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Spent Mushroom Compost as a Soil Amendment for Vegetables

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Abstract. **Spent mushroom compost (SMC) was used as a soil amendment for field-grown vegetables. Four rates (0, 2, 10, or 20 kg/m²) of SMC were applied to a fine sandy loam in 1981 and 1982. SMC application decreased bulk density and increased the percentage of small pore space, pH, and electrical conductivity. Yields of cucumber and snap bean increased and yield of onion decreased, as the rate of SMC increased in 1981. Yields of cabbage, radish, and tomato were not affected significantly by the addition of SMC. Tomato yield was maximum at 10 kg/m², then declined as SMC was increased to 20 kg/m² in 1982. Yield responses of cucumber, fall-planted radish, spinach, and mustard were similar to that of tomato. Salt sensitive crops, such as snap bean, onion, and spring-planted radish, suffered severely reduced plant stands and, consequently, decreased yields. Yield of cabbage, a relatively salt tolerant crop, was not affected by SMC. Concentrations of K in all leaf tissues increased significantly as the level of SMC increased. Mg content in leaf tissue decreased.**

The incorporation of organic materials into soils increases water holding capacity, water infiltration, and aeration porosity, decreases crusting and bulk density, and improves cation exchange capacity, tilth, and nutritional status (1, 6, 11, 13, 15, 17). Two major hazards to plants encountered from the application of organic wastes to soil are the accumulation of excess total salts (1) and specific microelement toxicities (5, 21).

Spent mushroom compost (SMC), derived from harvested mushroom beds and unsuitable for further mushroom cultivation, has been used as a soil amendment (24). The utilization of this waste product seems to be a promising way to improve soil properties and increase nutrient resources for vegetable crop production. This study was conducted to determine the effects of SMC as a field soil amendment for growing vegetable crops under field conditions.

Materials and Methods

Experiments were conducted in 1981 and 1982 at the Plant Sciences Field Laboratory, Knoxville, Tennessee, on a Statler fine sandy loam (Humic Hapludit). This soil contained 1% organic matter, 62% sand, 6% coarse silt, 16% silt, and 16% clay. Its available water holding capacity was 0.15 cm of water/cm of soil. The experimental design was a randomized complete block with 4 treatments and 3 replications with individual plot sizes of 6 m × 6 m. SMC received from the Ralston Purina Mushroom Farm (Loudon, Tenn.) consisted of wheat straw, horse manure, peat, limestone chips, gypsum, cottonseed meal, urea, and residual fungal mycelia. It was applied each spring to the same plots at rates of 0, 2, 10, or 20 kg/m² (wet weight). The moisture content of SMC on a wet weight basis was 46% ± 3% and 41% ± 4% for 1981 and 1982, respectively. The compost was incorporated 15 cm into the soil by disking. Prior to the compost application, 3.4N–3.0P–5.6K g/m² were added to each plot. Plots did not receive supplemental irrigation.

Soil samples (0–40 cm) were collected during each growing season from each treatment plot and pooled by blocks. Saturated paste extracts were prepared by adding deionized water to 250 g of air-dried soil, equilibrating overnight, and then vacuum-extracting through Whatman No. 42 filter paper. The filtrate was analyzed for electrical conductivity (EC) and pH immediately after extraction, and, subsequently, Ca, Mg, and K concentrations were determined by atomic absorption spectroscopy. Soil pore size distribution and bulk density were determined by the tension-table method (23) on 2 undisturbed soil core samples per plot, collected after the over-wintering of SMC applied one year and before the application for the coming year.

Vegetables evaluated in 1981 were 'Scarlet Knight' radish (*Raphanus sativus* L.), 'Poinsett 76' cucumber (*Cucumis sativus* L.), 'Early Gallatin' snap bean (*Phaseolus vulgaris* L.), 'Better Boy' tomato (*Lycopersicon esculentum* Mill.), 'Supermarket Hybrid' cabbage (*Brassica oleracea* var *capitata* L.), and 'Ebenezer' onion (*Allium cepa* L.). 'Dark Green Bloomsdale' spinach (*Spinacia oleracea* L.) and 'Tendergreen' mustard (*Brassica juncea* L.) were added as fall crops in 1982. Onions were grown from sets, and cabbage and tomato were grown from transplants. Radish was directly seeded at a rate of 50 seeds per meter of row in the spring and fall of each year. Snap bean and spinach were planted at 25 seeds per meter of row, and mustard was sown at 35 seeds per meter of row. Row spacings were 75 cm for radish, spinach, mustard, onion, cabbage, and snap bean, and 100 cm for cucumber and tomato. Spacings within rows were 40 cm for cabbage, tomato, and cucumber, 5 cm for onion, spinach, and mustard, and 3 cm for radish. Recommended cultural practices were followed for each vegetable (12). Each crop was harvested at market maturity, and yields were taken from 5 m of row.

The following plant tissue samples were collected for elemental analysis: young mature trifoliate leaves of snap bean prior to bloom, wrapper leaves of cabbage at heading, and young mature leaves and petioles of tomato and cucumber at early fruit set. Plant samples were dried in a forced air oven at 60°C and ground in a stainless steel Wiley mill to pass a 2-mm mesh screen. Subsamples of ground tissue (1 g) were digested with HNO_3-$HClO_4$ (9) after which P was measured by molybdate-vanadate colorimetry (10), and Ca, K, and Mg were analyzed by flame atomic absorption. Ground tissue samples (0.5 g) were

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digested in H_2SO_4 and H_2O_2 for N analysis via the colorimetric indophenol method (22).

The Statistical Analysis System (SAS) was used for the analysis of variance. Partitioning of treatment effects was conducted by polynomial, single degree of freedom contrasts to determine the linear and quadratic trends of yield responses and tissue elemental concentrations to SMC applications.

Results and Discussion

Chemical and physical properties of SMC amended soil. After the application of 2, 10, and 20 kg/m^2 of SMC, the 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, respectively (Table 1). According to Bernstein (3), yields of many vegetables are restricted between 4 and 8 dS/m of salinity. Thus, when the SMC application rate exceeded 10 kg/m^2 (EC then was above 4), the increased salinity would be expected to affect the germination, emergence, growth, and yield of salt-sensitive vegetables. EC decreased during and between cropping seasons as a result of nutrient uptake by plant roots and of salt leaching by rainfall. By August of each year, EC values had dropped to levels tolerated by most crops. After winter rainfall, EC values had dropped to pretreatment levels.

The pH of saturated paste extracts increased with increasing rates of SMC and continued to rise over time (Table 1). In April of 1983, after 2 years of SMC applications, the pH had risen from an average of 7.3 for the control plot to 7.7, 7.9, and 8.0 for 2, 10, and 20 kg/m^2 of SMC, respectively. The liming effect from the limestone chips in SMC was the probable cause for the increase in pH.

Variations in soil cations between treatments and over growing seasons were largely a consequence of the cation content of SMC, and of the relationship of K^+ to Ca^{++} and Mg^{++}. Since the uptake of these nutrients is influenced by the relative levels of other nutrients (2, 3), balanced cation nutrition is important. Therefore, soil test data are expressed as the mole ratio of K/(Ca + Mg) to define variation in monovalent vs. divalent cations.

The mole ratio of K/(Ca + Mg) from all treatment plots prior to the 1st application of SMC averaged 0.09 (Table 1). The ratios of K/(Ca + Mg) rose as increasing rates of SMC were applied to the soil, but the ratios were higher in 1981 than in 1982 at all treatment levels. Perhaps the slow dissolving of the limestone chips (the major source of Ca in SMC) and the decomposing of organic compounds, such as straw and manure in SMC, contributed to the increased concentration of soluble Ca measured after the 2nd application of SMC. Although concentrations of K and Mg also increased in the 2nd year, the increase in Ca was proportionally greater than the increase in K and Mg, resulting in the overall decreases in K/(Ca + Mg).

No consistent trends were found in the percentage of large pore space in soil due to the application of SMC. Small pore space increased from an average of 31% in the control to 34% in plots with 20 kg/m^2 of SMC, and bulk density decreased from an average of 1.51 to 1.46 after the addition of SMC. The organic matter content of SMC probably contributed to the changes in small pore space and bulk density. Stable aggregates and reduced bulk densities, leading to increased porosity, have been associated with soils treated with organic matter (6, 7).

Yield responses of vegetable crops. Crops responded differently to the addition of SMC (Tables 2, 3), and these differences may be explained partially by salinity (or EC) changes following the addition of SMC. Cabbage yields were not influenced significantly by the addition of SMC (Table 2); in general, cole crops are more tolerant than other vegetable crops to salinity effects (2). Onion yields decreased as the rate of SMC increased, probably due to the increased total soluble salts. Onion is a salt-sensitive vegetable, and yield decreases to 50% have been reported at an EC of 4 dS/m (3, 4, 14). Yields of cucumber and tomato increased with the addition of SMC, but the yields were higher overall in 1982 than in 1981. This difference may have been due to weather conditions. Salinity effects are more severe in dry and hot climates than in moist and cool ones (8, 14, 16, 20). In Knoxville, Tenn., the average temperature was 20.3°C from March to August of 1981 vs. 19.7° in 1982. The precipitation was 55 cm from March to August of 1981 vs. 72 cm in 1982.

SMC had no effect on spring-grown radishes in 1981, but SMC reduced root weight and plant stands in 1982 (Table 3). Even though the growing season was hotter and drier overall in 1981 than in 1982, the specific period of time during which spring-grown radish seeds germinated, emerged, and developed

Table 1. Electrical conductivity (EC), pH, and K/(Ca + Mg) mole ratio of soil saturated paste extracts as influenced by rates of spent mushroom compost applications in 1981 and 1982.

Soil measurement	SMC rate (kg/m^2)	1981 26 Mar.[z]	1981 23 Apr.[y]	1981 17 Aug.[x]	1982 22 Apr.[z]	1982 13 May[y]	1982 19 Aug.[x]
EC (dS/m):	00	0.5	0.7	0.5	0.3	0.7	0.5
	02	0.7	1.1	0.6	0.4	3.1	0.7
	10	0.5	3.9	2.2	0.6	5.2	2.6
	20	0.6	4.8	3.9	0.7	6.2	3.3
pH:	00	7.2	7.0	7.3	7.2	7.0	7.3
	02	7.1	7.2	7.4	7.3	7.4	7.5
	10	7.2	7.3	7.5	7.6	7.7	7.8
	20	7.2	7.5	7.6	7.6	7.7	7.9
K/(Ca + Mg):	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

[z]Before application of spent mushroom compost.
[y]After incorporation of spent mushroom compost into soil.
[x]At end of growing season or the seeding of fall crops.

Table 2. Effect of spent mushroom compost application rates on fresh weight of snap bean, cabbage, cucumber, onion, and tomato in 1981 and 1982.

		Fresh Weight (kg)[z]				
Year	SMC rate (kg/m^2)	Snap Bean pod	Cabbage head	Onion bulb	Cucumber fruit	Tomato fruit
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	7.60	7.26	26.86	13.04
	20	4.28	5.30	5.09	26.77	13.40
	Linear[y]	***	NS	*	*	NS
	Quadratic[y]	**	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[y]	***	NS	***	***	NS
	Quadratic[y]	NS	NS	*	NS	***

[z]Based on 5 m of row.
[y]Significant at 0.1% (***), 1% (**), 5% (*), or nonsignificant (NS).

Table 3. Effect of spent mushroom compost application rates on fresh weight and plant stand of spring and fall-grown radish and fall-grown spinach and mustard in 1981 and 1982.

SMC rate	Spring radish		Fall radish		Spinach	Mustard
(kg/m^2)	1981	1982	1981	1982	1982	1982
			Fresh wt (kg)[z]			
00	1.52	1.56	0.21	0.91	0.02	0.41
02	1.46	2.19	0.44	1.67	0.08	1.05
10	1.53	1.56	1.00	2.09	0.52	2.34
20	1.35	0.40	0.95	2.00	0.52	2.55
Linear[y]	NS	**	*	*	*	***
Quadratic[y]	NS	NS	*	*	*	*
			Plant stand[z]			
00	80	72	76	100	03	22
02	71	93	99	122	07	23
10	70	58	121	140	19	43
20	62	20	120	151	16	29
Linear[y]	NS	***	**	**	*	NS
Quadratic[y]	NS	NS	NS	NS	*	*

[z]Based on root weight of radish and leaf weight of spinach and mustard harvested from 5 m of row.
[y]Significant at 0.1% (***), 1% (**), 5% (*), or nonsignificant (NS).

was more favorable in 1981 than in 1982. By the time the radish seeds were sown, more soluble salts would have been leached out by accumulated precipitation in 1981 than in 1982, and there was more rainfall in 1981 than in 1982 during the 10 days following sowing. In addition, EC, after the addition of SMC, was lower in 1981 than in 1982 (Table 1). High initial salinity along with the dry soil and weather conditions in 1982 probably led to the significantly decreased plant stands, which consequently decreased yields. The same factors probably contributed to snap bean yields, which increased in 1981 and decreased in 1982 (Table 2).

Radish, spinach, and mustard all showed a quadratic response to SMC (Table 3). Although the fresh weight yields and plant stands of these fall-planted vegetables were somewhat low, the yield responses to the rates of SMC addition were positive and probably reflected the residual effects from the spring application of SMC.

Overall, differences in the responses of vegetables to SMC application during a growing season probably can be attributed to differences in the tolerance of each vegetable species to salinity. Differences in the yield responses of the same vegetable species between the 2 growing seasons perhaps were due to the combined effects of salinity (EC), weather conditions, and the residual effects from the 1st year's application of SMC.

Elemental concentration in leaf tissue. In 1981, the concentration of K generally increased with the addition of SMC, whereas the concentration of Ca was unchanged (Table 4). The Mg concentration decreased in all 4 crops as the rate of SMC increased, but the decrease in Mg was not significant in tomato. Decreasing Mg was probably an example of the antagonism between K and Mg (18, 19). The K/(Ca + Mg) ratios increased as the rate of SMC increased (Table 1). The relatively high concentration of K in the soil solution probably facilitated the uptake of K and depressed the Mg concentration as a consequence of antagonism. P was unaffected by the SMC application in 1981, except in cabbage.

K concentrations also increased in all 4 crops (Table 4) in 1982. With the exception of snap bean, Ca in leaf tissue was not significantly affected. The P concentration increased significantly as the rates of SMC increased in 1982. The only significant increase in N was found in snap bean.

Conclusions

The increased organic matter from the application of SMC improved certain soil properties. Bulk density decreased and the percentage of small pore space increased. The pH and EC of SMC treated plots increased. For all vegetables tested, K concentration in the leaf tissue increased significantly as the rate of SMC increased. The concentration of Mg decreased, as expected, because of antagonistic effects.

SMC as a soil amendment seems beneficial for certain vegetable crops. It supplied some plant nutrients, but the excessive K present in SMC has the potential of causing Ca and/or Mg deficiencies in plants, and its high soluble salts content could make the repeated or excessive use of SMC harmful to plants that are sensitive to salinity.

Table 4. Effect of spent mushroom compost application rates on elemental concentration in leaf tissue of snap bean, cabbage, cucumber, and tomato in 1981 and 1982.

SMC rate (kg/m^2)	mmol/kg 1981 P	K	Ca	Mg	1982 N	P	K	Ca	Mg
				Snap bean					
00	57	478	336	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[z]	NS	***	NS	**	**	NS	***	**	NS
Quadratic[z]	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[z]	**	**	NS	**	NS	**	***	NS	*
Quadratic[z]	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[z]	NS	***	NS	***	NS	***	***	NS	***
Quadratic[z]	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[z]	NS	***	NS	NS	NS	***	**	NS	***
Quadratic[z]	NS	NS	NS	NS	NS	NS	NS	NS	**

[z]Significant at 0.1% (***), 1% (**), 5% (*), or nonsignificant (NS).

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Development of the Flower Spike of Bird of Paradise and its Flowering Period in Hawaii

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Abstract. **Time intervals between leaf emergence, flower stalk emergence, and flower cut were determined for 550 *Strelitzia reginae* Ait. (Bird of Paradise) flowers during 1977–80 at an elevation of 25 m in Hawaii. The interval between leaf emergence and flower stalk emergence averaged 186 days with a range of 173 to 204. The interval between flower stalk emergence and flower cut averaged 64 days with a range of 54 to 74. Seasonal differences in the duration of development did not account for the seasonal differences in yield. Dissection of flowering fans revealed sequences of flower bud abortion which occurred during June to October, and accounted for low flower production during winter and early spring months in Hawaii.**

During a cooperative international experiment, Halevy (5) observed that considerable variation existed in the flowering of the bird of paradise, *Strelitzia reginae*. Peak flowering occurred at different times of the year in different geographic locations. In Hawaii, this time is from the end of June until the end of September (Fig. 1). In San Diego (1) and Los Angeles (12) the flowering is from September through May with peaks in October–December, March, and May. In Israel, the time is in March, April, and again in September (7). In South Africa, flowering occurs during the fall-winter-spring period (10).

Previous studies (3, 4) have revealed a flower bud to exist in the axil of each leaf. Assuming there is no flower loss, flower production should parallel leaf production. In Hawaii, however, flower production, expressed as a percentage of leaves bearing flowers, is less than 50% for leaves emerging in April through August and ranges from 75% to 85% for leaves emerging December to February (Fig. 2), because all flower buds do not develop.

Low flower productivity could be explained if leaves were produced irregularly or seasonally, as in South Africa (10), or if flower development were limited by environmental factors. Flower induction in *Strelitzia* apparently is not responsive to photoperiod (5), but light intensity (5, 11) and temperature (1, 5, 9, 11) do modify flower development. The objective of this study was to determine the biological basis for low seasonal flower production, and to determine the time frame of significant biological events near sea level in Hawaii. (Since the completion of this study, observation of a high elevation commercial planting has shown a different pattern of seasonal flower production.)

Materials and Methods

A nonclonal field of 108 *Strelitzia reginae* plants, established in 1969–1971 and located at the Waimanalo Experimental Farm on Oahu, Hawaii, was used for this study. At this site, 25 m above sea level, the daily photoperiod varies between 10 hr 50 min and 13 hr 26 min (+ 20 min until twilight), the average daily solar integral is between 220 and 500 cal cm^{-2}, and the monthly average temperature is between 20° and 26°C. Normal yearly rainfall is about 1 m, and the field received overhead irrigation at the rate of 25 mm/week when required.

The plants in this study were chosen at random from vigorous, healthy plants which had been the subject of a fertilizer × planting density experiment (2). They received fertilizer in May and November as one-half rates of yearly levels of 0, 87.5, 175, and 350 kg N/ha/yr from a controlled release 14N–6P–12K fertilizer. The planting densities were 2, 3, and 4 plants per 1.5 m^2 plots. Determinations from all plots have been pooled for the purpose of this paper and do not reflect the original experiment for which per plot data were collected (2).

In Dec. 1976, 60 fans (a compressed stem with distichous leaf arrangement) on 27 plants were chosen to follow the patterns of leaf and flower emergence. Leaf zero was the youngest leaf present on the fan in Dec. 1976. For the next 3 years, each new

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