**HANDLING AND USING “SPENT” MUSHROOM SUBSTRATE AROUND THE WORLD**

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**ABSTRACT**

Many species of mushrooms are cultivated world-wide. Global production is greater than six million tonnes and has an approximate value of at least $US14 billion. Mushrooms are produced on natural materials taken from agriculture, woodlands, animal husbandry, and manufacturing industries. After mushroom crops are harvested, millions of tonnes of “spent” (used) mushroom substrate become available for other uses. The used growing medium is far from spent. Many beneficial uses for spent mushroom substrate are currently being implemented or evaluated internationally. These uses vary with the mushroom species. Most of the published literature in the West describes the use of spent mushroom substrate from the cultivation of the *Agaricus bisporus* species (although less than 40% of the spent material is from this species). Spent substrate from *Agaricus bisporus* production is already in wide use as follows: in horticulture as a component of potting soil mixes; in agriculture or landscape trades to enrich soil; as a casing material in the cultivation of subsequent *Agaricus* crops, in vermiculture as a growing medium, in wetlands for remediation of contaminated water, in stabilizing severely disturbed soils, in the bio-remediation of contaminated soils, as a bedding for animals, as an animal feed, and to control plant diseases. Spent substrate from other mushroom species has found acceptance as food for animals, as ingredients in the cultivation of other mushroom species, as fuel, as a medium for vermiculture, to enrich soils, and as a matrix for bio-remediation. This paper will describe the utility of spent mushroom soil as well as point to potential additional uses for this valuable substance.

**INTRODUCTION**

Many species of mushrooms are cultivated world-wide. Global production increased to about 6.2 million tonnes in 1997, with a more than 12% increase annually from 1981 to 1997 (Chang 1999). Seventy percent of the global mushroom production is derived from three mushroom groups, *Agaricus bisporus, Pleurotus* spp, and *Lentinula edodes*. The remaining mushroom volume is generated by at least a dozen species (Chang 1999).

In the production of any and all species, significant residual material remains after cultivation. Every tonne of mushrooms produced results in one to two tonnes of dry spent residual material. The important question in this day of limited natural resources and concerns over human health and the environment is, “What use or value does this residual material from mushroom production have?”

The following discussion briefly outlines the materials and techniques used to produce the vast volumes of “spent” (used) mushroom substrate in the production of these principal mushroom species.

**A BRIEF DESCRIPTION OF THE PRINCIPAL CULTIVATED MUSHROOM SPECIES**

***Agaricus bisporus***

The commercial mushroom, *Agaricus bisporus*, represented about 32% of the world mushroom production in 1997 (Chang 1999). This species is cultivated typically on a straw or hay base, amended with animal manures and gypsum. The materials initially undergo a two-phase composting process, one at high temperature (up to 85°C) and another for pasteurization and conditioning (beginning at 60°C and decreasing to about 45°C). The colonization stage by this mushroom fungus is followed by covering the surface of the colonized compost with a layer of peat, top soil or other suitable material. Within two weeks mushrooms are visibly ready for harvest. After about three weeks of mushroom harvest, the growing material is considered spent. After usually undergoing a post-crop heat treatment, the growing material is removed and the chamber is ready for a new crop.

***Pleurotus* spp**

The oyster mushroom consists of a number of several edible *Pleurotus* species. This species represented 14% of the world production in 1997 (Chang 1999). *Pleurotus* can be cultivated on wood sawdust, on various plant fibres or plant residues, which are amended with locally available proteins and carbohydrates to optimize its growth requirements. The materials are generally not composted previous to inoculation. The wood sawdust may be aged or the plant fibres hydrated for several days. The growing materials are treated with either heat or chemicals to augment the selectivity of these materials for the oyster mushroom fungus. After colonization is complete, the colonized substrate is subjected to conditions suitable to initiation and maturation of fruiting bodies. At the end of several mushroom harvests, the growing material is considered spent. It may be heat treated before being removed from the growing chamber.

***Lentinula edodes***

Shiitake mushrooms, *Lentinula edodes*, represented 25% of the 1997 world mushroom production (Chang 1999). This species is either cultivated on natural logs or on a ‘synthetic’ logs. Natural log production utilizes various species of trees, especially oak. Trees are cut down after leaf fall and the wood cut in lengths of about one meter. Within one month these logs may be inoculated with the shiitake fungus. After up to one year of incubation, the colonized logs are brought under conditions that initiate fructification. Mushrooms are harvested about twice per year for several years. Once production ceases, these logs are considered spent. ‘Synthetic’ logs for production of shiitake mushrooms are formed from sawdust, straw, corn cobs or mixtures thereof. Starch-based additives from cereals are often added to optimize the nutritional needs of the fungus. The growing materials are generally sterilized. After colonization is completed, conditions are changed to initiate the formation of mushrooms. After several harvests, these synthetic logs are considered spent.

This paper will outline the utility of spent mushroom substrate. Characteristics of spent substrate are outlined, and the following uses for spent substrate are detailed: Bioremediation, crop production, re-use in the cultivation of mushrooms, food for animals and fish, and pest management. Each of these uses is noted in association with one of the particular mushroom species noted above. The environmental impact of weathering spent compost is also discussed.

**CHARACTERISTICS OF SPENT SUBSTRATE**

*Agaricus bisporus* spent substrate: Microbiology of composted (Raymond *et al*. 1997) or steamed material (Kleyn and Wetzler 1981); physical and/or chemical characteristics of fresh and/or weathered material (Beyer 2001, Gerrits 1997a, Iiyama *et al*. 1995, Lemnaire *et al*. 1985, Levanon and Danai 1995, Lohr *et al*. 1984b, Maher *et al*. 2000, Szmidt and Chong 1995).

**BIOREMEDIATION**

**Purification of air**

*Agaricus bisporus* spent substrate: As mix with other materials for removal of H2S (Shojaosadati and Siamak 1999) or volatile organic compounds (Mohseni *et al*. 1998, Mohseni and Allen 1999).

**Purification of water**

*Agaricus bisporus* spent substrate: Treatment of metal-contaminated water from coal mines (Anon 1997, Dvorak *et al*. 1992, Stark *et al*. 1994); treatment of acid mine drainage (Chang *et al*. 2000) in wetland environments (Karathanasis and Thompson, 1990, Manyin *et al.* 1997, Stark and Williams 1994, Stark *et al*. 1995, Stark *et al*. 1996, Tarutis and Unz 1995, Vile and Wieder 1993, Wieder 1993); treatment of nickel-contaminated mine water (Hammack and Edenborn 1992); biological treatment of sewage (International Organic Solutions Corp. 1996); treatment of waters polluted with radioactive elements and heavy metals (Groudev *et al*. 1999).

*Agaricus* waste mushroom/tissue: Production of phenoloxidases (Steffen *et al*. 1995).

*Pleurotus* spp spent substrate: Reduction of phenol content and toxicity in olive mill waste (Martirani *et al*. 1996).

*Lentinula edodes* spent substrate: Treatment of acid mine drainage (Chang *et al*. 2000); treatment of effluents from olive mill (D’Annibale *et al*. 1998).

**Purification of soil**

*Agaricus bisporus* spent substrate: Effect on zinc distribution (Shuman 1999a, 1999b), cadmium and lead (Shuman 1998) among soil fractions; amelioration of zinc toxicity (Shuman and Li 1997); degradation of chlorophenols, polycyclic aromatic hydrocarbons or aromatic monomers (Semple *et al*. 1995, Semple *et al*. 1998, Fermor *et al* 2000, Staments 2001); inhibition of nitrification (Bazin *et al*. 1991); treatment of hazardous wastes (Buswell 1994); stabilization of disturbed and commercial sites (Rupert 1995).

*Pleurotus* spp spent substrate: Blend of fish oil and spent substrate for degradation of polycyclic aromatic hydrocarbons in age-creosote contaminated soil (Eggen 1999); removal/degradation of pentachlorophenol (PCP) (Chiu *et al*. 1998).

*Lentinula edodes* spent substrate: Removal/degradation of pentachlorophenol (PCP) (Chiu *et al.* 1998).

**Purification of substrates contaminated with pesticides**

*Agaricus bisporus* spent substrate: Degradation of carbaryl, 1-naphthol (Kuo and Regan 1992, 1999) and carbamate (Kuo and Regan 1998, Regan 1994); sorption and movement of atrazine and 2,4-D by soils (Baskaran *et al.* 1996).

**CROP PRODUCTION**

**Greenhouse crops - flowers**

*Agaricus bisporus* spent substrate: Production of Chrysanthemum (Rathier 1982) and Easter lilies (Dallon 1987, White 1976a,d), *Helleborus* (Richter *et al.* 1980); petunias (White 1976c) and poinsettia (White 1976b); problems in use (Anon. 1985).

**Greenhouse crops - vegetables**

*Agaricus bisporus* spent substrate: Production of vegetable transplants (Lohr 1983, Lohr *et al.* 1984a, Lohr and Coffey 1987, Wang *et al.* 1984a), cucumbers (Celikel and Buyukalaca 1999c), tomatoes (Celikel and Tuncay 1999a, Rathier 1982, Steffen *et al.* 1994, 1995,Vavrina *et al.* 1996) and eggplant (Celikel and Tuncay 1999b); impact on post-harvest quality (Dundar *et al.* 1995); general evaluation (Verdonck 1984).

**Field crops - vegetables**

*Agaricus bisporus* spent substrate: Production of asparagus, beet root, cauliflower, cabbage, capsicums, celery, cucumber, lettuce, mustard, onion, potato, radish, snap bean, spinach, sugar beet, tomato (Abak and Gul 1994, Anon. 1979, Faassen *et al.* 1992, Kaddous and Morgans 1986, Maher 1994, Maher *et al.* 2000, Male 1981, Massi, A. 2001, pers. comm., Maynard 1989, Maynard 1991, Maynard 1994b, Nguyen *et al.* 1987, Pill *et al.* 1993, Ranganathan and Selvaseelan 1997a, Rhoads and Olson 1995, Selvi and Selvaseelan 1999, Sochtig and Grabbe 1995, Stephens *et al.* 1989, Stewart *et al.* 1998b, 1998c, Schwank 1985, Wang 1983, Wang *et al.* 1984)

*Pleurotus* spp spent substrate: Interplanting with cabbage and eggplant (Abdallah 2000); wood shaving substrate for cultivation of lettuce (Batista *et al.* 2000); cucumber production (Nguyen *et al.* 1987).

*Lentinula edodes* spent substrate: Production of tomatoes (Lin and Chuen 1993).

Other species spent substrate: Production of cabbage (Lin 1993).

**Field crops - fruit**

*Agaricus bisporus* spent substrate: Mulching applied to “Italian” prunes (Robbins *et al.* 1986), apples (AntSaoir *et al.* 2000, Delver 1982, Delver and Wertheim 1988), apple seedlings (Koch 1980), grapes (Beyer, D. 2001, pers. comm.); peaches (Derkacz, M. 2001, pers. comm.); organic alternative to methyl bromide in strawberries (Sances and Ingham 1997).

**Field crops - other**

*Agaricus bisporus* spent substrate: As a soil amendment for tea (Manivel *et al.* 1994); effect on green gram (Ranganathan and Selvaseelan 1994); as soil amendment for field corn (Weber *et al.* 1997, Wuest and Fahy 1991, Wuest *et al.* 1991, Wuest *et al.* 1995); effect on perennial rye grass, wheat (Maher 1994, Maher *et al.* 2000).

**General soil amendment**

*Agaricus bisporus* spent substrate: Effect on soil physical and physico-chemical properties (Ranganathan and Selvaseelan 1997b); as organic fertilizer (Cameron, K. 2001, pers. comm.); Gerrits 1987b, Levanon and Danai 1997, Maher 1990, Maher *et al.* 2000, Pryce 1991, Ranganathan and Selvaseelan 1997c, Robinson 1988, van Keulen, H. 2001, pers. comm.).

*Agaricus blazei* spent substrate: As organic fertilizer (Dias, E. S. 2001, pers. comm.).

*Pleurotus* spent substrate: Cotton seed substrate pelletized for organic fertilizer or mixed with *Agaricus* spent substrate for organic fertilizer (Keil, C. 2001, pers. comm.); sawdust substrate as organic fertilizer (Anderson, D. 2001, pers. comm.).

*Lentinula edodes* spent substrate: Pelletized for organic fertilizer or mixed with *Agaricus* spent substrate for organic fertilizer (Keil, C. 2001, pers. comm.).

**Nursery and landscape**

*Agaricus bisporus* spent substrate: Production of foliage crops as potting mix (Beyer, D. 2001, pers. comm.); Chong *et al.* 1987, Chong and Wickware 1989, Chong *et al.* 1990, 1991a,b,c,d,e, Chong and Hamersma 1996a, b, Chong and Rinker 1994a,b, Chong 1991, 1999, Devonald 1987, Eames 1977, Henny 1980, Poole and Conorer 1974, Raymond *et al.* 1998, Smith 1982, van Keulen, H. 2001, pers. comm.); production of foliage crops in the field (Maynard 1994c); improving turf (Landschoot and McNitt 1994).

*Pleurotus spp* spent substrate: Production of nursery crops (Quimio *et al.*, 1990).

**RE-USE IN THE CULTIVATION OF MUSHROOMS**

**Casing material for *Agaricus bisporus***

*Agaricus bisporus* spent substrate: Comparisons with peats and/or other local materials (Eicker and van Greuning 1989, Garcha and Sekhon 1981, Happ II 1974, Nair 1976a,b, Nair and Bradley 1981, Seaby 1999, Shandilya 1989a, b, Singh *et al.* 1992, 2000, Stoller 1979); leaching experiments (Riahi *et al.* 1998) or treatment with chelating agents (Sharma *et al.* 1999); recomposting and leaching (Szmidt 1994, Szmidt *et al.* 1995); handling and use (Kinrus 1976, Schisler and Wuest 1982, Wuest 1976); separation and reuse of casing from spawn-run compost (Hesling 1981, Jablonsky and Srb 1989, Nair and Bradley 1981, Nair 1985).

*Pleurotus* spent substrate: Composted sawdust media as casing (Kim *et al.* 1998).

**Casing material for *Agaricus bitorquis***

*Agaricus bisporus* spent substrate: Comparisons with local materials (Guleria *et al.* 1989).

**Cultivation of other species**

*Agaricus bisporus* spent substrate: Cultivation of 11 species (Flick 1981) cultivation of *Agaricus bisporus* (Rinker and Alm 1990, Schisler 1988, Till 1963), *Auricularia (*Sharma and Jandaik 1994), *Lentinula* (Kilpatrick *et al.* 2000), *Pleurotus* (Mueller *et al.* 1984, Sharma and Jandaik 1994); *Volvariella* (Poppe 2000).

*Pleurotus* spp spent substrate: Cultivation of *Pleurotus* spp (Nakaya *et al.* 2000, Sharma and Jandaik 1985, 1992), *Stropharia* (Poppe 1995).

*Lentinula edodes* spent substrate: Cultivation of *Pleurotus* (Jaramillo, C. 2001, pers. comm., Royse 1993); mixed into *Agaricus* substrate (Yeatman, J. 2001, pers. comm.).

Spent substrate from other species: *Volvariella* substrate for *Pleurotus* production (Chang and Miles 1989, Quimio 1988); *Flammulina* or *Ganaderma* substrate for *Coprinus comatus* (Chen, A. 2001, pers. comm.).

# FOOD FOR ANIMALS AND FISH

*Agaricus bisporus* spent substrate: Feeding studies with sheep (Wilson *et al*. 1983).

*Pleurotus* spp spent substrate: Cattle feed from spent wheat straw compost (Adamovi *et al.* 1998, Jaramillo, C. 2001, pers. comm., Kakkar *et al.* 1990, Keil, C. 2001, pers. comm.); spent sugarcane bagasse compost in a dietary blend for ruminants (Permana 1990, Zadrazil and Puniya 1995) adult and young buffaloes fed spent wheat or rice straw from *Pleurotus* cultivation (Kakkar and Dhanda 1998, Bakshi *et al.* 1985); feed for lambs and sheep (Calzada *et al.* 1987a, b, Sanchez, J.E. 2001, pers. comm.); degradation studies (Bisaria and Madan 1984, Braun *et al.* 2000, Permana *et al.* 2000, Pratt *et al.* 1981, Sosulski and Coxworth 1986, Streeter *et al.* 1981, Zadrazil 1977, 1980, 1984, Zhang *et al.* 1996).

*Lentinula edodes* spent substrate: Ground waste logs from natural log shiitake cultivation (Yoshida *et al.* 1978); rice straw fermented with waste shiitake sawdust media, corn and molasses (Lin *et al.* 1998a,b); degradation studies (Braun *et al.* 2000, Zhang *et al.* 1996).

Other species spent substrates: *Volvariella volvacea* grown on rice straw or banana leaves for sheep (Sevilla *et al.* 1989); *Coprinus fimetarius* grown on rice and oat straws for goats (Mann *et al.* 1994).

**Aquaculture**

*Agaricus bisporus* spent substrate: Wheat straw substrate as a component in the diet of carp (*Cirrhina mirigala*) (Sehgal and Thomas 1987, Sehgal and Simmi 1991, Sehgal *et al.* 1993).

**PEST MANAGEMENT**

**Insect management**

*Agaricus bisporus* spent substrate: Effects on Colorado potato beetles populations (Stoner *et al.* 1996, Gent *et al.* 1998).

**Disease management**

*Agaricus bisporus* spent substrate: Effect of water extracts (Yohalem *et al.* 1994, 1996) and mechanism and dynamics of inhibition on apple scab (Cronin *et al.* 1996); effect on: damping-off and root rot of creeping bentgrass (Craft and Nelson 1996); *Pythium* damping-off disease of tomatoes (Reigner *et al.* 2001); *Verticillium* disease in commercial mushrooms (Guardino 1998, Labuschagne *et al.* 2000, Wuest *et al.* 1996); root-knot nematode, *Meloidogyne incognita* (Kaul and Chhabra 1993, Verma 1986, 1993); chilli leaf and stem necrosis (Upadhyay 2000); wilt of carnation and black root rot of cucumber (Ebben 1980); suppression of turfgrass diseases (Viji *et al.* 2000); potato early dying disease caused by *V. dahliae* and *P. penetrans* (Gent *et al.* 1998, LaMondia *et al.* 1999); *Rhizoctonia* in cucumbers (Nguyen *et al.* 1987); *Fusarium* wilt of tomato (Harender *et al.* 1997); predaceous nematodes (Koning *et al.* 1996); influence on gas exchange in potatoes in presence of *Verticillium dahliae* or *Pratylenchus penetrans* (Gent *et al.* 1999).

*Pleurotus* spp spent substrate: Attacks nematodes (Hibbett and Thorn 1994, Thorn and Barron 1984).

*Lentinula edodes* spent substrate: Suppression of Rhizoctonia damping-off of cabbage (Huang 1997, Huang and Huang 2000); disease incidence of tomato (Lin and Chuen 1993).

**MISCELLANEOUS USES**

*Agaricus bisporus* spent substrate: Used in airlift bioreactor used to assess plant available nutrients (Velthof *et al.* 1998); used in heat resistant formulas (Donnelly and Busta 1980); as a alternative fuel (Maher *et al.* 2000); used as bedding for hogs (Beattie *et al.* 2001, Durrel *et al.* 1997); recovery of lignocellose-degrading enzymes (Ball and Jackson 1995); monitoring fate of entomopathogenic nematodes (Richardson *et al.* 2000); carrier material for preparation of bio-inoculants (Bahl and Jauhri 1986, Bahl *et al.* 1989); production of biogas (Tumwasorn *et al.* 1980); vermiculture (Edwards *et al.* 1985, Massi, A. 2001, pers. comm.).

*Pleurotus* spp spent substrate: Production of biogas (Bisaria *et al.* 1983, 1990, Mehta *et al.* 1990); as alternative fuel (Rahman, H. 2001, pers. comm.); extracellular enzyme production (Tan and Wahab 1997); vermiculture (Rahman, H. 2001, pers. comm., Sanchez, J.E. 2001, pers. comm.).

*Lentinula edodes* spent substrate: As alterative fuel (Dias, E.S. 2001, pers. comm., Pauli 1999); vermiculture (Pauli 1999).

Other species spent substrate: Mushrooms in general as animal feed (Sova and Cibulka 1980); cellulolytic bacteria from *Volvariella volvacea* (Wong *et al.* 1990); *Volvariella* as alternative fuel and vermiculture (Rahman, H. 2001, pers. comm.).

**ENVIRONMENTAL IMPACT OF WEATHERING SPENT COMPOST**

Spent mushroom substrates are often spread onto land and allowed to weather for several years. This allows salts and nitrates to leach from the spent materials. The impact of storage and leaching has been explored.

**Weathering process**

*Agaricus bisporus* spent substrate: Organic matter transformations during weathering process (Chefetz *et al.* 2000).

**Impact on ground water**

*Agaricus bisporus* spent substrate: Nitrates in ground water beneath sandy terrace soil in intensive vegetable production (Maynard 1993a, b, 1994a); impact on water quality through applications to agriculture land (Kapland *et al.* 1995, Pannier 1993, Wuest 1992, Wuest and Fahy 1992, Wuest *et al.* 1991); release of sulfate-sulfur, potassium, calcium, magnesium (Stewart *et al.* 2000) and inorganic-N (Stewart *et al.* 1998).

**Impact on surface water**

*Agaricus bisporus* spent substrate: Effect on adjacent surface water (Reed and Keil 2000).

**Impact on air quality**

*Agaricus bisporus* spent substrate: Odorous components (Bazemore *et al.* 2000); effect on health (Cobb *et al.* 1995).

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