Analysis of Fresh Mushroom Compost

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Summary. Fresh mushroom compost is a byproduct of the edible mushroom (*Agaricus bisporus*) industry and represents the composted growing substrate that remains after a crop has been harvested to completion. Thirty samples were obtained from commercial mushroom farms in southeastern Pennsylvania and sent to a laboratory for analysis to determine plant nutrient content, bulk density, and particle size distribution of fresh mushroom compost. Fresh mushroom compost had an average pH of 6.6, with an average carbon:nitrogen ratio of 13:1. Organic matter content averaged 25.86% (wet weight), 146.73 lb/yard^3 (wet volume) or 60.97% (dry weight). For the primary macronutrients, average total nitrogen content averaged 1.12% (wet weight), 6.40 lb/yard^3 (wet volume) or 2.65% (dry weight), phosphorus measured 0.29% (wet weight), 1.67 lb/yard3 (wet volume) or 0.69% (dry weight), and potassium was 1.04% (wet weight), 5.89 lb/yard^3 (wet volume) or 2.44% (dry weight). Average soluble salt content was 13.30 mmho/cm (wet weight basis). However, on a per acre basis, the calculated sodium absorption ratio of 0.38 was considered very low. The average bulk density of fresh mushroom compost was 574.73 lb/yard^3 (wet volume basis), and 91% of the material measured ≤3/8 inch in diameter as determined on a wet weight basis. Overall, fresh mushroom compost is suitable as a natural organic fertilizer and soil amendment for agriculture and horticulture.

Production of the edible mushroom in the United States totaled 802 million pounds during the 2007–08 growing season, with 521 million pounds or 65% produced in Pennsylvania (Norris, 2009). The major ingredients in mushroom-growing substrate from farms in Pennsylvania are typically recycled agricultural waste products and other materials, which include hay, straw and horse bedding, poultry litter, corn cobs, corn stover, cottonseed meal, cocoa hulls, and gypsum in various amounts and proportions (Chang and Miles, 1989; Stamets, 2000). The ingredients are mixed, blended, and irrigated thoroughly, placed inside a production facility, and pasteurized with steam heat to sterilize the substrate before inoculation with mushroom spawn (Wuest, 1982). Sphagnum peatmoss is added later in the growing process (Beyer, 2003; Chang and Hayes, 1978).

After a cropping cycle has been completed and the substrate has been depleted of nutrients needed for growing mushrooms, the substrate is removed from the production facility and the discarded material is then referred to as fresh mushroom compost (Beyer, 2003; Chang and Hayes, 1978; Wuest, 1982). Before removal, however, the substrate is again pasteurized with steam heat to eliminate the potential for unwanted fungi and weed seeds (Wuest, 1982). Fresh mushroom compost was previously called spent mushroom substrate or mislabeled as "mushroom soil" (American Mushroom Institute, unpublished data). Although weathered or outdoor-aged mushroom compost has been used as an organic fertilizer and soil amendment for plant production in agriculture and horticulture (Chong et al., 1991b; Lohr et al., 1984a; Maher, 1991, 1994), limited information is available regarding the analysis of fresh mushroom compost (American Mushroom Institute, unpublished data). An estimated 650,000 to 700,000 yard^3 of fresh mushroom compost are generated annually by the mushroom industry in Pennsylvania (American Mushroom Institute, unpublished data; Fidanza and Davis, 2009). The objective of this project was to analyze the fresh mushroom compost produced in southeastern Pennsylvania for chemical and physical properties considered important for plant growth and soil improvement.

Materials and methods

During late Winter/early Spring 2005, 30 fresh mushroom compost samples were collected from mushroom farms in southeastern Pennsylvania, particularly the mushroom-growing regions in Berks and Chester counties. The samples were acquired as the material was being removed from a production facility, and were not allowed to stockpile or age outdoors. Each sample was placed in a 1-gal plastic container and was securely shipped to the Agricultural Analytical Services Laboratory (Pennsylvania State University, University Park) for processing and analysis. Laboratory tests measured the following properties: pH, carbon:nitrogen (C:N) ratio, soluble salts, solids, moisture, organic matter, carbon, total nitrogen (N), organic nitrogen, ammonium nitrogen, phosphate (P_2O_5), potash (K_2O), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), aluminum (Al), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn). Although laboratory results reported P_2O_5 and K_2O values, actual phosphorus (P) and

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha^{-1}	0.8922
0.5933	lb/yard^3	kg·m^{-3}	1.6856
1	mmho/cm	dS·m^{-1}	1
2.2417	ton/acre	Mg·ha^{-1}	0.4461
1.8893	yard^3/acre	m^3·ha^{-1}	0.5293

potassium (K) were calculated from P_2O_5 and K_2O, respectively (Brady and Weil, 1996). Two additional laboratory tests measured bulk density and particle size distribution. Laboratory test methods and procedures are based on the Test Methods for Evaluation of Compost and Composting program as recommended by the U.S. Composting Council (West Conshohocken, PA) and the American Society of Testing Materials (Rokonkoma, NY), and also based on analytical methods described in Eaton et al. (2005). A detailed list of the analytical methods used for each test can be obtained through Agricultural Analytical Services Laboratory. Of interest for growth media in horticulture, soluble salt content was measured indirectly from electrical conductivity (EC) using a 1:5 (compost:water) slurry (Agricultural Analytical Services Laboratory, unpublished data).

The laboratory tests determined compost characteristics on a wet weight, wet volume, and dry weight basis. Bulk density was determined "as is" (i.e., as received at the laboratory, and not oven-dried) on a wet volume basis [test method TMECC 3.01-A, U.S. Composting Council (Westerman, 1990)] and particle size also was determined "as is" on a wet weight basis. Data from all samples were compiled to determine mean, standard deviation, and the minimum and maximum values (Steel and Torrie, 1980) for each parameter (Statistix, version 9; Analytical Software, Tallahassee, FL). Also, wet volume laboratory results data were used to calculate the amount of plant nutrients in fresh mushroom compost per acre, as well as the sodium adsorption ratio (SAR) per acre (Swift, 2009). The SAR, calculated as follows,

$$SAR = \frac{[Na^+]}{\sqrt{\frac{([Ca^{2+}] + [Mg^{2+}])}{2}}}$$

compares Na concentration relative to the concentrations of Ca and Mg (Brady and Weil, 1996).

Results and discussion

pH AND C:N RATIO. Fresh mushroom compost had an average pH of 6.6 (Table 1) within the optimum soil pH range of 6.0 to 7.0 for growing most agricultural and horticultural crops (Acquaah, 2009; Foth, 1984). Lohr et al. (1984b) reported an average leachate pH of 8.0 for fresh mushroom compost. Only three samples were used in that study from a single mushroom farm in Tennessee (Lohr et al., 1984b) compared with 30 samples from multiple farms in this investigation, and the amount and quality of materials used to make mushroom substrate is dramatically different in Pennsylvania (Beyer, 2003; Wuest, 1982; Wuest et al., 1995). The C:N ratio of fresh mushroom compost in this study averaged 13:1 (Table 1), within the desired range of 10:1 to 15:1 for ideal compost (Stoffella and Kahn, 2001).

SOLUBLE SALTS. The average EC of fresh mushroom compost was 13.30 mmho/cm (Table 1), which is not considered high enough to damage turfgrass (Landschoot and McNitt, 2005) or impede plant production (Wang et al., 1984). In addition, salt concentrations can be significantly diluted when a compost is incorporated or tilled into a soil or soil amendment (Stoffella and Kahn, 2001). Lohr et al. (1984b) reported an EC of 22 mmho/cm for fresh mushroom compost, and concluded that K, Ca, and Mg concentrations accounted for 80% to 90% of total dissolved salts present in saturated paste extracts used to measure EC in that study. However, it is difficult to compare soluble salt concentration in compost from previous research when different analytical methods are used (Carter, 1993). Although soluble salt concentration of compost is often a concern to practitioners (Tyler, 1996), this material has been used successfully in many plant production systems (Chong and Rinker, 1994; Chong et al., 1991a; Philippoussis et al., 2004; Romaine and Holcomb, 2001; Wang et al., 1984; Wuest et al., 1995).

BULK DENSITY, SOLIDS, AND MOISTURE. Mean bulk density (Table 2) averaged 574.73 lb/yard^3 (wet volume), with over half of the weight attributed to water. Lohr et al. (1984b) reported an average bulk density of 428.12 lb/yard^3 for fresh mushroom compost, and again, this lower value reflects a difference in the amount and quality of materials used to make mushroom substrate today in Pennsylvania (Beyer, 2003; Chang and Hayes, 1978; Wuest, 1982; Wuest and Fahy, 1992; Wuest et al., 1995). In this study, fresh mushroom compost contained an average amount of solids at 42.67% (wet weight) or 243.37

Table 1. Analysis of fresh mushroom compost on a wet weight basis.

Parameter measured[z]	Mean	SD	Range Minimum	Range Maximum
pH	6.62	0.47	5.90	7.80
Carbon:nitrogen ratio	12.79:1	1.00	10.50	14.90
Soluble salts (mmho/cm)[y]	13.30	1.80	9.68	17.97
	%			
Solids	42.67	6.85	31.40	60.60
Moisture	57.33	6.85	39.40	68.60
Organic matter	25.86	3.69	20.40	37.50
Carbon	14.29	2.15	10.60	18.80
Total nitrogen	1.12	0.20	0.80	1.50
Organic nitrogen	1.10	0.22	0.70	1.50
Ammonium nitrogen (NH_4-N)	0.03	0.01	<0.01	0.06
Phosphorus	0.29	0.08	0.15	0.52
Potassium	1.04	0.24	0.61	1.55
Calcium	2.32	0.60	1.29	3.59
Magnesium	0.36	0.12	0.16	0.74
Sulfur	0.86	0.19	0.55	1.22
Sodium	0.11	0.04	0.05	0.20
Aluminum	0.15	0.09	0.04	0.57
Iron	0.18	0.10	0.04	0.43
Manganese	0.02	0.01	<0.01	0.05
Copper	<0.01	<0.01	<0.01	0.01
Zinc	<0.01	<0.01	<0.01	0.01

[z]Fresh mushroom compost samples (n = 30) were collected in 1-gal (3.8 L) containers and analyzed by the Agricultural Analytical Services Laboratory (Pennsylvania State University, University Park) from Jan. 2005 through Apr. 2005. Mushroom compost samples were analyzed "as is" when received at the laboratory for measurements on a wet weight basis. Actual phosphorus (P) was calculated from laboratory-measured P_2O_5 (P = $P_2O_5 \times 0.4365$), and actual potassium (K) was calculated from laboratory-measured K_2O (K = $K_2O \times 0.8301$).
[y]Soluble salts determined by measuring EC in a 1:5 (compost:water, weight ratio) slurry; 1 mmho/cm = 1 dS·m^{-1}.

lb/yard³ (wet volume), and moisture at 57.33% (wet weight) or 331.47 lb/yard³ (wet volume) (Tables 1 and 2). Fresh mushroom compost is within the ideal ranges for compost of 35% to 55% (wet weight) for solids and 45% to 65% (wet weight) for moisture (Stoffella and Kahn, 2001).

Organic matter and carbon. Organic matter content of fresh mushroom compost averaged 25.86% (wet weight), 146.73 lb/yard³ (wet volume) or 60.97% (dry weight), and an average carbon content of 14.29% (wet weight), 81.13 lb/yard³ (wet volume), or 33.42% (dry weight) (Tables 1–3). The organic matter in mushroom compost consists of decomposed plant, animal, and fungal residues and materials, and is often recommended for use in land reclamation or soil remediation (Rupert, 1995), as well as plant production (Davis et al., 2006; Lemaire et al., 1985; Lohr et al., 1984a; Rinker, 2002; Wang et al., 1984; Wuest et al., 1995).

Primary and secondary macronutrients. Average total N content of fresh mushroom compost was 1.12% (wet weight), 6.40 lb/yard³ (wet volume) or 2.65% (dry weight) (Tables 1–3). The majority of this N is in the organic form, with a very small amount in the ammonium form. In general, composts have low N content, typically in the 1% to 3% range (Acquaah, 2009). Average P content was 0.29% (wet weight), 1.67 lb/yard³ (wet volume) or 0.69% (dry weight) (Tables 1–3). Average K content was 1.04% (wet weight), 5.89 lb/yard³ (wet volume) or 2.44% (dry weight) (Tables 1–3). On average, fresh mushroom compost contains the secondary macronutrients Ca at 2.32% (wet weight), 13.17 lb/yard³ (wet volume) or 5.38% (dry weight), Mg at 0.36% (wet weight), 2.01 lb/ yard³ (wet volume) or 0.83% (dry weight), and S at 0.86% (wet weight), 4.91 lb/yard³ (wet volume) or 2.02% (dry weight) (Tables 1–3). Overall, the average amounts of primary and secondary macronutrients determined from the 30 samples tested did not show extreme minimum or maximum vales, thus indicating similar methods used by mushroom farms for producing this material in Pennsylvania (Beyer, 2003; Wuest, 1982).

Micronutrients. The micronutrients Fe, Mn, Cu, Zn, Na, and Al were detected in fresh mushroom compost at a very low average range of <0.01% to 0.18% (wet weight), 0.03 to 1.07 lb/yard³ (wet volume), or 0.02% to 0.43% (dry weight) (Tables 1–3). This information is consistent with previous findings on the micronutrient content of aged mushroom compost (Wuest and Fahy, 1992).

Table 2. Analysis of fresh mushroom compost on a wet volume basis.

Parameter measured[z]	Mean	SD	Range: Minimum	Range: Maximum
	(lb/yard³)[y]			
Bulk density	574.73	82.05	432.00	777.00
Solids	243.37	41.68	179.00	344.00
Moisture	331.47	71.70	209.00	469.00
Organic matter	146.73	17.67	119.00	199.00
Carbon	81.13	10.52	61.00	105.00
Total nitrogen	6.40	1.06	4.50	9.00
Organic nitrogen	6.19	1.07	4.30	8.80
Ammonium nitrogen (NH_4-N)	0.21	0.07	0.03	0.34
Phosphorus	1.67	0.41	0.90	2.95
Potassium	5.89	1.17	3.69	8.40
Calcium	13.17	3.31	6.71	20.28
Magnesium	2.01	0.61	0.99	3.53
Sulfur	4.91	1.12	3.12	7.72
Sodium	0.67	0.25	0.35	1.26
Aluminum	0.89	0.53	0.28	3.07
Iron	1.07	0.57	0.29	2.57
Manganese	0.12	0.07	0.04	0.29
Copper	0.03	0.01	0.02	0.08
Zinc	0.05	0.02	0.03	0.09

[z]Fresh mushroom compost samples (*n* = 30) were collected in 1-gal (3.8 L) containers and analyzed by the Agricultural Analytical Services Laboratory (Pennsylvania State University, University Park) from Jan. 2005 through Apr. 2005. Mushroom compost samples were analyzed "as is" when received at the laboratory for measurements on a wet volume basis. Actual phosphorus (P) was calculated from laboratory-measured P_2O_5 (P = P_2O_5 × 0.4365), and actual potassium (K) was calculated from laboratory-measured K_2O (K = K_2O × 0.8301).
[z]1 lb/yard³ = 0.5933 kg·m^{-3}.

Table 3. Analysis of fresh mushroom compost on a dry weight basis.

Parameter measured[z]	Mean	SD	Range: Minimum	Range: Maximum
	(%)			
Organic matter	60.97	5.42	50.90	72.70
Carbon	33.42	4.27	23.80	43.90
Total nitrogen	2.65	0.39	1.90	3.50
Organic nitrogen	2.57	0.38	1.90	3.40
Ammonium nitrogen (NH_4-N)	0.09	0.03	0.01	0.18
Phosphorus	0.69	0.16	0.46	1.23
Potassium	2.44	0.36	1.78	3.20
Calcium	5.38	0.89	3.73	7.70
Magnesium	0.83	0.23	0.50	1.84
Sulfur	2.02	0.36	1.49	2.70
Sodium	0.28	0.09	0.14	0.45
Aluminum	0.36	0.17	0.13	0.95
Iron	0.43	0.18	0.15	0.85
Manganese	0.05	0.01	0.02	0.10
Copper	0.02	<0.01	0.01	0.03
Zinc	0.02	0.01	0.01	0.04

[z]Fresh mushroom compost samples (*n* = 30) were collected in 1-gal (3.8 L) containers and analyzed by the Agricultural Analytical Services Laboratory (Pennsylvania State University, University Park) from Jan. 2005 through Apr. 2005. Mushroom compost samples were first oven-dried to remove moisture and then analyzed on a dry weight basis. Actual phosphorus (P) was calculated from laboratory-measured P_2O_5 (P = P_2O_5 × 0.4365), and actual potassium (K) was calculated from laboratory-measured K_2O (K = K_2O × 0.8301).

AMOUNT OF N AND P PER ACRE. The amount of plant nutrients supplied on a per acre basis is useful in field or horticultural crop production to determine nutrients provided by compost and those needed from additional fertilizer inputs (Brady and Weil, 1996). To uniformly apply 1-inch-thick fresh mushroom compost to 1 acre of land would require ≈40 tons/acre or 139 yard^3/acre of fresh mushroom compost as calculated from an average bulk density of 575 lb/yard^3 (Table 4). A 1-inch-thick layer of mushroom compost is typically applied to agricultural fields in Pennsylvania (Wuest et al., 1995). Forty tons of material would supply 891 lb total N, of which 29 lb is in the form of ammonium N and 862 lb is in the form of organic N (Table 4). With the recent increase in synthetic fertilizer costs (Torres, 2008), N supplied from fresh mushroom compost could help meet plant nutrient needs while reducing expenses by needing less fertilizer inputs (Stewart et al., 1998). Also, 40 tons/acre of fresh mushroom compost results in 232 lb of P being applied (Table 4). Information on P on a per-acre basis is useful for developing and maintaining soil nutrient management plans and practices (Jones, 2003).

Table 4. Amount of plant nutrients from fresh mushroom compost applied to 1 acre (0.4 ha).

Parameter measured	Amount (lb/acre)^z
Solids	33,877
Moisture	46,140
Organic matter	20,425
Carbon	11,294
Total nitrogen	891
Organic nitrogen	862
Ammonium nitrogen (NH_4-N)	29
Phosphorus	232
Potassium	820
Calcium	1,834
Magnesium	280
Sulfur	683
Sodium	94
Aluminum	124
Iron	150
Manganese	17
Copper	6
Zinc	7

^{z}Calculation based on applying a 1-inch (2.5 cm) thickness of fresh mushroom compost on a wet volume basis to 1 acre of land, which requires ≈139 yard^3/acre (262.6 m^3·ha^{-1}) or 40 tons/acre (89.7 Mg·ha^{-1}) fresh mushroom compost calculated from an average bulk density of 575 lb/yard^3 (341.1 kg·m^{-3}) and information from Table 2. Actual phosphorus (P) was calculated from laboratory-measured P_2O_5 (P = P_2O_5 × 0.4365), and actual potassium (K) was calculated from laboratory-measured K_2O (K = K_2O × 0.8301); 1 lb/acre = 1.1209 kg·ha^{-1}.

SODIUM ADSORPTION RATIO. Although SAR is typically based on concentration of ions in solution (Carter, 1993), a calculated (Swift, 2009) estimate from 40 tons fresh mushroom compost applied to 1 acre results in SAR = 0.38. A SAR ≥15 would typically indicate excess Na accumulation compared with Ca and Mg, and that sodium would be adsorbed by soil clay particles, thus causing problems with soil aggregation and drainage, as well as inhibiting water absorption by plant roots (Brady and Weil, 1996).

PARTICLE SIZE. On average, 91% of fresh mushroom compost particles measured ≤3/8 inch in diameter, with ≈8% at 3/8 to 5/8 inch, and <1% at 5/8 to 1 inch (Table 5). No particles were measured >1 inch in diameter. Overall, this material is of a consistent and uniform size and is easy to handle, apply, and distribute to lawns, landscapes, sports fields, and agricultural fields, and is amendable for most horticultural uses (Landschoot and McNitt, 1994; Stoffella and Kahn, 2001).

Table 5. Particle size distribution of fresh mushroom compost on a wet weight basis.

Particle diam (inches)^z	Mean	SD	Range: Minimum	Range: Maximum
	(%)			
≥2 inch	0.00	0.00	0.00	0.00
1–2 inch	0.00	0.00	0.00	0.00
5/8–1 inch	0.52	1.48	0.00	6.38
3/8–5/8 inch	7.89	6.75	0.36	26.39
1/8–3/8 inch	28.84	8.31	4.30	45.15
<1/8 inch	62.05	11.00	39.79	77.15

^{z}Fresh mushroom compost samples (n = 30) were collected in 1-gal (3.8 L) containers and analyzed by the Agricultural Analytical Services Laboratory (Pennsylvania State University, University Park) from Jan. 2005 through Apr. 2005. Mushroom compost samples were analyzed "as is" when received at the laboratory for particle size measurements on a wet weight basis; 1 inch = 2.54 cm.

In Pennsylvania, the state legislature has recently reclassified fresh mushroom compost from an agricultural waste product to now listing it as a fertilizer and soil amendment (American Mushroom Institute, unpublished data). While stockpiled outdoor or passively aged mushroom compost has been used for many agricultural and horticultural purposes, the accumulation of weed seeds deposited into that material by nature has provided challenges to the end user, as well as the cost and maintenance of storing that material by the mushroom industry (Rinker, 2002). In conclusion, fresh mushroom compost should be considered a viable, recycled agricultural product useful as a soil amendment or natural organic fertilizer, and could potentially be surface-applied or incorporated into soil or plant growth media. The methods used to grow white button mushrooms are very similar among the farms in southeastern Pennsylvania (Beyer, 2003; Wuest, 1982). Therefore, results of the analysis of fresh mushroom compost in this report should be representative of the chemical and physical properties throughout that material as produced in Pennsylvania.

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