# Use of Spent Mushroom Compost as a Growing Medium Component and Organic Soil Amendment

Spent Mushroom Compost (SMC) is the substrate that is left at the end of the commercial mushroom production process. SMC consists of a blend of mushroom compost that is manufactured from wheat straw, gypsum, poultry litter and/or horse manure and casing material that is manufactured from peat and sugar beet lime or chalk (see Appendix 1 for information on mushroom compost and casing formulations). It is estimated that 250,000 tonnes of SMC are produced in Ireland and in Great Britain per annum. It is generally acknowledged that SMC is a valuable organic material with physical and chemical properties that are of potential use for the horticulture industry, either as a soil conditioner or for incorporation into growing media. Indeed, there is a demand for SMC by the horticulture industry for use in these product types (see Appendix 4 for letters of support).

SMC currently has two waste exemptions in the UK:

- U10 for spreading on agricultural land to replace manufactured fertiliser or virgin material to improve or maintain soil;
- U11 for spreading on non- agricultural land to replace manufactured fertiliser or virgin material to improve or maintain soil.

Regulations covering the end of waste status of SMC so that it can be re-used in horticultural crop production are present in other EU countries, including France[18], Germany[19] and Spain[20].

The composition of SMC can vary due to variation in the manufacture of the mushroom compost and casing. In addition, the watering management of the compost and casing during mushroom growing can vary. Table 1 indicates the variability in a series of standard quality parameters measured on 65 SMC samples from Northern Ireland and the Republic of Ireland[1,12]. These parameters are within expected limits, with respect to other published data[8,9] and the variability is due to the varying mixes and types of ingredients used to manufacture the mushroom substrate. In particular, the C:N ratios were below 25, indicating that the SMC is stable.

**Table 1. Minimum, maximum, mean and standard deviation of analytical values of 65 SMC samples[1, 7,12].**

| Parameter | Min | Max | Mean | SD |
|---|---|---|---|---|
| Dry Matter (g $Kg^{-1}$) | 216 | 512 | 312 | 46.4 |
| Organic Matter (g $Kg^{-1}$) | 107 | 761 | 645 | 58.6 |
| pH | 6.0 | 8.4 | 6.8 | 0.48 |
| EC (ms $cm^{-1}$) | 2.35 | 15 | 10 | 108 |
| Bio Available P (g $Kg^{-1}$) | 1.3 | 25 | 4 | 3.8 |
| Total P (g $Kg^{-1}$) | 11 | 38 | 18 | 5.8 |
| Bio Available K (g $Kg^{-1}$) | 8 | 21 | 13 | 2.9 |
| Total K (g $Kg^{-1}$) | 11 | 34 | 20 | 6.2 |
| Total N (g $Kg^{-1}$) | 17 | 28 | 21 | 2 |
| C/N Ratio | 14 | 24 | 18 | 2 |
| Total Ca (g $Kg^{-1}$) | 3 | 101 | 28 | 49.1 |
| Total Mg (g $Kg^{-1}$) | 0.55 | 39 | 18 | 19.4 |
| Total Na (g $Kg^{-1}$) | 0.05 | 5.32 | 1.68 | 2.7 |
| Lignin (%) | 11 | 49 | 25 | 9.5 |
| Cellulose (%) | 11 | 62 | 38 | 8.6 |
| Hemicellulose (%) | 2 | 41 | 19 | 8.7 |

The mushroom composting process involves four stages, the first of which involves the mixing and wetting of the raw materials (pre-wetting), which are then placed in turned stacks or windrows or in a controlled aeration indoor bunker (Phase I). During Phase I, which lasts around one week, the compost is mechanically or force aerated and the temperature of >95% of the compost will exceed 70°C. Phase II of the mushroom composting process involves the volatilisation of ammonia (from the manure) and pasteurisation at 58-62°C for at least 6 hours to control pathogens and other unwanted organisms. Sterile grain 'spawn' of the commercial mushroom (*Agaricus bisporus*) is then introduced for colonisation of the compost during Phase III. Phase III compost is filled into mushroom houses and covered with peat casing for the growth of mushrooms under controlled conditions. After a number of mushroom flushes, the compost and casing is termed spent and is removed from the houses, after steam treatment (cooking-out) at 60 - 70°C for 12 hours.

SMC is a friable material and is characterised as having a slightly alkaline pH (≥pH7.0), high potassium and calcium contents, as well as useful levels of phosphorus and magnesium, and low levels of nitrogen (Tables 1 and 2). It also has a low bulk density (Table 2) and high organic matter content. These physical and chemical properties would be of benefit for the recycling of SMC into soil conditioners or growing media, reducing reliance on chemical fertilisers, peat and other growing medium components.

**Table 2. Physicochemical parameters of SMCS analysed at Monaghan Mushrooms (MM) and in other reports [7, 9, 12, 14]**

| Parameter | AFBI [7,12] | MM | RECOVEG[9] | Amsing[14] |
|---|---|---|---|---|
| Ammonium N (g $Kg^{-1}$) | 0.22 to 0.23 | 0.35 | <0.1 to 0.35 | - |
| Nitrate N (g $Kg^{-1}$) | - | - | <0.1 to 0.44 | - |
| Total Cl ( g $Kg^{-1}$) | - | - | - | 3.8 to 19.9 |
| Bulk density (g/l) | 447 to 507 | - | 365 to 469 | - |

Heavy metal concentrations in SMC (Table 3) are below the EU recommended limits for organic amendments applied to soil[7] with the exception of cadmium, where a different extraction method was employed. In further reports[13,14], the level of cadmium in mushroom compost and casing and SMC was less than 1.3 mg $kg^{-1}$ on a dry matter basis. Therefore, heavy metals should not pose any environmental or health risks.

**Table 3 Minimum, maximum, mean, standard deviation (SD) of selected heavy metals on SMC samples (n=63) on a dry matter basis (mg $kg^{-1}$)[3].**

| Parameter (mg/kg) | Min | Max | Mean | SD | Upper Limit (PAS 100) |
|---|---|---|---|---|---|
| Total Cu | 17 | 106 | 54 | 21.2 | 149 |
| Total Zn | 58 | 284 | 143 | 39.2 | 397 |
| Total Mn | 32 | 328 | 164 | 36.5 | - |
| Total Fe | 2.4 | 9.0 | 4.7 | 0.95 | - |
| Total Pb | 7.3 | 15.6 | 10.4 | 1.7 | 149 |
| Total Cd | 0.4 | 8.2 | 6.2* | 1.2 | 1.3 |
| Total Cr | 0.21 | 0.31 | 0.21 | 0.01 | 92 |
| Total Ni | 5.8 | 5.8 | 5.8 | 0.02 | 56 |

The majority of bacteria that have been isolated from SMC are of environmental origin such as *Bacillus* spp, *Klebsiella/ Enterobacter* spp, and *Microbacterium* spp[11]. Different studies have shown differences in the detection of other faecal pathogens, such as *Salmonella spp.* and *Campylobacter spp*[17]; however, these have not been detected during any analysis of SMC from Monaghan Mushrooms.

Only one pesticide is used in the mushroom industry in Europe. Sporgon, active ingredient 50% prochloraz manganese, is used to control *Verticillium* (dry bubble), *Mycogone* (wet bubble) and *Cladobotryum spp* (*Dactylium dendroides*) (cobweb) diseases in mushrooms. The maximum approved dose for Sporgon is 120 g per 100 $m^2$ of mushroom production bed area. Recent analysis of the levels of prochloraz in SMC indicated that the levels are between 0- 0.43mg $kg^{-1}$ (n=5). This is well below the EU maximum residue limit (MRL)[15] for prochloraz in fresh mushrooms of 3 mg $kg^{-1}$. Growth regulators, such as chlormequat or mepiquat were not detected above the limits of detection in the samples of SMC analysed. The risk of other possible other contaminants is very low since the SMC has been produced in a tightly regulated food environment, with stringent HACCP control systems and quality protocols.

SMC is a valuable resource for use in horticulture, agriculture, forestry and land reclamation as (a) a growing medium component and (b) an organic soil amendment and plant nutrient source. The comparator material which SMC is about to replace is PAS100 green waste compost (GWC).

<u>SMC as a plant growing medium component</u>

There is a need to identify peat replacements as UK government policy is to reduce the amount of peat used in horticulture by 2020[2]. The extraction of peat for horticulture is not only unsustainable, but produces greenhouse gases and destroys rare wetland habitats[3]. In 2009, almost 3 million $m^3$ of peat was used by the UK horticulture industry, 70% of which was sold as bagged products[4]. There is a big demand for soil conditioners in both the amateur and professional markets (estimated sales of 300,000 $m^3$ per annum). One of the main products used to replace peat in growing media is PAS100 green waste compost (GWC).

**Table 4. Minimum, maximum, mean and standard deviation of analytical values of GWC samples[9,10] compared with minimum and maximum SMC values from Tables 1 and 2.**

| Parameter | GWC Min | GWC Max | SMC Min | SMC Max |
|---|---|---|---|---|
| Dry Matter (g $Kg^{-1}$) | 560 | 680 | 216 | 512 |
| Organic Matter (g $Kg^{-1}$) | 310 | 370 | 107 | 761 |
| pH | 7.4 | 8.3 | 6.0 | 8.4 |
| EC (ms $cm^{-1}$) | 0.8 | 1.08 | 2.35 | 15 |
| Bio Available P (g $Kg^{-1}$) | 0.06 | 0.27 | 1.3 | 25 |
| Total P (g $Kg^{-1}$) | 22 | 27 | 11 | 38 |
| Bio Available K (g $Kg^{-1}$) | 2.7 | 4.5 | 8 | 21 |
| Total K (g $Kg^{-1}$) | 4.7 | 7.7 | 11 | 34 |
| Total N (g $Kg^{-1}$) | 12 | 17 | 17 | 28 |
| C/N Ratio | 13 | 22 | 14 | 24 |
| Ammonium N (g $Kg^{-1}$) | 0.03 | 0.25 | <0.1 | 0.35 |
| Nitrate N (g $Kg^{-1}$) | 0.05 | 0.23 | <0.1 | 0.44 |
| Total Ca (g $Kg^{-1}$) | 0.14 | 0.18 | 3 | 101 |
| Total Mg (g $Kg^{-1}$) | 0.05 | 0.25 | 0.55 | 39 |
| Total Na (g $Kg^{-1}$) | 0.3 | 1.1 | 0.05 | 5.32 |
| Total Cl ( g $Kg^{-1}$) | 1.7 | 2.3 | 3.8 | 19.9 |
| Lignin (%) | 20 | 24 | 11 | 49 |
| Cellulose (%) | 5.9 | 17.8 | 11 | 62 |
| Hemicellulose (%) | - | - | 2 | 41 |
| Bulk density (g $l^{-1}$) | 480 | 620 | 365 | 507 |

Table 4 shows that SMC and the comparator material GWC have similar physico-chemical properties with the following exceptions:

- SMC has higher levels of some plant nutrients (P, K, Ca, Mg) than GWC, but similar levels of N, ammonium N and nitrate N
- The sodium and chloride levels in SMC are slightly higher than in GWC; however, the introduction of food waste into many PAS 100 composts would negate this difference.

**Table 5 Mean values of selected heavy metals in >36 samples of GWC[10,16] and SMC from Table 3 on a dry matter basis (mg $kg^{-1}$).**

| Parameter (mg/kg) | GWC | SMC | Upper Limit (PAS 100) |
|---|---|---|---|
| Total Cu | 54 | 54 | 149 |
| Total Zn | 197 | 143 | 397 |
| Total Mn | 497 | 164 | - |
| Total Fe | 93 | 4.7 | - |
| Total Hg | 0.2 | 0.10* | 1.0 |
| Total Pb | 117 | 10.4 | 149 |
| Total Cd | 0.7 | 6.2, 0.47* | 1.3 |
| Total Cr | 22 | 0.21 | 92 |
| Total Ni | 17 | 5.8 | 56 |

* data from 22 samples analysed by Amsing[14]

Table 5 shows that SMC has lower levels of heavy metals than GWC, with the exception of Cd based on the Jordan[3] results but not on the Amsing[14] results. As explained previously, this was due to the Cd extraction procedure used on SMC in the Jordan report since other studies have shown Cd in SMC to be consistently below 1.3 mg/kg dry weight and therefore within the PAS 100 limit [13].

The growth of cabbage seedlings in a peat-based potting compost was improved by the addition of 25 or 50% by volume of SMC in the growing medium, compared with growing medium amended with green waste compost or 100% peat medium containing only inorganic fertilisers[9].

SMC has several advantages over PAS 100 green waste compost as a growing medium component:

- Lack of physical contaminants such as stones, glass and plastic which are present in GWC[10]
- Lack of herbicide residues, which are a significant problem with green composts due to widespread use on grass clippings[6]. Recent analysis of 5 different batches of SMC indicated that levels of the fungicides/ pesticides boscalid, Piperonyl butoxide, Azoxystrobin and Pyraclostrobin were all below 0.1mg/kg.
- The entire material is pasteurised, unlike PAS 100 green waste compost which relies on a waste turning schedule to achieve sanitisation, allowing for pathogen survival on the outside of windrows. Indeed, recent analysis of 5 different batches of SMC indicated that no Salmonella spp, Listeria spp or E. coli 0157 were detected. The limit for *E. coli* in PAS 100 GWC is 1000 cfu/g.
- Uniform raw materials throughout the year are used for producing SMC, unlike green waste compost where the green waste feedstocks vary both seasonally and geographically[10].

SMC as an organic soil amendment and plant nutrient source

The comparator material is PAS 100 green waste compost. Experiments have shown that SMC is a more available source of N, P and K than green waste compost with improved yields of cabbage, potatoes and onions at equivalent application rates[9]. SMC is also comparable with inorganic potassium and superphosphate fertilisers in terms of K and P supply, with improved yields of crops (such as cabbage and potato) when applied at equivalent K and P application rates[9]. It is a less readily available source of N than calcium ammonium nitrate but provides useful and slowly available amounts of N when applied at rates of 50t/ha or less [8,9].

The initial composting process used to produce the mushroom substrate is extremely rigorous (compared to PAS100). Throughout the composting process, samples are taken for physico-chemical analysis (dry matter, total and ammoniacal nitrogen, pH, EC, ash, C:N ratio). Samples of Phase III compost are also analysed weekly by accredited laboratories for the presence of food pathogens such as *Salmonella spp*., *E. coli* and *Listeria spp*. (see Appendix 3). There have been no reported cases of Botulism due to mushroom compost production or disposal of SMC at the end of the growing cycle. Raw mushrooms or the compost on which they are grown, and ultimately SMC, pose no risk to human health because the chicken litter or horse manure have been pasteurised during the composting process.

Casing materials are also tested for *Salmonella* spp. and *E. coli* (see Appendix 3). This process is subject to more controls that are carried out under a HACCP controlled process in order to produce mushrooms that are considered fit for human consumption. These controls include a full microbiological testing and positive release procedures (Appendix 3).

After the mushroom cultivation production process, SMC is steam treated at 60-70$^{o}$C for 12 h to kill any mushroom mycelium and spores, bacteria and other fungi that may be present in the substrates. The SMC is then transferred from a HACCP controlled mushroom production unit by a licensed haulier to be stored or spread on land, currently under EA spreading waste to land exemption U10 (code 020199). Currently, SMC can be bagged and stored before dispatch under EA low risk waste activity LRW 373.

## Procedures for ensuring quality standard

1. Processing

The steaming of SMC at 60-70$^{o}$C for 12 hours before removal from a mushroom house has been shown to decrease the production of $H_2S$ during subsequent storage at a maximum of 35$^{o}$C, due to the removal of sulphate reducing bacteria[5] Representative samples of cooked out SMC are analysed weekly for pathogens (Salmonella, Listeria, E. coli).

2. Management (records)
    a. Records of compost temperature and cook out process to be maintained for each mushroom house (Environmental control computer).
    b. Pathogen testing records (from accredited laboratories).
    c. Moisture analysis records.

The above records will be made available to the receiving party by the mushroom farm.

3. Storage

Storage of organic wastes can be problematic if anaerobic conditions are reached. Under these conditions, organic materials such as animal slurries, sewage slurries, digestates (including PAS 110) and SMC can release hydrogen sulphide ($H_2S$). This gas is toxic and can cause respiratory paralysis following exposure at levels of 1000 ppm. The short term exposure limit (STEL) for $H_2S$ is currently 10 ppm for a period of 15 minutes. Studies in Ireland have shown that it is possible to manage SMC under normal operating procedures to avoid the build up of toxic levels of $H_2S$[5]. The storage of SMC should be conducted in an open covered shed to ensure that the material does not become waterlogged, whilst allowing evaporation to occur. This, along with regular turning, prevents the SMS from becoming anaerobic, which would lead to the production of $H_2S$. However, immediate usage of the SMC in horticulture formulations will negate the necessity for storage and remove the risk of anaerobic $H_2S$ production.

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