Spent mushroom substrate, SMS; ‘livestock manure’ according to the Nitrate Directive or compost?

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Summary

In many EU member states button mushrooms, *Agaricus bisporus*, are produced as well as the rest product called spent mushroom substrate, SMS. SMS is used in agriculture as a soil conditioner and fertilizer. Because of risks of surface and ground water contamination with nitrate from agricultural sources, the EU developed legislation to protect these waters, the Nitrate Directive.
The directive states " 'livestock manure`: means waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form". The aim of this report was to identify the position of SMS within the scope of the Nitrate Directive, either as 'livestock manure' or as another category, not (yet) defined within the Nitrate Directive: compost. For this reason a desk study was performed based on scientific literature.
Studied were:
- the size of the European mushroom industry and the amounts of SMS produced,
- the way in which SMS is produced and its basic composition,
- the stability and maturity of SMS,
- the amounts of nitrogen, specifically the mineral amounts, and the risks for their leaching from SMS,
- compost standards in an international perspective
- legislative aspects

It is concluded that SMS is quite stable and mature. The amounts of mineral nitrogen in SMS are as low as in other composts, much lower than in solid manure. The risk of leaching of mineral N from SMS is limited.

The final conclusion is that SMS is a compost.

1 Introduction

The rest product of the industry producing button mushrooms, *Agaricus bisporus*, is called Spent Mushroom Substrate, SMS (in Dutch: champost).
SMS consists of a mixture of two substrates been used: i) compost for the nutrition of mushroom mycelium, and ii) 'casing soil' that allows the development and growth of fruit bodies. The main ingredients for compost are straw, straw-rich horse manure, chicken manure and gypsum. The main ingredients for casing soil are peat and sugar beet lime.

SMS is applied in agriculture as an organic amendment based upon its function as a fertilizer as well as a soil conditioner. The EU Nitrate Directive (Nitrate Directive 1991) has an important impact on the agricultural application of SMS. The directive states " 'livestock manure`: means waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form ". The opinion that SMS should be considered a 'livestock manure' can be questioned; it can perhaps be considered a compost. A shift in definition is considered to facilitate the marketing and application of SMS in agriculture.

The aim of this report is to identify the position of spent mushroom substrate, SMS, either as a livestock manure or as a compost.

2 Material and Methods

A desk study was conducted based upon literature study. Relevant scientific literature was identified using databases like CAB-Abstracts, Current Contents and Web of Science. Relevant additional information was found on the internet.

3 SMS; production, characteristics, use

3.1 The European mushroom industry

In many European countries mushrooms are produced, and SMS as a consequence. The production of mushrooms in EU member states in 2005 is given in ascending order in Table 1 (Van den Berg 2006). As mushrooms require a specific highly conditioned substrate, the composition of the substrates as well as the remaining SMS will be similar in the different countries.

Table 1. Mushroom production in EU member states.

country	mushroom production $* 10^6$ kg (2005)
the Netherlands	240
Poland	200
France	110
Spain	88
Italy	80
United Kingdom	70
Ireland	66
Germany	61
Belgium	33
Hungary	20.9
Denmark	4.4

The material flow of ingredients for compost production to SMS in the Dutch mushroom industry, with a specification for the flows of nitrogen and phosphate, is given in Appendix 2. Those data can be used to estimate the amounts of SMS in EU member states. For this estimation mushroom productions in Table 1 need to be multiplied with a factor equalling 910/270 = 3.4.

The amounts of nitrogen and phosphate in SMS in the Netherlands are low in relation to the production of manure by Dutch livestock and the use of chemical fertilizer in Dutch agriculture (last lines in Table of Appendix 2). Nitrogen from SMS equals 1.4 % of the total amount of manure, phosphate from SMS equals 2.1 % of the total amount of manure. SMS adds 0.8 % to the total N balance of the Netherlands (manure and fertilizers) and 1.8 % to the P balance.

3.2 Production of substrates for mushroom growing (compost and casing soil)

Two substrates are used for the cultivation of mushrooms. A lower layer consisting of compost that feeds the mushroom mycelium and a covering layer called the casing soil that allows for the development and growth of fruiting bodies, the mushrooms.
The main ingredients for compost are straw, straw-rich horse manure, chicken manure and gypsum. The main ingredients for casing soil are peat and sugar beet lime.
The processes of compost production and cultivation are described in more detail in Appendix 1.

The nutrient requirements of mushrooms demand for a specific composition of the compost. Decisive are the nitrogen and moisture contents, optima being 2.2 % and 67 %, respectively (Gerrits 1988, Straatsma et al. 1995). This implicates that compost batches from different compost yards over seasons and years, even of composts prepared by different formulations, are much alike. Composts for mushroom cultivation, and SMS as a consequence, are quite constant in composition. Additional information on composition is given in Appendix 3. SMS is more constant in composition than compost from household refuge and/or gardens.

Because of the well defined conditions for compost production and of compost composition, mushroom compost and SMS have often served as reference in studies in other composting systems, such as green waste composting.

3.3 Application of SMS in agriculture

Traditionally SMS in the Netherlands is applied in arable farming (Gerrits 1994, Zhu & Van Roestel 2002). In other countries SMS is used in similar ways, with a tendency for 'capital intensive' use for turf and lawns and for gardening (Beyer 2006).
The amounts of SMS applied to soil are limited by legislation. In the Netherlands three legislative standards apply:
• livestock manure at maximally 170 kg N per hectare
• total amount of N depending on soil type and crop; up to 250 kg N per hectare for potatoes and cabbage
• total amount of phosphate at 85 kg P_2O_5 per hectare (year 2006)
These standards, together with compositional data on SMS (Appendix 2), can be used to calculate the amount of SMS allowed to be applied. Standards, composition and calculation results are given in Table 2. The lowest amount of SMS, limited by phosphate, would be allowed.

Table 2. Standards, composition and calculation results for maximally allowed SMS application in the Netherlands.

standard for application, per hectare per year		legislation
N	170 kg N	Beschikking 2006 ('live stock manure')
P, P_2O_5	85 kg P_2O_5	
SMS composition		
dry matter	329 g/kg	
N	21.0 g/kg dm	
N-mfe *	25 %	Uitvoeringsregeling 2005
P, P_2O_5	12.0 g/kg dm	
allowed application of SMS per hectare		
N	98.4 tonne	(as 'live stock manure')
P, P_2O_5	21.5 tonne	

* N-mfe, 'mineral fertilizer equivalents'

Alternative applications of SMS like that in potting media have been studied for some decades but large scale applications have not been implemented until know. Use of SMS as a bio control agent in horticulture against plant pathogens (Hoitink & Grebus 1995, Yohalem 1995; Steinberg et al 2004) and of SMS for bioremediation of soil contaminated with organic pollutants, or in air scrubbers (Regan 1995, Buswell 1994, Stark & Williams 1995, Rupert 1995) are in development.

3.4 Stability/ Maturity of SMS

The organic matter within the ingredients for compost for mushroom production, straw and straw rich manure, go through intense degradation processes for 70 days, the transformation into SMS.

3.4.1 Degradation during composting and cultivation

Degradation of organic matter is not a linear process, but, under ideal conditions, an exponentially declining process. Rates of exponential degradation are hardly known although modelling studies use estimates for it.

During composting for mushroom compost production until phase III, in four weeks, more than 30% of dry matter is degraded. Including the cultivation period, in total in eight or nine weeks, almost 50 % of dry matter is degraded. In terms of organic matter, degradations are 40 and almost 60 %, respectively.

Degradation in other composting systems has not been described very often. Van Ginkel (1996) found dry matter losses of about 30 % in seven weeks in 'windrow' composting of straw and chicken manure mixtures. Elwell et al. (1996) found dry matter losses of over 30 % and organic matter losses of over 50 % in pilot-scale reactors in four weeks. Eghball et al. (1997) found carbon losses of up to 60 % in windrow composting of manure. Tiquia et al. (2002) found carbon losses up to almost 70 % in windrows in six weeks. Barrington et al. (2002) found carbon losses up to 55 % in pilot-scale reactors in three weeks. Ekinci et al. (2006) found dry matter losses up to 40 % in pilot-scale reactors in one week.

3.4.2 Limited self-heating of SMS

Composting proceeds by self-heating due to microbial degradation of organic matter. Mainly depending on the content of lignocellulose, nitrogen and water, organic matter can decompose very actively, producing heat, water vapour, ammonia and stench. After some time decomposition slows down and self-heating does not interfere any longer with further handling and use of the composted material. This last period is called the stabilization or maturation phase and the material is called stable or mature compost. The composting process has not necessarily stopped completely. If, for some reason, self-heating starts again, the compost is called unstable. Stability can be defined as the reluctance to decomposition.

Companies selling SMS temporarily store SMS in piles. During storage some self-heating is observed as an increase in the temperature within the pile but only after raking and turning of the piles SMS shows external signs of self-heating like vapour and/or stench production (odorous components of SMS in America were identified by Bazemore et al. 2000). During storage the bulk volume of SMS decreases by self-compression but the total mass of material shows hardly any reduction. Only after specific treatment SMS shows consistent self heating. That is in treatments to transform SMS into horticultural substrate (Seuren 1979, Maher 1991, Szmidt 1994, Levanon & Danay 1995, Soechtig & Grabbe 1995, Bazemore et al. 2000, Garcia Gomez et al. 2002). In horticulture it is sometimes observed that piled up peat, a very stable product, shows self heating incidentally (Wever & Kipp 1997).

For reasons of quality control for handling, sale and use of composts (regards phytotoxicity and nutrient immobilisation), parameters for stability/maturity are developed (Dinel et al. 1996, Bernal et al. 1998, Changa et al. 2003, Wang et al. 2004) but no consensus exists to their usefulness (see also paragraph 4). For horticultural potting media a European initiative to standardize definitions and measurements exists (Horizontal).

3.4.3 (Bio) chemical changes, humic substances

After composting, easily degradable carbohydrates will have disappeared and recalcitrant cellulose and in particular lignin will have remained. Nitrogen will have been partly incorporated into the remaining organic matter for instance as humic acid.

Microbial degradation during composting results in dark coloured colloidal material on straw remains, at least partly of microbial origin. This material is humus like and has raised interest since long (Waksman & Nissen 1932, Davies et al. 2001). Some of the nitrogen in compost after phase II is tightly bound into the lignocellulose originating from straw. It is speculated that dark coloured substances are of essential importance for the nutrition of the mushroom. Gerrits et al. (Muller 1967, Gerrits et al. 1967, Gerrits 1969) analysed the nitrogen contents of different compost fractions, hot water soluble and hot water insoluble nitrogen of compost and nitrogen within the 'α-cellulose' and 'lignin' fractions of hot water extracted compost. Their analytical method would have resulted in the α-cellulose to contain microbial chitin and the lignin to contain components of humus and/or melanin. We re-analysed their primary data. Insoluble N peaked after phase-II and declined during cropping. At the end of cropping about 60 % of N-total was insoluble. N-insoluble was associated with α-cellulose and in particular with lignin. Similar information is provided by Van Faassen & Van Dijk (1979) who studied composting of swine liquid manure and straw mixtures.

Wain (1981) collected dark coloured material for chemical analysis. Blended freeze dried compost was sonicated in 0.5 M NaOH and filtered through muslin. The filtrate was centrifuged to collect the 'debris' and the supernatant was acidified and centrifuged to collect the 'acid insoluble fraction - AIF'. Debris and AIF accounted for ~ 26 % of compost dry matter (compost at spawning – Phase II). The protein content was reported as ~ 25 % which equals 4.0 % N (factor 6.25). This would mean that N contained in the dark matter, expressed in the amount of dry matter of the compost, was ~ 1 % N. This indicates that almost half of the nitrogen present in compost is contained within the dark matter (the analytical method removed all nitrogen dissolved in 0.5 M NaOH, not to be precipitated by acidification). During the period of mycelium growth all three studied components of the dark matter are degraded to about a half. During the cropping period, the 'carbohydrate' fraction was further degraded, while degradation of the 'protein' and 'phenol' fractions was not detected.

3.5 Nitrogen in SMS

3.5.1 Requirements of mushrooms

Compost for the production of mushrooms (phase II and phase III composts) needs to be free of volatile NH_3 because growth of mushroom mycelium is easily inhibited by NH_3. During phases I and II almost 20 % of the N amount is released into the process air, scrubbed from this air and re-used in subsequent processes. After phase II almost all N is present in organic forms. During mushroom growth and development N is liberated from compost and N-rich nutrient supplement as NH_4^+ and assimilated (Baars 1996, Kersten 1999).

Gerrits (1992) presented average data on N-NH_4 en N-NO_3 composition of six SMS samples of 0.09 and <0.003 % of dry matter, respectively. The total amount N equalled 1.98 % of dry matter (see also Table 2). Recently Straatsma et al (2006) studied the mineral composition of compost and casing soil and analyzed both total and 'available' nitrogen (extraction with 0.01 M $CaCl_2$) and N-NH_4 and N-NO_3. Average compositions are given in Table 3. After cropping all forms of nitrogen show increased concentrations; the concentration of N-total increases because the total amount of organic matter decreases. The increase of N-NO_3 in casing soil was relatively high. Within SMS, a mixture of mainly compost and a smaller amount of casing soil in a ratio of about 3 : 1, the amount of N-NO_3 is low, as Gerrits (1992) found.

Table 3. Nitrogen forms and amounts in compost and casing soil before and after cropping.

		before cropping	after cropping
compost, n=8			
parameter	unit		
N-total	g / kg-DM	24.0	24.3
N-available	% of N-total	11.7	17.0
N-NH_4	"	1.0	1.5
N-NO_3	"	0.01	0.14
casing soil, n=2			
parameter	unit		
N-total	g / kg-DM	7.2	10.2
N-available	% of N-total	1.8	8.0
N-NH_4	"	0.3	0.3
N-NO_3	"	0.03	5.0

ratio compost to casing soil in SMS is about 3 : 1
for both total and dry matter

3.5.2 Mineral N in manures and composts, leaching risks

Moral et al. (2002) and Van Dijk (2003 and additional information from Bokhorst & Ter Berg 2001) give information on the amounts of N in manures and composts, discriminating between organically bound N and mineral N. The data on SMS of Van Dijk (2003) agree with those presented in Table 3.

Stewart et al. (1998) performed a leaching experiment in 'leaching tubes' and found an amount of inorganic N in the leachate 8 % higher with SMS than in a control tube without SMS (SMS application equivalent to 20 tonnes per ha). If inorganic N fertilizer was added, the fertilizer alone affected an increase of inorganic N in the leachate of 95 %. If SMS and N fertilizer were given, the effect of SMS was 3 %. Guo & Chorover (2004) studied leaching from SMS in a 'column' of 150 cm high and a diameter of 20 cm. The leaching of 'dissolved organic nitrogen' showed the same pattern in time as the leaching of 'dissolved organic carbon'. Among the cations the leaching of K^+, Ca^{2+} and Mg^{2+}, individually was higher than that of NH_4^+. Among the leached anions SO_4^{2-} and Cl^- were abundant. Some minor leaching of NO_3^- took place, starting 60 days after the beginning of the incubation. No comparison was made with soil, manure or a compost.

The data presented in paragraph 3.4, in Table 3, together with the data from Gerrits (1992), Moral et al. (2002), Van Dijk (2003), Stewart et al. (1998), Guo & Chorover (2004) and Li et al. (1997) are summarized in tabulated form (Table 4). Parameter values for composts, except SMS, are expected to show large variations.

Table 4. Characteristics of manures and SMS relevant to the risk of nitrate pollution of the soil water when used as fertilizer.

	stability / maturity	N inorganic (NH_4, NO_3) g per kg dm	g per kg N	risk of N leaching
liquid manure		40^+	500^+	+++
solid manure	very unstable	10	250	++
'compost'*		1.5	100	+
SMS	quite stable	1	50	+

* organic household and garden waste compost (GFT)

3.5.3 Fertilizer value

SMS is applied in arable farming and horticulture to improve plant growth, crop quality and yield by amelioration of the soil with organic matter. The provision of mineral nutrients is an important aspect in particular that of nitrogen. Other aspects play a role as well (see below) and interact with effects of minerals. Straightforward experiments, like dose-response experiments with SMS applications to a soil with a crop are difficult to evaluate if flanking experimental treatments and measurements are lacking. Comparative testing of SMS and mineral fertilizers has hardly been done (Stephens et al. 1989, Weber et al. 1997, Sangwan et al. 2002). A conclusive value for what is called the 'mineral fertilizer equivalence' (MFE) is not available. Quite some studies have been done on the availability and the release of nutrients from plant residues, manure and composts. SMS occasionally was taken as reference compost (Raijmakers & Janssen 1993, Van Faassen & Lebbink 1992, 1994, Velthof et al. 1998, Stewart et al. 1998, Moolenaar & Postma 2003, Veeken et al. 2003. De Visser et al. 2004, Heinen & De Willigen 2005). Such studies are less based on field observations and field experiments but more on (bio) chemical analysis under laboratory conditions and *in silico* analysis (Van Veen et al. 1984, Liang et al. 2004) of quite simple basic information. Van Dijk et al. (2004) reported on the *in silico* estimation of MFE used for Dutch legislation (Uitvoeringsregeling 2005). For SMS a MFE value of 25 % was estimated.

The C/N ratio of an organic material has traditionally been seen and is still seen a good predictor for degradation and mineralization, also of nitrogen (Janssen 1984, 1996). This is remarkable since both C and N can be bound within the organic matter in different forms, 'pools', of which it is known that they are differently degradable. Apparently the C/N ratio is 'smoothing' the effect of different 'causal' factors. Despite efforts to improve the applied value of the C/N ratio, for instance in the ratio of $C_{available}/N_{available}$, or C/N ratios of different fractions of the organic material, the 'overall' C/N ratio remains a valuable parameter (Henriksen & Breland 1999, Hartz et al 2000, Kumar & Goh 2003, Gutser et al 2005).

Other effects of SMS on plant growth may relate to its relatively high level of 'salts' as reflected in relatively high EC values (Kaufmann 1967, Wever et al. 2005). For some period after application of SMS, immobilization of nitrogen has been observed. This is considered to be the effect of organic matter (carbon) degradation. Microbes performing this degradation need nutrients like nitrogen and take up such nutrients. This makes those nutrients inaccessible for plant uptake. A positive effect of SMS, as observed for other composts, is disease suppression (Hoitink & Grebus 1994, De Visser et al. 2004, Davis et al. 2005) due to a stimulus of the soil microbial antagonism to rapid development of newly colonizing microbial species like pathogens.

4 Other composts, standards

Recycling of rest and waste products is supported by governmental as well as non-governmental organisations. The need for standardization for composting processes and composts is widely recognized within the recycling industry as well as by authorities. However, final standards are rare. In Canada a worked out standard has been published (BNQ 2005). Brinton (2000) published guidelines for standards/standardization for the USA, in particular NY State. His paper gives an overview of the complexity of standardization. For Europe no generally accepted standards exist but many initiatives exist, reviewed by ECN (2006).

In general, provisional compost standards are concerned with the amounts of heavy metals, agents pathogenic to plants, animals and humans (negative elements) and the plant nutritional and soil conditioning value (positive elements, except for nutrient immobilisation, a negative element).

The lack of standards for compost seems to make it difficult to decide whether SMS is a true compost or not. In the past composting for mushroom production has been an example for the development of other composting processes. The consistent composition of SMS has often made SMS-treatment a control in laboratory and field testing of composts. People in the field consider mushroom compost and SMS to be compost by definition.

5 Definitions in legislation

The application of excessive amounts of fertilizers in agriculture results in the pollution of surface and ground water, with nitrate. The potential risks accompanying fertilization resulted in European legislation laid down in the Nitrate Directive (1991; 91/676).
The Nitrate Directive defines:
• (e) 'fertilizer`: means any substance containing a nitrogen compound or nitrogen compounds utilized on land to enhance growth of vegetation; it may include livestock manure, the residues from fish farms and sewage sludge;
• (f) 'chemical fertilizer`: means any fertilizer which is manufactured by an industrial process;
• g) 'livestock manure`: means waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form;

Unfortunately 'compost', as a fertilizer and/or as a soil conditioner is not (yet) defined in European legislation. The subject of compost has been touched on in the regulation of organic production (2092/91), and in the reports 'Greening the CAP' and 'Energy for the future'. In these texts the recycling of agricultural rest products and the prevention of soil erosion are mentioned. In case of soil erosion compost can be applied for remediation. The waste directive (2006; 2006/12) states: 'The recovery of waste and the use of recovered materials as raw materials should be encouraged in order to conserve natural resources. It may be necessary to adopt specific rules for re- usable waste.'

SMS is considered as 'livestock manure' in Dutch legislation (Uitvoeringsregeling Meststoffenwet, 2005). The accompanying commentary to legislation states that the general services of the EU do not allow for another consideration ('… de Nitraatrichtlijn (EU 1991) geen andere aanmerking toelaat (door Diensten van de Commissie)').

The view that SMS belongs within the category 'live stock manure' seems the consequence of a very strict interpretation of the Nitrate Directive.

The primary aim of composting for mushroom production is to produce an optimal substrate for mushroom growing, not to process livestock manure for temporary storage, sale as a fertilizer etc. If costs for the production of mushroom compost were not considered, mushroom compost could be produced with urea or ammonium sulphate replacing livestock manure. Mushrooms require a large amount of organic matter in their substrate. For this reason straw, a litter in animal husbandry, is used. This straw is not used for the comfort of animals or for the absorption of faeces and/or urine in the keeping of animals. It is used for the production of a substrate for mushrooms, stable and rich in organic matter. For SMS (and other composts) a new category needs to be raised and defined: compost.

6 Conclusions

• Spent mushroom compost, SMS, is produced, marketed and applied in many EU member states. The amounts concerned can be estimated from the amount of mushrooms produced (Table 1), to be multiplied with a factor 3.4 (paragraph 3.1).

• The composition of SMS is relatively constant over time, over producers and regions. SMS is less variable in composition than compost of household refuse and livestock manure. This is the result of the specific requirements of the mushroom crop met by compost producers and mushroom growers (paragraph 3.2).

• Dutch legislative standards on nitrogen and phosphate applications limit the application of SMS in agriculture to 21.5 tonne per hectare. Ultimately the phosphate standard is the limiting factor (paragraph 3.3).

• SMS is stable and mature. Much of its original organic matter has been degraded, the remaining material shows elevated concentrations of lignocellulose. SMS has a limited self-heating capacity. Microbial and biochemical transformations of carbon and nitrogen have occurred (paragraph 3.4)

• SMS contains N, related to the requirements of the mushroom crop. Most N is organically bound. The concentrations of mineral N are much lower than in animal manures, even lower than in some other composts. Mineral N does leach from SMS but only in limited amounts (Table 4, paragraph 3.5).

• Clear and authoritative standards for compost are lacking, not only in Europe but elsewhere too (paragraph 4).

• Definitions of 'live stock manure' and 'chemical fertilizer' in the Nitrate Directive do not make a definition of compost redundant (paragraph 5).

• SMS is compost, not 'livestock manure'.

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Appendices

1. Composting and cultivation processes

Compost for white button mushrooms is produced in a sequence of three bulk processes, phases I – III, in so called tunnels. At the end of phase III, compost is fully colonized with mushroom mycelium ('spawn run compost', 'fully grown compost') and is transported from the composting facility to the mushroom grower for cropping.

		processing room	temperature, °C	inoculum	time, days
	mixing ingredients	hall			1
1	phase I	tunnel	70		6
2	phase II	tunnel	45	phase II compost	6
3	phase III	tunnel	24	mushroom spawn	14
4	cultivation, casing soil colonization	growing room	24		10
	, fruit body development	growing room	20		30

Tunnels are structures with a perforated floor and an air-conditioning system to force air through the compost pile on the floor. Process air is re-circulated.

Phase I is a high temperature process. By self-heating the temperatures rises up to 80 °C. This is important for a rapid 'opening up' of straw and maximal water absorption. The high temperature also eradicates pathogens to the mushroom crop as well as pathogens to animals, plants and humans. After phase I the compost should remain much of the structure of the compost ingredients. The compost should be able to resist compression so that water as well as air remains present in sufficient amounts.

Phase II is a process at 45 °C. In between phase I and phase II the compost is inoculated with about 1% (w/w) of compost already gone through phase II. This material contains micro organisms that are important for the performance of mushroom mycelium later on. Among these micro organisms, the thermophilic fungus *Scytalidium thermophilum* plays a key role. In phase II much heat is produced by self-heating. This heat is ventilated off as water vapour. Self-heating and evaporation cause losses of organic matter and water. After phase II the compost is fully colonized with beneficial micro organisms, this makes the compost 'selective' for growth of mushroom mycelium. Mushroom mycelium is inoculated, 'spawned', and phase III is started, a process at 24 °C.

After transportation of finished phase III compost to the mushroom grower, the compost is filled in trays in growing rooms. Before filling, a nutrient supplement is added to the compost consisting of treated soy meal. The layer of compost is covered with a layer of 'casing soil', a mixture of peat and sugar beet lime. Mushroom mycelium in the compost easily regenerates after handling and transport. The mycelium within the compost almost immediately starts to spread into the casing soil. Conditions in the casing soil, together with a lowering of the temperature to less than 20 °C, stimulate the mycelium to form fruit body initials. Subsequently initials develop into mushroom fruit bodies. After harvesting much of the compost and the casing soil remain. The growing room is pasteurized at 80 °C to eliminate any (micro) organisms pathogenic to a new mushroom crop in the growing room. The pasteurized finished substrate, SMS, is removed from the growing room. The total period of composting and cultivation spans almost 70 days.

The amount of animal manure in compost depends on the compost formulation used. Important is the nitrogen contents in phase III compost. The optimum N contents for the mushroom crop equals 2.2 % N of dry matter. The required N is provided for by the compost ingredients. Volatile NH_3 is produced during the composting process. NH_3 is scrubbed from the process air and recycled. The amount of N volatilized, scrubbed from process air and recycled relates to almost 1/3 of N in the compost.

A formulation of straw and an inorganic nitrogen source (urea or ammonium sulphate) shows perspectives according to experiments on pilot scale. Implementation of this approach is limited due to increased costs of ingredients and the expected requirement for process modifications (costs of optimizing the new process and costs related to the equipment for a modified process).

Growth of the white button mushroom, *Agaricus bisporus*, depends on the degradation of organic matter within the compost by mycelium. The compost colour changes from dark brown to a brighter, almost reddish colour due to mycelium activity. This colour shift bears similarity to that in wood due to 'white rot', a type of degradation caused by a group of mushrooms that have ecological characteristics in common with 'litter degraders' like *A. bisporus*. Apparently, dark coloured material on the compost, that developed during composting, disappears during cultivation. It is speculated that the 'dark matter' consists of degradation products of the organic matter of compost and of dead microbes and their remains. The organic matter in compost ingredients, straw rich horse manure, straw, chicken manure, gypsum and water, consists mainly of lignocellulose, plant cell wall material that is recalcitrant to degradation by most organisms. Plant cell walls and lignocellulose are complex in composition and difficult to characterize in detail. Although studies on degradation by *A. bisporus* have been done (Gerrits et al 1967, 1969, Iiyama et al 1994, Sharma et al 2000, Chen et al 2000), the number of studies is limited by the relatively modest economical impact and financial resources of the sector for science and research. Some efforts have been done to elucidate the composition of the, maybe humus like, 'dark matter' (Wain 1981, Iiyama et al 1996, Sharma et al 1996). It accounts for about 25 % of compost dry matter after phase-II composting and it has an elevated N contents compared to compost as a whole.

During composting and cultivation 60% of the organic matter within the compost is degraded microbiologically. Degradation is very intense and also minerals are involved in metabolic cycles of degradation, assimilation and again degradation. Compost after cultivation is very much a microbial rest product. After cultivation, the compost dry matter contains almost 40 % ash, and roughly 20 % lignin, 10 % cellulose and 5 % hemicellulose. These data relate to compost only, not to a mixture of compost and casing soil as in SMS.

2. Balance sheet Dutch mushroom industry

The amount of SMS produced in the Netherlands is estimated to be 900 10^6 kg per year (Straatsma, unpublished balance study on 2003 data). The yearly production expressed in amounts of nitrogen and phosphate is about 6 10^6 kg N and 4 10^6 kg P2O5 respectively. These amounts are low in relation to the production of manure by Dutch livestock and the use of chemical fertilizer in Dutch agriculture.
The difference between N input and N output in the mushroom industry is caused by volatilization of NH_3 during composting; this amount is not measured directly; NH_3 is scrubbed from waste process air and recycled into the ingredients but its amount is not measured directly.

	fresh weight, 10^6 kg	N, 10^6 kg	P_2O_5, 10^6 kg
Dutch mushroom industry			
compost ingredients			
staw rich horse manure	650	3.0	1.6
straw	87	0.5	0.2
chicken manure, stackable	50	1.6	1.0
chicken manure, liquid	120	1.2	0.7
mixture (incl water, gypsum)	1443		
casing soil ingredients			
peat	300	0.4	0.1
sugar beet lime	30	0.1	0.3
nutrient supplement (soy)	10	0.8	0.2
total, in		**7.5**	**4.0**
mushroom crop	270	1.0	0.5
trimmed stipes (waste)	41	0.2	0.1
spent mushroom substrate	910	4.5	3.2
total, out		**5.7**	**3.8**
Dutch live stock, manure production, ex NH_3 volatilization[a]		416	185
Dutch agriculture chemical fertilizer input[b]		292	21

[a], Van Bruggen, 2006
[b], CBS

3. Composition of SMS

The mineral composition of SMS is relatively well known. Data on 25 Dutch samples per year from the years 2001, 2002 and 2005 analysed by an accredited analytical laboratory are presented below. Individual measurements of some parameters resulted in values at the detection limit, for instance for Cd, Hg and Pb. Parameters showed differences in their patterns of variation; some showed high coefficients of variation. Some parameters had their values distributed non-normally according to a Kolmogorov-Smirnov test, in particular Hg, Pb, As). This means that individual values for parameters like Cd, Cr, Hg, Pb and As have to be interpreted with some caution. The compositional data are largely in agreement with older data published by Gerrits (1994) on 11 years in the period from 1966 to 1993 and Gerrits (1997) on the analysis of more than 30 different minerals in a round robin (ring test).

Table. Composition of 25 Dutch SMS samples per year from the years 2001, 2002 and 2005.

parameter	unit	median	average	standard deviation	coefficient variation	minimum	maximum	n, samples	n, below detection
dry matter	g/kg	329	327	33	10	245	416	75	0
organic matter	% of dm	61.5	61.0	2.5	4	54.2	65.8	75	0
N, in dm	g/kg	21.0	20.8	1.6	8	15.9	24.9	74	0
P, P_2O_5	g/kg	12.0	12.1	1.7	14	7.8	17.0	75	0
K_2O	g/kg	22.8	23.4	4.9	21	15.5	36.0	74	0
Cd	mg/kg	0.24	0.27	0.05	20	0.20	0.41	66	9
Cr	mg/kg	6.6	7.5	3.7	49	3.5	26.0	74	1
Cu	mg/kg	31.0	34.1	16.3	48	17.0	112.0	75	0
Hg	mg/kg	0.04	0.04	0.01	28	0.03	0.07	67	8
Ni	mg/kg	4.2	4.4	1.3	30	2.7	12.0	74	1
Pb	mg/kg	<6.6	7.2	2.0	27	6.3	16.0	30	45
Zn	mg/kg	133	135	24	18	56	192	75	0
As	mg/kg	1.3	1.8	0.9	51	1.1	4.3	70	5
EC	mS/cm	13.1	13.0	1.9	14	9.9	18.8	74	0
C/N	estimat.	10.2	10.4	1.2	11	8.2	14.1	74	0