The alternative uses of spent mushroom compost

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Samenvatting: alternatief gebruik van champost,

Aanleiding en doel

Het Productschap Tuinbouw heeft op verzoek van de Commissie Paddestoelen opdracht gegeven aan Stichting ECO Consult om naar alternatieven te zoeken voor champost. Nieuwe regelgeving leidde tot hogere afzetkosten van de champost, omdat deze als dierlijke mest wordt beschouwd.

Resultaat: De volgende alternatieven zijn door ECO Consult in samenwerking met het Fujian Mushroom R&D Station geïnventariseerd en beschreven:

1. Inzetten als veevoeding,
2. Verbranding,
3. Cofermentatie voor bemesting,
4. Direct gebruik als bemester,
5. Vergisten,
6. Bodemverbeteraar,
7. Substraat voor planten ter vervanging van veen
8. Als substraat voor andere paddestoelensoorten
9. Planthormonen
10. Bio-pesticides
11. Grondstof voor dekaarde
12. Bodemsanering

De toepasbaarheid van die mogelijkheden in Nederland is onderstaand ingeschat:

1. direct inzetten als veevoer zal op veel weerstand van de voedingssector stuiten, het winnen van hoogwaardige eiwitten daarentegen is wellicht wel interessant
2. direct verbranden levert vanwege het hoge vochtgehalte nauwelijks rendement op
3. cofermentatie op champignonbedrijven stuit op hygiënische bezwaren
4. direct gebruik als bemester is de huidige referentie situatie
5. voor vergisten is de energie inhoud te laag (zelfs nog lager dan mest)
6. gebruik als bodemverbeteraar is net als punt 4 de huidige referentiesituatie en zal de hoge transportkosten niet kunnen dekken
7. substraat voor potplanten lijkt wel haalbaar indien er een oplossing komt voor de hoge zoutgehaltes in de champost
8. de hoeveelheid champost is zo groot dat er geen andere soorten paddestoelen zijn die voldoende champost kunnen afnemen als grondstof voor substraat
9. het extraheren van planthormonen is wellicht een optie, nader onderzoek is nodig naar de inhoudsstoffen
10. biopesticides zijn technisch eenvoudig te bereiden uit champost, maar het volume biedt geen soelaas voor kwekers waar wekelijk honderd ton champost verwijderd dient te worden.
11. grondstof voor dekaarde is alleen in gebruik in landen waar geen veen voorhanden is
12. bodemsanering is in Nederland geen continu proces, wellicht liggen er in de sfeer van afvalwaterzuivering mogelijkheden, maar de kans dat daarbij grote hoeveelheden nodig zijn, wordt laag ingeschat.

Nieuwe inzichten op het gebied van bioraffinage en biocascades leiden tot het volgende ontwerpprincipe voor de verwerking van champost:

1. scheiden van de dekaarde van de champost bij het leeghalen van de cellen en benutten van de dekaarde voor potplanten
2. droogpersen van de champost en benutten van beide fracties
3. droge fractie inzetten voor potplanten of biobrandstof
4. natte fractie gebruiken om planthormonen en/of eiwitten uit te winnen.

Op alle vier de bovengemoemde punten is nader onderzoek nodig naar de technische en financiële haalbaarheid.

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Introduction

The Dutch mushroom sector has recently been confronted with new legislation concerning spent mushroom compost, or champost as it is called in The Netherlands. The sector has to spend several millions Euro's each year to transport the champost to the area's where it can be applied to the soil. ECO Consult Foundation proposed the Agaricus-growers to investigate which alternative uses champost has in other countries in cooperation with the Fujian Mushroom Research and Development Station in Fuzhou. The Productschap Tuinbouw funded the desk research.
It is well known that China is the biggest producer of mushroom in the world. In 2005, it produced 11.6 million tons of fresh mushrooms, about 75% of the world's total production. The production value was 4.8 billion euro[1]. More than 4 million tons of mushroom cultivation residue were reused [2]. The Chinese call it mushroom bran or mushroom residue, even mushroom soil, Europeans call it spent mushroom compost (SMC), and the Americans call it spent mushroom substrate (SMS).

What is SMC, or SMS? SMC is made from agricultural materials, such as wheat-straw horse manure, hay, poultry manure, cottonseed meal, cocoa shells and gypsum. Mushroom production takes place in specialized, climate controlled rooms and lasts for approximately 70 days before new compost is required.

When new compost is needed in modern *Agaricus* cultivation, the SMC remaining from the old compost is usually steam pasteurized to reduce hygiene problems for the next mushroom crop and then removed from the growing rooms. SMS can be used for the other agricultural crops and products since it is an ideal soil enrichment with important nutrients.

SMS is a bulky waste product of the mushroom industry and produced abundantly. Depending on the different cultivated mushroom species, the respective SMS types have different contents because they were made from different substrate ingredients and the substrate preparation method and type of cultivated mushroom have different impacts. The Straw mushroom (Volvariella) for example degrades mainly cellulose and leaves the lignin almost intact, whereas white rot fungi from genera like *Pleurotus* and *Lentinula*.

China produces more than 4 million tons of SMC annually. The traditional method was discarding or burning. As burning generates only 10% of the energy value (because of the high moisture content), it is a waste of biological resources. Discarding can bring about the pollution of environment for its abundance organic nutrient or/and the plastic.

In contrast to Holland, spent mushroom compost (SMC) is not considered a waste in China. A vegetable grower will often spend RMB100 (about Euro 10) to buy one ton SMC from the mushroom farm, therefore the people in China developed several methods to utilize this "expensive" SMC.

This report introduces these different methods and may serve as inspiration when developing products from champost in The Netherlands. Most of the applications below were scientific experiments, in some cases the reports indicate whether the method has been put into practice on a larger scale.

A. Feeding to earthworm, insect, etc. to produce protein for fish and chicken, or directly feed domestic animals

Edible fungi secrete many kinds of extra cellular enzymes that have strong capacities for decomposing cellulose, hemicelluloses and lignin, and can therefore optimize the ratio of ingredients in an animal feed. SMS from mushroom cultivation contains about 14% protein and an abundance of vitamins and microelements such as Fe, Ca, Zn and Mg. Mycelia remaining in the SMS also contain essential amino acids which are absent from common feeds, so that the nutritional value is equal to wheat bran or corn flour. Therefore, SMS represents a cheap and nutritious feed that can replace crude feeds such as grain and bran.

Based on collecting and screening the micro organisms for preparing fermented feedstuff, Tian Juan performed a study on fermented feedstuff production by solid fermentation of *Pleurotus ostreatus* SMC. The results showed that after solid fermentation by micro organisms, not only the crude protein of SMC increased (up to 16.34%), but it was enriched in vitamins, amino acids, cellulases and living spores, which made the fermented SMC to be good feedstuff for animals such as beef,, rabbits and pigs. The solid fermentation technology for SMC was simple and feasible, and could be popularized in mushroom production area [3]. Li Zhixiang also studied the solid fermentation of *Pleurotus ostreatus* SMC by adding several kinds of yeasts, and analyzed the fermented SMC. It was shown that the fermented SMC of different substrates all contained more than 20% of crude protein, and could be developed as functional feedstuff for fowls and domestic animals. [4]

In Zhuo Shaoming's study, the shiitake SMC, cow manure, banana stems and their various combinations were used as food materials to raise earthworms. Table 1. below showed the 7 treatments (3 repeats each) and their characters. 5Kg (wet weight) raw materials for each repeat was added with Em microorganism mixture (which was sold on the market and contained dozens of kinds of microorganisms) and fermented for 7 days. After 2 hours of ventilation, the fermented substrate was fed to 50 matured earthworms. The earthworms were harvested and counted after 70 days of breeding. As a result, a total of 1388 earthworms were produced in the treatment sample feed with SMC, the highest number among all the treatments. The earthworms reproduction rate was the highest when the pH value was 7.0and the water content was 60-65%.[5][6]

Table 1. The worms yield in different treatment

Treat-ment	Component and proportion of substrate (%)			content	C/N	Water content (%)	pH before fermenta-tion	Average pH after harvest	Average worm yield
	Cow manure	Banana stems	SMC						
A	100	/	/	Granule with diameter of about	25:1	60-70	6.0	6.5	799
B	/	100	/	20cm*5cm*0.5cm	21:1	60-70	7.0	9.0	46
C	/	/	100	Granule with diameter of about	25:1	60-70	6.0	7.0	1388
D	50	50	/	Granule mixture of A+B	23:1	60-70	6.5	7.7	297
E	20	80	/	Granule mixture of A+B	21:1	60-70	6.5	8.5	65
F	/	50	50	Granule mixture of B+C	23:1	60-70	6.5	7.8	104
G	/	80	20	Granule mixture of B+C	21:1	60-70	6.5	8.5	67

It was also reported that all kinds of SMC could be used as feedstuff for raising earthworms. The SMC is rich in mycelia and part-decomposed cellulose, and what you should do is to add a certain proportion of soil and adjust the C/N ratio. The technology was simple and commonly used.[7]

Hu Huangyu et al. carried out a preliminary study of using eelworm to transfer *Pleurotus ostreatus* SMC as feedstuff. The result showed that *Bursaphelenchus mucronolus* could reduce the crude fiber of SMC by 42.2%, and increase the crude protein by 80.1%. Using the mixed feedstuff prepared from the transferred SMC to feed rabbits, each rabbits increased weight by 0.52Kg every month. [8]

Dong Zhi-guo reported that 60% of diet replaced by *Pleurotus ostreatus* SMC mainly containing cottonseed shell, compared with 45% of diet or all diet replaced by the SMC, the average daily gain difference of the Karacul sheep is not outstanding($P > 0.05$). But the cost of per kilogram feed is 0.11 RMBYuan(0.011Euro) lower than contrast group, 11.4% cheaper. The economical evaluation is striking. [9]

Li Hao-Bo reported feeding different percentage (20%, 25%, 30%) of waste material from *Lentinus edodes* and *Pleurotus ostreatus* (WMLE) and normal diet to non-pregnant sows, pregnant sows and suckling sows. He studied their reproductive performance. Results showed that living piglet number, average weight of new born piglet, lactation ability of sows are all improved. Among trial groups, group that adding 30 % WMLE was the best, and the group also brought the most significant effect on piglet weight during 0~21 days and 21~35 days. Trials showed that the rate of piglet mortality and diarrhea decreased. The result showed that WMLE feed has important meaning for grain-saving, and efficient and safe swine production. [10]

It is also reported that utilizing the mixed feedstuff from straw SMC of *Pleurotus ostreatus and Pleurotus sajar-caju* to feed pigs could get the effect of feeding corn, and decrease the cost and increase economic benefit. To feed pigs using the mixed feedstuff containing one third SMC, each pig increased weight by morn than 780g daily, and saved foodstuff by 40%, reduced cost by 50%. Adding SMC to the feedstuff needs an adaptation period of about one week, increasing gradually from 10% to 30%. It's widely used in some hoggery. [11]

The experiment by Lei Xueqin was conducted to use 5% and 10% *Pleurotus ostreatus* SMC to take place of same quantity mixed concentrate to feed dairy cattle. The result showed that milk production ($P > 0.05$) and the economic efficiency of treatment groups were higher than control group by 3%~6.1%. [12]

In the article of Bao Ruohong et al., Cell wall constituents (CWC) of the waste material from fungal culture (WMFC) by different treatments were assayed for studying the effect of different treatments such as chemical, microorganism, combination of chemical and microorganism on improvement of the feeding value of WMFC. Four hybrid yellow cattle flitted with rumen canellas were selected to study degradability of organism material (OM) of WMFC by above different treatments using the method of rumen by 4 ×4 Latin square design. The results were as follows : (1) The three kinds of WMFC such as neutral detergent fiber (NDF) , acid detergent fiber (ADF) and acid detergent lignin (ADL) decreased by chemical treatment , the effect of NaOH treatment was the best , in all chemical treatments .NDF , ADF , ADL decreased by 5.71 %~9.92 % , 7.43%~13.36 % and 10.55%~20.47%, respectively; three kinds of white rot fungi, (Y4 , Y5 and Y8) decreased NDF, ADF，CEL, HC and ADL of waste material from *Lentinus edodes* (WMLE) significantly , among these treatments the effect of Y8 was the best , and the effect of combination treatment of the NaOH and microorganism on the improvement of the CWC was better than that of single chemical or microorganism treatment. (2) The effective degradability of OM of WMLE by the three kinds of chemical treatment (NaOH, urea and urea + NaOH) , increased by 19.60 % , 13.16 % and 21.02 % respectively ($p < 0.05$). The effects of Y4, Y5 and Y8 were best in microorganism treatments, their effective degradability of OM of WMLE increased by 31.65 %, ($p < 0.05$) , 47.69 % ($p < 0.01$) and 55.82 % ($p<0.01$) , respectively . The effects of Y5 and Y8 were better than those of Y4. The Effect of combination treatment of NaOH and microorganism was better than that of single chemical or microorganism treatment on improvement of CWC of WMLE and CWC. [13]

It's reported that SMC(we think it was wood mushroom) was also a kind of fish feedstuff with rich nutrient. The preparation method for complex fish feedstuff is: dry and comminute the SMC, and completely mixed with barley powder at a proportion of 3:7. The experiment showed that using the complex fish feedstuff, fish production increased 35.91%, and reduced feed cost by 23.7% compared with that of feeding barley powder only.[14]

No reports were found how champost from Agaricus could be used as feed.

B. Fermentation with other additives

The goal is to produce organic fertilizer with a high N source for plants, which is called top fertilizer and can be sold at a relatively high price.

At present, the main raw materials for most of flowers nutritive soil were natural peat moss or forest humus. Producing nutritive soil for flowers using SMC of *Agaricus bisporus* and crop straws avoids the environment pollution by organic residue. Liang Zhi et al. performed the trial of preparing flowers nutritive soil using organic residue, and the results showed that the flowers nutritive soil could be prepared by using organic residue (leaves, straws, SMC and livestock manure) and soil, slag, perlite and so on. The key technique for flowers nutritive soil production was: the organic residues (SMC 500Kg, urea 5Kg, corn straw (5-10cm) 500Kg, calcium superphosphate 10Kg, sheep manure 500Kg, K_2SO_4 1Kg and a certain volume of water) were fermented to produce humus firstly (about 30days totally, and turned every 7-10 days), and then the nutritive soil was prepared according to its index requirements (pH = 5.5-7, unit weight < 1 g / cm^3, organic matter ≥8%, $NH4^+$ - N≥150 mg / kg, Olson - P≥30 mg / kg, NH4AC - K≥300 mg / kg) and the characteristics of the raw materials. [15]

Utilization of solid wastes like spent compost to produce horticultural substrate has become an environmental friendly measure to full-utilize the natural resources. In this study, the spent compost of *Flammulina velutipes* was tested as raw material to produce horticultural substrate. $1m^3$ SMC was added 0.5Kg urea, 3Kg (dry weight) sesame residue, 3Kg chicken manure and 0.2Kg marketing microorganisms reagent (containing azotobacteria, phosphorus or potassium degradation microorganisms) as supplemental materials. The composted spent compost should be mixed with vermiculite at 6:4 in volume. The mixture was proved to be a good horticultural substrate in cutting costs and improve yields by cucumber and net melon cultural experiments. [16]

Three continuous rotations of non-heads Chinese cabbage pot experiments were conducted together with the application of different mixture of *Pleurotus ostreatus* SMC and microbiological agents in a glass greenhouse to study the influences of microbial manures on non-heads Chinese cabbage growth and yield by measuring plant height, root length, number of leaves during different plant stages. The results indicated that microbial manures promoted non-heads Chinese cabbage growth and increased its yield; and that Treatment 1 (*strephomyces sp.* + *bacillus megatherium* + SMC) had the best effects among all the treatment. [17]

Pepper pot experiments were conducted together with the application of different microorganism and *Pleurotus ostreatus* SMC in a glass greenhouse to study the influences of microbial manures (microorganisms + residue of mushroom medium) on pepper yield，nutrient uptake and soil nutrients by measuring yield of pepper，and by determining changes of soil alkaline hydrolysis N，available P，available K contents and total N，P，K contents of pepper plant after harvesting. The results indicated that microbial manures increased pepper yield and were conducive to improvement of soil fertility and total N，P，K contents of pepper plant. Treatment 3 (*strephomyces sp.* + *bacillus megatherium* + SMC) had the best effects among all the microbial treatments. [18]

The following experiment was to study the effect of waste mushroom compost mixed with livestock manure, soybean cake and chemical fertilizer on soil response, yield and quality of tomato.

Compost materials at C/N=30, moisture content is about 60%, volume is 1.5 x 1.5 x 1 m, turn over at every 10 days, if mixed with chicken and cattle manures, castor oil extract, soybean cake and chemical fertilizer, 60 days after piling up, the C/N ratio could reduced to the maturation index of about 20. The compost was applied to field before transplanting. Field trial of tomato result indicated that the chicken manure plot have the highest fruit yield of fall crop of 5,054 kg/0.1 ha, which is 30.8% higher than the control plot. Fruit yield in treatment of mushroom compost mixed with 5% compound fertilizer was 4,959 kg/0.1 ha, which is 28.4% higher than control plot, followed by soybean cake plot, which are 4,886 kg/0.1 ha. Result of spring crop of tomato indicated that chicken manure plot have the highest fruit yield, which is 4558 kg/0.1 ha, followed by castor oil extract, soybean cake and compound fertilizer plots, which is 12.5 - 14.3% higher than that of control plot. Fruit yield of control plot is 3773 kg/0.1 ha. The low yield of control plot is due to the waste compost have low nutrition after growing mushroom and was polluted by miscellaneous fungi. Effect of recycled waste mushroom compost on sugar content of tomato fruit, in fall crop is ranged from 4.94~5.25; in spring crop is ranged from 4.89~5.25. Application of compost didn't show any difference in pH and EC value of soil reaction, but the content of organic matter, potassium, calcium and magnesium is increased, while the phosphorous content is declined. In general, the recycled mushroom compost could increase the soil fertility, enhance the yield and quality of tomato fruit, it is recommendable to the production of vegetable crops. [19]

C. Mixed with other manure to produce biogas for heating or cooking.

Spent mushroom substrate is an ideal material for producing marsh gas. There are many nutrient substances in SMS that provide the basis for the long-term propagation of methane-producing bacteria, and using SMS as a starting material for producing marsh gas shortens the fermentation time. Furthermore, since SMS is readily broken up into smaller pieces, there is less time and workload involved in the preparation and reloading of feedstock material.

In Zhou Songlin's report, the technology of utilizing several kinds of SMC from bed or bag cultivation of *Agaricus bisporus, Lentinula edodes* or *Auricularia anricula* to produce biogas was popularized at Sanzhi County in 2001. Based on the detection results, this technology had a faster rate and a higher heat value of producing biogas compared with those of utilizing straws and sawdust, and 3~5Kg SMC could produce 6~10m^3 of biogas, which was enough for daily use of a family with 3~5 persons. Now, the dried SMC was hot sold at Sanzhi County, with a price of more than 10 RMB Yuan per 50Kg. This technology has been popularized in the county nowadays. [20]

Dr. Ron Fleming's study was to discuss the feasibility of using anaerobic digestion to further process SMS-esp. value of the methane gas and the feasibility of using composting to further process and add value to SMS. In the compost trial, the temperatures were in 40 to 60℃ range within 1 day, while the outside weather temperature was close to 0℃ for entire time. The compost was left for 150 days but most composting in first month. Germination results (cucumber) were 86%, 89%, 97% and 97% for SMS and compost from Ch1, 2, 3, respectively.

In the anaerobic digestion, the SMS loading rate of 6.7 kg/day produced methane 355 L/day with methane concentration of 49.3%. So the methane yield was 53.0 L/kg, which was much lower than 288 to 562 L/kg, the expected range for livestock manure. [21]

Mixing / heating tank

Drawing

Gas meter

Collecting biogas

Pictures above by Fleming

Table 2. Changes in Mass from start to study completion			
	Channel Mass (k	Channel Mass (k	Channel Mass (k
Start (Day 0)	24,22	24,22	24,22
Final day 150	13,17	9313	11,78
Final as % of initial	54	38	49
Channel 1 - no turning; Channel 2 - turned monthly; Channel 3 - t weekly			

Table 3. Chemical characteristics of fresh SMS vs compost at Day 56 (N - % "As is"; EC - mS/cm)				
	SMS	Ch1	Ch2	Ch3
N	0.95	0.84	0.81	0.85
P	0.49	0.59	0.54	0.58
K	0.81	0.74	0.85	0.89
EC	5.6	6.2	6.5	6.4

In the two reports above, using SMC to produce marsh gas had a higher yield than that of using straw and sawdust, but had a much lower yield than that of using livestock manure, which resulted in different conclusion of SMC in the efficiency of producing marsh gas. Whether the SMC is a good source for biogas should be depended on the raw materials resources in local place.

Not only can the marsh gas produced from SMS be used as a fuel but also for storing foods and fruits. Residue from the methane ponds can be used to nurse rice seedlings, and pond liquid can be employed for immersing seeds prior to planting, or as a pig feed additive. Utilization of SMS for marsh gas production can form part of a crop recycling strategy-edible fungi – marsh gas-organic fertilizer, feed stuff-biomass. Such a system is an effective ecological-agricultural model.

It’s said that Japanese developed the technology of ethanol production by sawdust SMC fermentation and American developed the technology by button mushroom SMC fermentation, but the details were not found. And in China, there was no related report or publication.

D. Bottom fertilizer: SMC directly used for planting vegetable, fruit, etc.

SMC when added to soils can have a number of beneficial effects. Because it contains significant amounts of essential plant nutrients, it can supply these to the crop and thus replace inorganic fertilizer. Trials have shown that it is an excellent source of phosphorus (P), potassium (K) and trace elements but needs supplementation with nitrogen (N) for best results.

Because SMC has high organic matter content, it can have important benefits in improving the physical structure of the soil. Soils in continuous tillage systems can have reduced organic matter content with a consequent poor structure that makes the soil difficult to work and impedes drainage. This is probably most likely in intensive horticultural or tillage systems where, in the past, farmyard manure was traditionally used. Use of SMC will increase the activity of soil micro-organisms and earth worms, help develop a good crumb structure, improve soil porosity and make it easier to work.

He Guoxiang reported that the SMC of *Agaricus bisporus* used as paddy bottom fertilizer with a usage of 1-4 tons per 660m^2 would increase the organic matter, effective phosphorus and effective potassium, and improve the rice production. The trial results showed that when the

SMC fertilization was 1-2 tons per 660m^2, the organic matter and effective nutrients kept equation; when the SMC fertilization was 4 tons per 660m^2, compared with the basic soil, the organic matter increased 2.1g/Kg, with an amplitude of 5.2%; the effective phosphorus increased 9.2mg/Kg, with an amplitude of 67.2%; the effective potassium increased 19.2mg/Kg, with an amplitude of 24.0%. In the summer trial, the rice production in the field fertilized SMC increased 19~68Kg/660m^2, with an amplitude of 5.3~19.0% compared with that of control not fertilized, while these value were 22~45Kg/660m^2 and 5.3~10.9% in the autumn trial. [22]

Wang Meiqin prepared complex organic fertilizer with treated SMC and some inorganic nitrogen, phosphorus and potassium, and put it into trial in paddy field. The results showed that the SMC complex organic fertilizer could stabilize the number of effective spikes and increase the ratio of mature spikes. Compared with the controls of fertilizing normally and using common complex fertilizer, the effective spikes of the SMC treatment increased 9.3% and 2.7% respectively, and the rate of mature spikes increased 16.66% and 15.17% respectively. The main reason for the SMC complex organic fertilizer improving the rice yield significantly should be that the complex fertilizer promoted its physical growth, improved its economic characteristics, increased its numbers of effective spikes and grains. [23]

According to the study by Xiao Shenggang et al., fertilizing SMC with main content of sawdust and cotton-seed shell to an orange garden could improve the soil quality, and the pH value, organic matter, hydrolyzed nitrogen, available P, K, Zn, Mn, exchangeable Mg, Ca, as well as water-soluble boron increased obviously. This technology was developed at Sanming City in 2001, and the orange quality, yield and good-quality orange rate all improved obviously. This technology has been popularized in the city nowadays. [24]

Wang Yangjun's study suggested that adding *Agaricus bisporus* SMC to flower and vegetable substrates with a certain proportion would result in regular seedlings, green and thick leaves, and strong plants. The flower number of each rhododendron and rose increased by 15.82~30.77% per batch, the florescence extended 1.3~2.5 days, and the disease incidence decreased 3.20~8.70%; the fruit number of each tomato and capsicum increased 8.36~20.00%, the single yield improved 7.48~19.86%, and the disease incidence decreased 5.57~7.72%; the seedling of green cauliflower and cabbage heighten 7.59~10.89%, the number of total leaves increased 2.20~7.80%, the disease incidence decreased 4.69~7.81%, and seedling production increased 7.5~14.5%.[25]

E. Soil improvement

For poor soils, SMC is cheaper and more effective than artificial fertilisers. SMC can be decomposed to humus material exhibiting good ventilation and water-retaining capacity. It can thus improve soil aeration and prevent soil hardening. SMC is also rich in organic matter and many kinds of mineral nutrients that not only offset any soil deficiency but also enhanced soil fertility and output per unit area. As a fertilizer, SMC has a low C : N ratio (equal to or less than 20:1) since it contains a lot of hypha protein, and because most of the cellulose and lignin components have been decomposed. Therefore, direct application of SMC on farms can prevent nitrogen deficiency. After three mushroom flushes, the spent substrate from the cultivation bag can be used as an acid fertilizer for application to alkaline soils to provide nutrients and improve soil quality.

In Hung-Jeng Chen's study, Petunia, Impatiens, cosmos and other annual flowers have been cultivated in the campus of National Chung Hsing University from October to next spring. In order to protect the turf grass of campus, spent mushroom compost (SMC) had been used as cover medium to soil of petunia and other flowers by non-tillage. Due to the higher electrical conductivity (E.C.) of SMC, the seedlings of plug can't be planted in the SMC directly except the pottings with 3 inches. The results showed that SMC has great potential to grow annual plants. In order to protect the environment, the SMC and other abandoned mushroom compost in local area should be recycled as cultivated medium for sustainable horticulture. [26]

Lin Shilian reported to transfer SMC of straw or cotton-seed shell to a kind of regulator for adjusting the soil nutrient and improving soil quality, and realize the reasonable reuse of SMC. The soil regulator he produced contained 43.94% of organic matter, as well as organic chlorine, phosphor, potassium and trace elements. After fermentation and maturation in soil, the regulator would improve soil structure, enhance soil ventilation, eliminate soil hardening, and increase soil temperature, resulting in suitable soil environment for crop and vegetable growing. Now this product is popularized at local vegetable field.[27]

F. Substrate for potted plants to replace peat moss.

Wang Fage reported that complex substrate prepared with perlite and SMC of *Agaricus bisporus* with a volume ratio of 2:1 or 1:2 have good physical and chemical indexes of proportion, water holding, pH value, EC value and so on. The lettuce seedling bred by the complex substrate had a good quality with more and larger leaves, taller plant, stronger stalk, more side roots and higher biological production. Based on the experimental results, it can be popularized in soilless cultivation of vegetables. [28]

Using SMC as a component of substrate for potted plants without soil, the pH is high and remains high. EC is initially high. It increases as nutrients are released during composting, and the salts can be easily leached from SMC during 6 weeks of composting if the crop is salt sensitive. (Section J also introduced in detail how to decrease the high salt content of SMC.) Water holding capacity slightly increased during composting. Biological activity reduced after 6 weeks of composting. Both Solvita and radish seed test agree compost is mature after 6 weeks. Plants will grow in many types of SMC, but best plant growth requires knowing the SMC.[29]

In Fang Guanna's study, the complex substrates with main content of SMC of *Pleurotus ostreatus* etc. and assistant materials of organic and chemical fertilizer were tested for the effect on the growth and production of potato seedling, and the result showed that the SMC substrate have obvious advantages in potato seedling production. It would be a kind of perfect substrate taking place of vermiculite and peat moss. [30]

G. To produce a plant hormone which increases the yield of cucumbers and melons, etc.

In Japan, a kind of liquid plant hormone was made by diluting the SMC extract, but which kind of SMC was not mentioned in the reference. This kind of liquid was used in cucumber, tomato, eggplant, haricot bean and soybean to promote their growth and increase their production. The soybean sprayed with the hormone liquid had stronger stems and leaves, stronger resistance to diseases, and higher production up to 2.6 folds. The technology for producing plant hormone was: 1Kg of SMC was mixed with 5L water, adjusted to a pH value range of 4.5～5.5, and incubated for 4～5 hours under 40～50℃ in a sealed plastic container. The SMC mixture was filtrated with gauze and then with film filter, and the extract containing plant hormone was collected. After 300～500 folds of dilution, it was sprayed over the plant leaves, and twice for every week.[5][31]

It was said that the similar plant hormone in a form of liquid also was produced in China using SMC, but the related publication was not found.

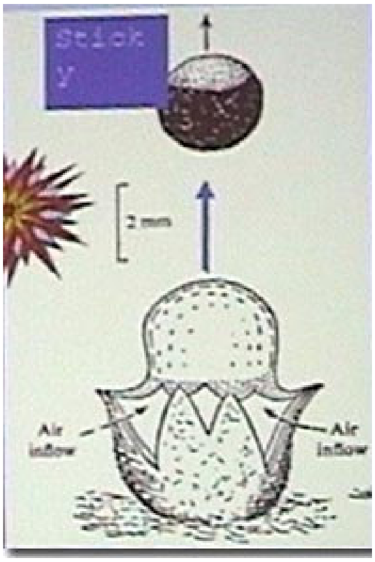
H. Biocontrol for the disease

In Jenn-Wen Huang's study, ten agricultural wastes were tested for their suitability as substrates for the growth of cabbage seedlings. Spent forest mushroom*(Lentinus edodes*) compost (SFMC) and spent golden mushroom (*Flammuline velutipes*) compost (SGMC) were found to be more suitable than raw spent forest mushroom growth medium (RFM), raw spent golden mushroom growth medium (RGM), rice hull, carbonized rice hull, peanut husk, coconut fiber, bagasse meal or wasted cotton. The optimum composting period for SFMC and SGMC was 10 and 6 weeks, respectively. A new container medium (SSC-06) was formulated using SFMC, carbonized rice hull, shrimp and crab shell meal, blood waste, and lime. The SSC-06 medium was suitable for growth of cabbage seedlings and was suppressive to *Rhizoctonia solani* AG-4. The suppressive effect of 20-day-old SSC-06 medium on colonization of cabbage seeds by *R. solani* AG-4 was reduced after it was steamed in 100°C hot air for 15~30 min. However, the inhibitory effect was restored to the steamed SSC-06 medium by inoculation with *Trichoderma harzianum* isolate TH-05 at a concentration of 10^5 cfu/g dry medium. After the medium was steamed for 5, 10, 15, 25 or 30 min, no fungal colonies were recovered, but the colony-forming units of the bacterial population were maintained at $>10^6$/g dry medium. The potential for SSC-06 as a container medium for commercial nursery industries is discussed. [32]

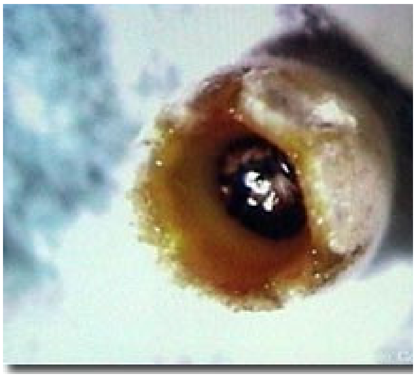
Yang Xiurong's study showed that the wasted material of mushroom can be used in the culture of *Trichoderma* spores which reached $248X10^6$/g after 6 days by adding wheat bran, bean dregs and inorganic nutrition. This kind of *Trichoderma* was isolated from soil, and had some certain inhibition effect on several kind of plant pathogeny. [33]

Dr. Don Davis was to show that blending SMS with landscape mulch suppresses artillery fungi. These fungi produce spores which they shoot against walls, which thus become stained. The landscape industry could purchase and blend mushroom compost into landscape mulch, and this could solve the artillery fungi problem and offer a market for unwanted mushroom compost. 40% SMS already suppresses artillery fungi, and the recommendation was: 50% SMS + 50% mulch. [34]

Artillery fungi



Artillery (1972)



The "artillery"

I. Cultivation other mushroom with SMS

Edible fungi use up approximately 70% of the available nutrients in the growth substrate and, if an appropriate amount of fresh substrate is added to the spent residue after harvesting, the latter can be used again for further mushroom cultivation. Straw mushroom used a little nutrient from straw, so we can add some beef manure to ferment again to cultivate coprinus mushroom in a good yield. [35]

In some provinces like Zhejiang, some growers cultivated straw mushroom *Volvariella* with

SMC of button mushroom, and the technology were commonly used in the mushroom farms.[36], but in Fujian, farmers are widely using spent mushroom compost from straw mushroom to grow the *Agaricus* mushroom, thus saving the costs of straw and beef manure as these are becoming too expensive, the price of rice straw. was over 60 Euro per ton in last season in the south of Fujian.

J. Used as a component of casing material

SMS can also be used as casing material. The maximum water-retaining capacity of casing soil is the main factor to influence the yield and quality of *Agaricus bisporus*. The garden soil which widely used in China restricted the improvement of yield because its maximum capacity is only 20%~30%. The maximum water-retaining capacity of peat is much higher (80%~90%) but its source is rare in China. It is so expensive that the Chinese farmer can not afford it. By adding waste compost which have been fermented in non-air condition to garden soil, the maximum water-retaining capacity was increased to 51%, and the mushroom yield was increased by 13.6%.[37]

The table 4. below shows the influence of different types of casing on the yield of *Agaricus bisporus.*

Table 4. Characteristics of different casing, materials, their effect on mushroom content and yield

	Casing analysis					Mushroom analysis				
casing materials	OM %	WHC %	EC mS/m	MO %	Ash %	DM %	OM %	Ash %	Pro %	Yield kg/ton
SMC	42.73	45.33	2.41	25.96	32.05	9.73	8.79	0.93	3.85	190.42
Peat	77.72	77.44	0.42	67.9	18.24	7.09	6.44	0.73	2.64	268.94
SMC80%+peat20%	51.91	46.9	2.28	28	36.63	8.67	7.78	0.89	3.45	232.3
SMC70%+P30%	52.69	47.65	2.25	30.27	33.10	8.41	7.42	0.84	3.5	247.84
SMC80%+coco peat20%	7.46	47.43	2.41	33.76	33.76	9.05	8.07	0.98	3.54	210.26
SMC80%+P10%+C10%	49.49	49.24	2.19	34.09	34.09	8.89	7.93	0.95	3.45	231.41
SMC80%+stone dust20%	35.77	35.58	2.29	28.45	28.54	9.21	8.53	0.90	3.18	211.49
SMC80%+SD10%+P10%	42.08	43.17	2.17	22.4	33.48	8.94	7.96	0.90	3.5	226.58
SMC80%+C10%+SD10%	41.05	42.95	2.46	24.41	32.16	9.1	8.35	0.97	3.5	224.41
SMC70%+P20%+C10%	50.28	49.52	2.04	28.32	31.73	8.64	7.7	0.86	3.25	262.4
SMC70%+SD15%+ palm fiber15%	36.81	43.33	2.61	22.25	28.58	8.85	7.94	0.88	3.57	208.2
SMC80%+PF20%	43.13	46.34	2.91	29.93	30.2	9.03	8.1	0.95	3.63	216.9

C=coco peat; SD=Stone dust; PF=palm fiber; WHC = Water holding capacity. OM=organism materials; MO=M
DM=dry matter; Pro=protein

The result of this experiment (the table above) showed that addition of SMC to peat positively affected the mushroom dry matter and protein content compared to control. Although a complete replacement for peat coincides with reduction of yield, but partial substitution of peat by SMC could be very beneficial especially for those countries where peat is not readily available.

Malard company, the largest mushroom producer in Iran (produces 3,000 tons mushroom annually) has made a special effort over the years to master the production of casing from SMC. Currently the 70~80% of SMC is blended with 20~30% of imported peat to improve both water holding capacity and structure. This mixture produces some of the firmest and heaviest mushrooms.

The better quality mushrooms, with less bacterial blotch, cobweb, dry and wet bubble were observed throughout the period of cropping compared with normal local peat and black peat. [38]

As casing material, the salinity of SMC is too high. Leaching is one of the possible options that will reduce salinity of SMC. In Dr. Hossein Riahi's presentation, the leaching yard is built in $2500m^2$ area with a capacity of $450m^3$.The SMC was spread evenly over the specially designed and constructed pads. The dimension of each concrete platform was 25 * 3 meters. The SMC was sprayed with a sprinkler system.[38]

Table 5. Determination of EC and amount of water used at different stag leaching

Days	Electrical conductivity (mS/m)				Water used/m^3			
	Repl1	Repl2	Repl3	Repl4	Repl1	Repl2	Repl3	Repl4
0	6.0	5.5	7.0	7.1	36	26	27	14
2	4.0	5.2	4.0	6.0	26	34	26	34
4	3.3	4.0	3.5	3.7	17	63	51	108

6	3.2	3.6	3.2	2.8	31	59	32	106
8	3.1	3.1	2.8	2.5	41	48	58	104
10	3.0	2.9	2.4	2.3	36	42	85	96
12	2.9	2.8	2.1	2.2	39	62	76	102
14	2.5	2.6	2.1	2.0	47	49	49	98
16	2.3	2.5	2.0	1.7	38	57	39	82
18	2.0	2.4	1.9	1.6	43	75	27	53
20	1.9	2.0	1.8	....	38	58	55	....
22	2.0	1.8	1.8	....	35	27	37	....
24	2.1	....	....	....	8.0	....	21	....
				Total	470	600	583	832

The electrical conductivity of 2 years old SMC was decreased from 7.1-5.5 to 2.1-1.6 (mS/cm) after 18-24 days of leaching. During this period 470-832 m^3 of water was used for leaching of 350-400 m^3 of SMC.

Table 6. Chemical properties of SMC at different stages of leaching							
	Cations				Anions		
Samples	Ca	Mg	Na	K	Cl	SO_4	HCO_3
Day (0)	46	25	50	145	102	36	9.9
Day (10)	25	11.7	36	105	73	65	8.3
Day (15)	20	10	7.8	15.7	8.8	39	4.8
Day (20)	11.9	3.8	5.7	9.4	4.4	36	3.5

K. Pollution control

Spent mushroom compost (SMC) is a bulky waste byproduct of mushroom industry and produced abundantly. The SMC of *Pleurotus pulmonarius* immobilized laccase (0.88 mmoles min(-1) g(-1)) and manganese peroxidase (0.58 mmoles min(-1) g(-1)) of which the optimal temperatures were 45 and 75 ℃, respectively. In laboratory test, complete degradative removal of individual naphthalene, phenanthrene, benzo pyrene and benzo perylene (200 mg PAH kg(-1) sandy-loam soil) by 5% SMC was obtained in two days under continuous shaking at 80 ℃. The SMC-treated PAH samples had significantly reduced or removed their toxicities as revealed by the Microtox bioassay. These results were confirmed by gas chromatography-mass spectrometry analysis on the breakdown products. A phthalic derivative which is reported as a degradative product of PAHs by ozonation or ligninolysis was also detected in the SMC-treated samples. The results demonstrate the potential in employing SMC in ex situ bioremediation. [39]

In the patent of CN200510031204.2, the method of utilization of SMC to eliminate Chromium from industry waste water was introduced. [40]

The *Lentinula edodes* SMC was used as a biosorbent for adsorbing cadmium, lead and chromium from solutions under batch conditions for the first time. Titration of the biomass revealed that it contain at least three types of functional groups. The fourier transform infrared spectrometry showed that the carboxyl, phosphoryl, phenolic group were the main groups. The simulated values of pKh and molar quantity were 5.00 and 0.44 mmol/g, 7.32 and 1.38 mmol/g, 10.45 and 1.44 mmol/g, respectively. The biosorption ability increased with pH in acid condition. [41]

The mechanism and function of sorption of Pb^{2+} in waters by *Lentinula edodes* SMC was studied. The carboxyl, phosphoryl, phenolic in the waste were the main functional group causing the sorption speed quicker, 30~50 min could reach equilibrium, the actual sorption process was identical relatively with pseudo-second-order Lagergren model. When the pH values were 4.09~6.00, the sorption efficiency was high relatively. When Pb^{+} concentrations were 20,50,100mg/L, the best use amounts of absorbent were 1,2,5g/L respectively. The greatest sorption amount was 714.29mg/g, when Langmiur isothermal sorption equation was used to estimated sorption. [42]

L. Comprehensive

Mi Qingshan's article summarized edible fungus waste material handling: abandon or pile. It summarizes some related comprehensive utilization. For example: cultivating edible fungus repeatedly; using SMC in button mushroom spawn making; using as fuel or feedstuff of livestock; replacing the organic soil in vegetable growing; extracting hormone or agricultural chemical and so on.[43]

Zhang Jianhua et al. analyzed the nutrition components of 4 kinds of different SMC, and compared with those of corn and paddy. The results showed that the nutrition components of SMC were relatively higher and more complete. Compared with corn and paddy, the tryptophan of SMC was similar, but the contents of Fe, Mn and Zn were much higher, which suggested that the SMC could be used as part of feedstuff for fowl and domestic animals. [44]Li Xuemei also analyzed the nutrition components of corn and 3 kinds of SMC, and obtained similar results. [45]

Table.7. The nutrition analysis of different SMC(%) (by Li Xuemei)

SMC	Dry materials	Crude Protein	Crude fattiness	Crude fiber	Extract without N	Ash	Ca	P
Cottonseed shell SMC	85.61	8.09	0.55	22.95	38.50	15.52	2.12	0.25
Straw SMC	87.57	8.37	0.95	15.84	38.66	23.75	2.19	0.33
Sawdust SMC	85.36	6.37	0.70	19.80	37.82	13.81	1.81	0.34
Corn	86.50	9.00	4.00	2.00	70.10	1.40	0.02	0.25

As feedstuff or fodder additive, SMC can evenly replace a part of feedstuff and other nutritional elements. Ma Shoufu discussed the nutritional value, production technology, utilization and development prospect of several kinds of SMC. It was a fact that the nutritional value of SMC is about equal to that of the feedstuff like wheat. It can be used as a new feed resource for animals to reduce feed cost. Meanwhile its utilization is of significance for protecting environment. [46]

The fungal communities in mushroom composting phase II was assessed using a combination of PCR amplification and sequencing of 18S rDNA from fungal isolates and “nested” PCR-TGGE analysis on the basis of DNA directly extracted from compost samples. The diversity of cultivated fungi isolated from compost samples was low. A total of 11 isolates were clustered to only 2 different species. One species, *Chaetomium elatum*, was identified within 10 isolateds, and the other, with high similarity belonged to *Penicillium expansum.* The fungal flora associated with mushroom compost was then monitored with “nested” PCR-TGGE. The patterns obtained revealed the more complex existence of fungal communities from the original compost samples than from those enriched with food waste and cow slurry. [47]

Yan Baosong et al. recommended that the sawdust SMC of *Auricularia anricula* and *Pholiota nameko* could be newly fermented by adding fresh materials and used for the cultivation of *Pleurotus ostreatus, Lentinula edodes, Pleurotus citrinopileatus* and *Coprinus comatus* etc. Cultivating different mushrooms needed different assistant materials because of the low C/N ratio. The straw SMC could also be newly fermented for cultivating other mushrooms, or used as organic fertilizer, or used as animal feedstuff. Because the straw SMC contained about 20% crude fiber, it’s suitable for herbivore, while its proportion could not be large when it’s used as part of feedstuff of pig or chicken. [48]

To keep the suitable development of edible mushroom industry, it is necessary to decrease the dependent on straw resource and forest resource excessively, and develop special material plant cultivation and the relative production technology of edible mushroom. In order to bring edible fungi industry into bionomic economy system and countryside circle–economy, it should be carried out to construct the bio-reactor system of edible mushroom, exploit the feedstuff of poultry and fish, and to process soil organic fertilizer utilizing the cultivated residues of edible fungi.[49]

The use of agricultural biomass as a resource material to cultivate edible fungi provides humankind with a high protein food material, and simultaneously reduces environmental pollution caused as a result of burning and otherwise disposing of wastes generated from crop production. By creating multi - functional SMS, the practice has important and practical implications for the recycling of agriculture biomass, and achieves economical, ecological and societal unification.

Recommendations for the Dutch situation

A double cascade approach for local situations, which considers both bio refinery and exergy aspects [50], leads to the following recommendations:

First of all the casing soil should be removed from the compost. This could either be done with separate nettings or with a kind of mechanical scraper when the cells are emptied. Then the moisture should be pressed out of the compost and the moisture should be analysed for its salinity and other components. Possibly proteins and valuable plant hormones like humic acids can be harvested from the moisture. An efficient process for pressing the moisture out of the

champost has to be developed, with respect to energy and treatment costs and the remaining moisture content in the champost itself. The champost should be analysed for salinity and could serve as a replacement for peat for potted plants.
If the moisture content can be brought back to ca. 20-30% the champost could also be used to fuel a bio energy installation. Ideally, the high temperature heat will be used for a process first and then secondly for a lower valued function, like heating rooms (cascading).

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