20	1771	1557	1057	893	614
30	1857	1843	1207	1193	879
50	2136	2386	1700	535	1800
Linear ^a	**	*	***	NS	***
Quadratic ^a	NS	NS	NS	NS	***
Phosphorus (mmol/kg)					
00	388	379	210	32	117
10	419	476	453	143	296
20	422	497	468	158	384
30	444	471	467	122	376
50	471	471	447	90	373
Linear ^a	*	*	**	NS	***
Quadratic ^a	NS	*	*	**	***
Potassium (mmol/kg)					
00	444	326	503	490	656
10	810	1074	746	1313	813
20	877	1420	805	1421	987
30	936	1287	885	1462	1123
50	987	1320	1262	1503	1421
Linear ^a	***	**	***	**	***
Quadratic ^a	**	**	NS	**	NS
Calcium (mmol/kg)					
00	380	505	728	535	768
10	388	350	605	293	390
20	385	337	610	243	383
30	370	350	483	205	378
50	295	365	410	185	358
Linear ^a	***	*	*	***	*
Quadratic ^a	**	*	NS	**	**
Magnesium (mmol/kg)					
00	150	545	321	479	415
10	142	283	208	192	146
20	138	258	208	246	140
30	146	267	192	200	125
50	150	292	213	233	163
Control vs Other ^a	NS	***	*	*	*

^aSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

The concentration of K also increased significantly in seedlings of all five vegetable species as the levels of SMC increased (Table 14). This result can be attributed to the increased concentration of K in soil solution by SMC addition, as well as the "luxury consumption" characteristics of K in crop uptake. The ionic imbalance which resulted from the antagonism between the monovalent K and divalent Ca uptake in seedling roots was the cause of significantly decreased Ca concentration in the seedling tissue of all species as the level of SMC increased (Table 14). The Mg concentration was also significantly depressed in cucumber, radish, spinach, and tomato when SMC was added, however the decrease of Mg concentration was not in a dose responsive manner to the levels of SMC (Table 14). It appeared that even a slight addition of SMC (10%), considerably decreased the Mg content in seedling tissue. Magnesium and Ca competition can occur in a highly limed soil (73). The excess K supplied by SMC addition can also induce an antagonistic effect between K and Mg uptake. Therefore, the obvious decrease of Mg content in seedling tissue was probably due to the competition between K and Mg for uptake, as well as the competition between Ca and Mg for uptake.

Spent mushroom compost seemed to be a good source of P for snap bean, since a significant linear increase of P concentration in seedling tissue was observed (Table 14). It is known that P is the most immobile of the primary plant nutrients in soil, therefore its uptake is very much dependent upon the development of the root

system (73). In addition, rate of P uptake is also pH dependent: the higher the pH, the lower the P uptake. The significant quadratic response of P concentration in seedling tissues of cucumber, radish, spinach, and tomato to the addition of SMC was observed. Below the level of 20%, SMC addition to soil probably supplied extra P to seedlings of cucumber, radish, spinach, and tomato, therefore P concentration in tissue increased. At 30% and 50% of SMC, the increased salinity probably limited the growth and development of seedling root systems. Increased soil pH may also have decreased the availability and rate of P uptake, thereby decreasing the P concentration in seedling tissue.

Chemical Characteristics of Spent Mushroom Compost Amended Soil after Seedling Growth

The pH values and electrical conductivities of the SMC treated soil after vegetable seedlings were grown for 4 weeks and harvested appear in Table 15. The increased pH with increasing levels of SMC reflects the high Ca content in SMC. The limestone chips in SMC had a liming effect, therefore the more SMC added the higher buffering capacity for hydrogen ions (Table 15). Reasons for the overall increases of about one unit of pH from any addition of SMC after seedlings of all species were harvested were probably because of the liming property of limestone chips in SMC and the possible release of Ca through organic matter decomposition.

Due to leaching and ion uptake, the EC decreased considerably as expected after growing seedlings (Table 15). Despite root uptake

Table 15. Values of pH and electrical conductivity of saturated paste extracts from spent mushroom compost treated soils before and after growing snap bean, cucumber, radish, spinach, and tomato seedlings in the greenhouse.

SMC (%)	Before	After Snap Bean	After Cucumber	After Radish	After Spinach	After Tomato
pH(-log[H ⁺]) ^a						
00	6.0	5.4	5.4	5.5	5.6	5.4
10	6.3	7.2	7.3	7.2	7.2	7.3
20	6.6	7.6	7.6	7.5	7.5	7.5
30	6.7	7.7	7.7	7.7	7.6	7.6
50	7.1	8.0	7.8	7.8	7.8	7.8
Electrical Conductivity (dS/m) ^a						
00	0.2	0.1	0.1	0.1	0.1	0.1
10	4.9	3.2	3.6	4.2	4.1	3.8
20	8.7	3.9	4.0	4.3	4.8	4.4
30	11.3	4.5	5.3	5.0	5.6	5.2
50	17.3	6.5	8.6	7.6	9.5	8.2

^aBased on pooled soil samples.

and leaching, the EC in saturated paste extracts after the termination of seedling growth experiments still showed a rather high soil salinity. Electrical conductivity was 3.8, 4.4, 5.2, and 8.2 dS/m at 10, 20, 30, and 50% of SMC after growing tomato seedlings, respectively. According to Bernstein (7), EC of more than 4 dS/m decreased germination, emergence, and yield of vegetable crops. The seedling emergence data (Table 11, page 57) showed only a delay in rate not an inhibition of seedling emergence within the ranges of 10 to 50% SMC. The results of seedling growth experiments (Table 13, page 61) indicated that the adverse effects were not observed until 50% SMC. The apparent higher crop tolerance to salinity in this greenhouse study may be because no extra fertilizers were added to any treatment, therefore, under the infertile soil conditions, salinity tolerance was increased as was indicated by Bernstein (8). The salinity effects may also have been alleviated by the constant supply of water to the plants in the controlled greenhouse environment. Therefore, water stress induced by high salinity may have been relieved by the favorable watering regime. This is in agreement with the results of others who have reported that even at high salinity levels, seedling emergence and growth can still occur if enough moisture is supplied (38, 80).

The preceding experiments on seedling emergence, growth, and development were designed to study the short term effects of SMC application under greenhouse conditions in an open drainage system which allowed the leaching of nutrients in soil media through watering.

Plant Growth, Development, and Appearance

Under greenhouse conditions, the response of plant growth to various levels of SMC addition in a closed drainage system where no leaching of salts from the soil media could occur through watering were also evaluated. At the beginning of the experiment, soil pH was 6.0, 6.3, 6.6, 6.7, and 7.1 and electrical conductivity was 0.2, 4.9, 8.7, 11.3, and 17.3 dS/m at 0, 10, 20, 30, and 50% of SMC, respectively (Table 16). The values in Table 16 indicated the near neutral pH of SMC added soil media throughout the experimental period. Since the pots were lined with polyethylene bags, no nutrient loss due to leaching occurred. The slight decrease in electrical conductivity after growing plants was mainly the result of the uptake of salts by the plant roots. Tomato and cucumber were grown in pots for 12 weeks; snap bean, radish, and spinach were grown in pots for 8 weeks. The relative amount of plant growth was different among the vegetable species. For example tomato and cucumber had more total net growth than others. Therefore, a greater decrease in EC was expected from the pots in which tomato and cucumber were grown than in others. A relatively high EC was observed throughout the duration of the experiment.

Since there was no fertilizer added to the soil, the addition of SMC supplied extra nutrients and organic matter. The organic properties of SMC were expected to improve the soil physical properties. The slow decomposition of SMC provided extra nitrogen and other plant nutrients. However, the high salinity resulted

Table 16. Values of pH and electrical conductivity of soil saturated paste extracts from spent mushroom compost treated soils before and after growing snap bean, cucumber, radish, spinach, and tomato in pots under non-leached conditions in the greenhouse.

SMC (%)	Before	After Snap Bean	After Cucumber	After Radish	After Spinach	After Tomato
pH(-log[H ⁺]) ^a						
00	6.0	6.0	6.4	6.0	6.3	6.3
10	6.3	6.1	7.0	6.1	6.2	6.9
20	6.6	6.8	7.1	6.8	6.7	7.0
30	6.7	7.0	7.3	6.6	6.8	7.2
50	7.1	7.4	7.5	7.2	7.3	7.6
Electrical Conductivity (dS/m) ^a						
00	0.2	0.1	0.1	0.1	0.2	0.2
10	4.9	3.1	3.2	2.2	2.7	3.9
20	8.7	5.3	4.3	3.9	5.1	4.5
30	11.3	7.4	5.1	6.2	7.3	5.2
50	17.3	13.5	9.7	13.6	16.0	9.7

^aBased on pooled soil samples.

from the addition of SMC at high rates (above 30%) was probably the main cause of depressed growth when applied, particularly, under unleached conditions.

Certain visual observations on the growth and development of various vegetables were noted. Six weeks after seeding, snap bean plants grown in 30% and 50% SMC showed a delayed rate of blooming. Perhaps this was due to the delayed rate of seedling emergence at the high salinity level induced by the addition of SMC. The root development of radish occurred first in the 20% SMC treatment. Ten weeks after seeding, cucumber plants grown in 30% and 50% SMC showed a progressively darker green color than those grown at lower levels of SMC. Plants in control pots showed symptoms of nutrient deficiency. This was expected since no fertilizer was added to the control treatment. The extra nitrogen that was slowly released from SMC decomposition was available to plants in 30% and 50% SMC, and delayed leaf senescence. Six weeks after seeding, tomato plants in the control pot showed symptoms of P deficiency (small darkish green leaves with a purplish veination), as well as symptoms of nitrogen deficiency (chlorosis of older leaves) due to lack of fertilizer additions in the control pots. Tomato plants grown in 30% SMC had healthy, green leaves probably due to the availability of N through decomposition of SMC. At 50% SMC, tomato plants suffered some stunting because of high salinity.

With the exception of snap bean, the height of plants appeared to have reached a maximum at 30% SMC. Further increase to

50% resulted in significant reductions in plant height (Table 17). Plant weight increased significantly as the level of SMC increased up to 30%; further increases to 50% decreased the fresh plant weight as it did plant height (Table 17). The yield of snap bean pods and radish roots in the greenhouse appeared to peak at 20% SMC; further increments of SMC to 30% and 50% decreased production significantly (Table 18). Spinach leaf and cucumber fruit yield reached a maximum at 30%, then, decreased at 50% of SMC. Tomato fruit yield decreased linearly from 10% to 50% of SMC. No fruit yields from control pots of cucumber and tomato indicated that plant growth was too poor under the infertile conditions to produce fruit of these crops.

Table 17. Height and fresh weight of pot grown snap bean, cucumber, radish, spinach, and tomato as influenced by various levels of spent mushroom compost under non-leached condition in the greenhouse.

SMC (%)	Snap Bean	Cucumber	Radish	Spinach	Tomato
Height (cm)					
00	27.2	41.0	13.0	4.6	67.9
10	40.7	153.3	17.3	11.9	81.8
20	37.8	135.7	18.5	13.5	87.0
30	39.2	167.5	18.9	16.0	92.6
50	42.7	141.8	14.9	7.0	65.3
Linear ^a	**	*	NS	**	NS
Quadratic ^a	NS	*	***	***	**
Fresh Weight (g/Plant)					
00	8.6	12.8	3.4	0.2	55.7
10	49.4	70.6	6.5	4.9	129.1
20	54.4	95.6	8.9	8.6	173.8
30	60.0	127.9	10.2	10.1	253.3
50	53.0	96.6	5.5	2.3	93.6
Linear ^a	***	***	**	**	NS
Quadratic ^a	**	**	**	***	***

^aSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

Table 18. Fresh weight yield of pot grown snap bean, radish, cucumber, tomato, and spinach as influenced by various levels of spent mushrooms compost under non-leached condition in the greenhouse.

SMC (%)	Snap Bean Pod	Radish Root	Cucumber Fruit	Tomato Fruit	Spinach Leaf
Fresh Weight (g/Plant)					
00	3.4	5.2	00	000	4.6
10	27.8	15.6	88.2	162.2	11.9
20	33.6	20.2	92.4	151.7	13.5
30	27.1	19.1	250.1	145.2	16.0
50	17.3	6.7	85.6	32.5	7.0
Linear ^a	NS	NS	*	**	**
Quadratic ^a	***	***	*	NS	***

^aSignificant at 0.1% (***), 1% (**), 5% (*), or non-significant (NS).

CHAPTER VI

SUMMARY AND CONCLUSIONS

The use of spent mushroom compost (SMC) as a soil amendment for growing vegetables under field conditions was studied. Four rates (0, 2, 10, and 20 kg/m²) of SMA application were used to determine their effects on soil physical and chemical properties, crop yield responses, and tissue elemental contents. Five levels of SMC (0, 10, 20, 30, and 50%) were used in greenhouse experiments to determine their effects on seedling emergence, seedling growth, elemental content, and plant growth and development.

Results from two years of field experiments indicated that the increased organic matter from the application of SMC improved certain soil properties. For instance, the decreased bulk density should facilitate root proliferation, and the increased small pore space should increase available water holding capacity, both of which are advantageous to seed germination, seedling emergence, seedling growth, and plant growth. The pH of treated plots increased considerably after two years of SMC application. With SMC application, the routine liming of vegetable soils probably would be unnecessary. Spent mushroom compost functioned somewhat as a fertilizer and supplied some plant nutrients. It appears that the SMC as a soil amendment can be beneficial to some vegetable crops, but its high soluble salts content could make excessive rates or long term usage harmful to plants that are sensitive to

salinity. Within the range of SMC rates tested in this research, 10 kg/m² of SMC application for two years seemed to produce a satisfactory yield response for the vegetable crops studied and would probably be sufficient for production of most vegetable crops.

Because of the high levels of soluble salts, especially K, in SMC, negative effects could result from its repeated or excessive use. For example, the well known physiological disorder of tomato fruit, blossom end rot, occurred as a result of SMC application, because a calcium deficiency was induced by the antagonism between K and Ca uptake. Excessive K present in SMC may also have the potential of causing Mg deficiency in plants, since high levels of K also restrict Mg uptake by plants. Besides the K and Mg antagonism, there is also the possibility of competition between Ca and Mg since SMC also contains high concentrations of Ca. For all vegetables tested, the elemental concentration of leaf tissue indicated that the K concentration increased significantly as the rate of SMC increased. Magnesium concentration decreased, as expected, because of antagonistic effects.

The results of the greenhouse experiments lead to some generalized conclusions. The applications of SMC ranging from 0 to 50%, by volume, did not affect the final percentage of seedling emergence, but did delay the rate of seedling emergence. Seedling growth of radish and spinach increased linearly up to 50%, with no adverse effects from salinity on growth being observed. Seedling growth of cucumber, snap bean, and tomato increased quadratically

up to 30% with adverse effects on growth probably from salinity being observed at 50% SMC. The elemental content in seedling tissue indicated a K and Ca and/or Mg antagonism in root uptake.

Under greenhouse conditions with a non-leached system, vegetable growth and development in pits fertilized with 0 to 50% SMC exhibited some stunting at the 50% level. The combined effects of high salinity as well as the excessively high levels of K were perhaps the cause of the depression in growth and yield at 50% SMC. In general, increased plant growth and yield were obtained with additions of 20% to 30% SMC. The limiting factor in the use of SMC as a fertilizer appeared to be its high soluble salt content. Under conditions with no provision for adequate leaching, the nonspecific effect of total soluble salt caused the stunting of plants; the specific antagonistic effect of potassium could have induced the deficiency of Ca and/or Mg in plants.

The overall general conclusions with respect to SMC application are as follows:

1. It improves certain physical conditions of the soil.
2. It neutralizes soil acidity and therefore serves as a liming material.
3. It provides plant nutrients such as N, P, K, Ca, and Mg for plant growth and production.
4. It increases soil salinity for a short time following application and therefore may inhibit the growth and development of salt sensitive crops, especially in situations where leaching is restricted.

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