Technical Bulletin

MANAGEMENT OF SPENT MUSHROOM SUBSTRATE

O.P. Ahlawat
and
M.P. Sagar

भाकृअनुप
ICAR

National Research Centre for Mushroom
(*Indian Council of Agricultural Research*)
Chambaghat, Solan - 173 213 (HP)

Printed: 2007, 1000 Copies

Published by:
Director
National Research Centre for Mushroom (ICAR)
Chambaghat, Solan – 173 213 (HP), INDIA
Phone: 01792-230451; **Fax:** 01792-231207
E-mail: rptewari@gmail.com; tewari_rp@rediffmail.com
Website: nrcmushroom.org

Designed & Printed at:
Yugantar Prakashan Pvt. Ltd.
WH-23, Mayapuri Indl. Area, New Delhi-64
Ph.: 011-28115949, 28116018

CONTENTS

FOREWARD

Mushrooms are known for their delicacy and nutritional values but the substrate released after mushroom crop harvest, better known as 'Spent Mushroom Substrate' is also the subject of great importance. The compost/substrate, a blend of agricultural/poultry/industrial wastes and prepared by controlled fermentation process, is first used for mushroom cultivation and the spent substrate obtained after crop harvest possesses all essential attributes of an organic manure which further gets enriched during its recomposting by natural weathering or any other process. The recomposted spent mushroom substrate has been found to be a good growing medium for majority of the vegetables and the field crops, and has shown multifacet utilities in improving the yield and quality of the crop, and management of the diseases, which is really encouraging for the mushroom industry. The other utilities of spent mushroom substrate, like in vermicomposting, bioremediation and as organic-mineral fertilizer are boon to the country's farming system. I appreciate the efforts and labour put in by the authors in compiling and editing the bulletin for its use at farmers' level. I also would like to encourage the farmers to start using of spent mushroom substrate for integrated farming and to obtain better revenue out of the agrowaste available at their door step and to make contribution towards a clean environment.

Rajendra Prasad Tewari
Director
National Research Centre for
Mushroom, Solan – 173 213 (HP)

Dated:

PREFACE

The compost released after the harvest of one full crop of mushroom, beyond which extension of crop becomes unremunerative is called as the 'spent mushroom substrate' (SMS). The spent substrate from different mushrooms varies in its physical, chemical and biological properties and each one has its own specific utility. The spent substrate from button mushroom has been found to be nutritionally rich with respect to its N:P:K contents, and being having high cation exchange capacity, it has the ability to replace Farm Yard Manure for the purpose of raising horticultural and cereal crops. Using spent mushroom substrate as feeding material for vermicomposting, plants diseases management, preparation of organic-mineral fertilizer and bioremediation of the contaminated soils are the other options of using SMS. Presently, farmers in different corners of the country are using SMS as manure for various field crops but without any support of the scientific data and because of which they are not getting the optimum benefits. The unscientific ways of using SMS are also creating several problems which include the accumulation of salts in soils and harmful effect on some crop plants. The one of the biggest mushroom units of the country, the 'Agro-Dutch Ltd.' at Lalru, Punjab is generating lakhs tons of SMS, which is being widely used for improving the soil health of the surrounding areas. Though research findings within the country and abroad have proved the advantages of using SMS in different farm activities but no compiled information is available till date particularly for the use of the farming community.

This bulletin contains information on the major aspects like, traits of spent mushroom substrate, methods of its recomposting, effects on the underlying soil, recycling for different farm activities (manure for vegetable/cereal crops, casing material for button mushroom, vermicomposting, organic-mineral fertilizer and plants diseases management) and bioremediation of the contaminated soils. The bulletin also deals in aspects of dose of SMS to be used, effect on fruit yield/quality and disease status along with their pictorial presentations. We hope that the information given in this bulletin will certainly enlighten the scientific and farming communities towards right ways of recomposting and uses of SMS.

The publication of this bulletin has become possible due to the constant support and critical advice of various colleagues. The support rendered by them is, indeed, praise worthy. But amongst them the typing/composing support from Mrs. Shashi Poonam and Mr. Pardeep Gupta is very special. We also got significant contribution from Dr S.R. Sharma, who helped us without any hesitation in guiding us for further improvement and editing of the document. Last but not the least the constant encouragement from Dr. R.P. Tewari, Director, National Research Centre for Mushroom, who really motivated us to take up such a time consuming task. We also thank the Indian Council of Agricultural Research, New Delhi for funding the Ad-hoc scheme on "Refinement in recycling technologies of spent mushroom substrate for soil amelioration and bioremediation" under which majority of the research work was carried out. Once again we thank all those who helped us directly or indirectly in bringing out this bulletin.

O.P. Ahlawat
M.P. Sagar

CHAPTER - I

Introduction

Plant waste is the basic substrate utilized for cultivation of different edible mushrooms. Mushroom growing is an eco-friendly activity as it utilizes the waste from agriculture, horticulture, poultry, brewery etc. for its cultivation. However, piling up of "spent mushroom substrate" released after mushroom crop harvesting may cause various environmental problems, including ground water contamination and nuisance (Beyer, 1996).

Compost is considered 'spent substrate' when one full crop of mushroom has been taken and further extension becomes unremunerative (Wuest and Fahy, 1991). Mushroom industry needs to dispose off more than 50 million tons of used mushroom compost each year called Spent Mushroom Substrate (SMS) (Fox and Chorover, 1999). Recently, the term spent compost or spent mushroom substrate has been replaced by a more appropriate term, "post mushroom substrate" because it is not 'spent' and is ready to be further attacked by a new set of microorganisms. The large dumped piles of spent mushroom substrate become anaerobic and give off offensive odour. The run-off from such piles contaminates nearby water sources and pollutes them (Beyer, 1996). Under normal circumstances, the spent mushroom substrate is discarded as waste without considering environmental repercussion (Fig. 1). During the recent years, environmental legislations have forced the mushroom growers to

Fig. 1. Spent mushroom substrate disposed off on road side

think about more amicable ways of SMS disposal. At the same time the demand for organic residues and compost has also increased several folds considering the ill effects of synthetic pesticides and fertilizers. The research work carried out around the world has proved that spent mushroom substrate possesses the quality of a good organic manure for raising healthy crops of cereals, fruits, vegetables and ornamental plants, in addition to its ability of reclaiming the contaminated soil. Although farm yard manure is mostly being used for production of organic food but its poor availability has restricted the production of organic crops at a large scale. Fortunately, SMS has many of the requisite attributes still left with for its exploitation in place of FYM in raising organic field crops and environment management. The empirical data depicted in Table 1 shows that the cultivation of mushrooms on different substrates increases the crude protein, crude fibre and crude ash contents of SMS in addition to enhancement in *in vitro* crude protein digestibility (Zhang *et al.*, 1995).

The SMS has been found to be a good nutrient source for agriculture mainly because of its rich nutrient status, high cation exchange capacity (CEC) and slow mineralization rate which retain its quality as an organic matter. Further, SMS contains 45% water though bulky, is light in weight (Dann, 1996). Considering the diversified uses of spent mushroom substrate, an urgent need was felt to compile the all

Table 1. Effect of pilot-scale solid state fermentation on the contents of spent compost medium.

	Media with 35% spent compost of			
	Pleurotus ostreatus		*Lentinula edodes*	
	Control	Fermented	Control	Fermented
Crude protein (%DW)	24.1	32.3	28.4	36.7
Crude fibre (%DW)	14.8	10.2	13.3	9.8
Crude ash (%DW)	6.5	9.0	6.5	9.3
In vitro crude protein digestibility (%DW)	64.2	67.8	68.7	70.1

DW - dry weight

(Source: Zhang *et al.*, 1995)

available information pertaining to the traits of SMS, its effect on surrounding environment and uses particularly for the benefit of farmers. Unless otherwise specified, post-mushroom substrate or 'spent compost' here will mean the substrate left after cultivation of white button mushroom (*Agaricus bisporus*/*A. bitorquis*).

CHAPTER - II

Traits of Spent Mushroom Substrate

Spent mushroom substrate (SMS) normally contains 1.9:0.4:2.4%, N-P-K before weathering and 1.9:0.6:1.0, N-P-K after weathering for 8-16 months. Nitrogen and phosphorus do not leach out during weathering but potassium being more leachable is lost in significant amount during weathering (Fig. 2) (Gupta *et al.*, 2004).

SMS contains much less heavy metals than sewerage sludge, which precludes its classification as hazardous substance (Wuest and Fahy, 1991). Weathering causes a slow decrease in the organic matter contents (volatile solids) and leads to different characteristics of weathered SMS because of on-going microbial activity (Beyer, 1999). The SMS obtained from different

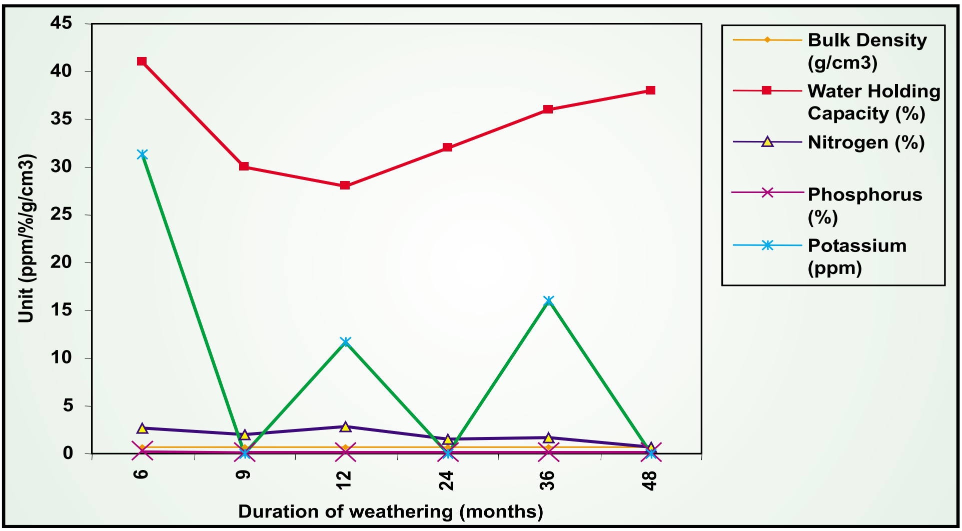

Fig. 2. Variation in selected parameters of SMS of different age weathered naturally in an unplanned manner

commercial sites reveal that except calcium, boron, copper and zinc, coefficient of variability are less than 25% (Devonald, 1987). In a latest study carried out at Penn State Mushroom Research Laboratory, a little variation in chemical and physical properties of SMS has been ascribed (Fox and Chorover, 1999) in comparison to earlier study carried out by Wuest and Fahy (1991) (Table 2).

Table 2. Characteristics of spent mushroom substrate (SMS) reported in different studies

Content	Unit	Wuest and Fahy, 1991		http:/aginto.psu.edu/psa/sgg/mushroom 5.html	
		Fresh SMS (Average)	8-16 months old weathered SMS (Average)	Fresh SMS (Range)	16 months old weathered SMS (Average)
Sodium, Na	% dry wt	0.72	0.22	0.21-0.33	0.06
Potassium, K	% dry wt	2.35	1.03	1.93-2.58	0.43
Magnesium, mg	% dry wt	0.71	0.91	0.45-0.82	0.88
Calcium, Ca	% dry wt	4.93	6.16	3.63-5.15	6.27
Aluminium, Al	% dry wt	0.40	0.80	0.17-0.28	0.58
Iron, Fe	% dry wt	0.44	0.92	0.18-0.34	0.58
Phosphorus, P	% dry wt	0.36	0.55	0.45-0.69	0.84
Ammonia-N, NH_4	% dry wt	0.11	0.03	0.06-0.24	0.00
Organic Nitrogen	% dry wt	1.83	1.89	1.25-2.15	2.72
Total Nitrogen	% dry wt	1.93	1.92	1.42-2.05	2.72
Solids	% dry wt	43.39	49.43	33.07-40.26	53.47
Volatile Solids	% dry wt	62.78	44.29	52.49-72.42	54.24
pH	Standard units	7.28	8.05	5.8-7.7	7.1
Manganese, Mn	ppm dry wt	332.92	438.62	NT	NT
Copper, Cu	ppm dry wt	46.26	61.68	NT	NT
Zinc, Zn	ppm dry wt	103.88	136.41	NT	NT
Lead, Pb	ppm dry wt	14.89	18.17	NT	NT
Chromium, Cr	ppm dry wt	8.53	11.31	NT	NT
Mercury, Hg	ppm dry wt	0.07	0.19	NT	NT
Nickel, Ni	ppm dry wt	11.93	15.74	NT	NT
Cadmium, Cd	ppm dry wt	0.43	0.32	NT	NT
N-P-K ratio	ppm dry wt	1.9-0.4-2.4	1.9-0.6-1.0	1.8-0.6-2.2	2.7-0.8-0.4

% x 10,000=ppm, NT = not tested

The SMS obtained from different sources usually has conductance in the range of 1.9 to 8.3 mmhos cm^{-1}. However, the chloride content in fresh SMS varies from 1.5 to 7.5 kg t^{-1} (Gerrits, 1987) and only about 294 ppm in a well rotten SMS (Chong and Wickware, 1989). The chloride content in SMS is attributed to level of chicken manure incorporated during composting (Chong *et al.*, 1991). There are contradictory reports regarding the pH of fresh and weathered SMS. According to Wuest and Fahy (1991), SMS has an initial pH of around 7.28, which increases during weathering, while, Devonald (1987) reported pH of the fresh SMS in the range of 7.01 and 8.04. In contrary to this, Chong *et al.* (1988) found a decrease in pH from its initial value 7.9 to 7.0 on weathering.

The volume of SMS also decreases (shrinkage) over the time. The fresh SMS obtained from various sources varies in density: 0.198 g cm^{-3} with a range of 0.15 to 0.24 g cm^{-3} in UK (Devonald, 1987); 0.475g cm^{-3} in Ireland (Maher, 1991) and 0.24 to 0.62 g cm^{-3} in USA (Dvorak *et al.*, 1991). The composting of SMS in semi-enclosed drums for 6 weeks enhances its bulk density from 0.256 g cm^{-3} to 0.293 g cm^{-3} (Lohr *et al.*, 1984).

WEATHERING OF SPENT MUSHROOM SUBSTRATE AND LEACHATE CHEMISTRY

Spent mushroom substrate contains high amount of salts and other elements which are harmful to plant growth and need to be leached out to make it usable for agricultural/ horticultural activities. In order to make SMS suitable for its use as manure, it is exposed to natural

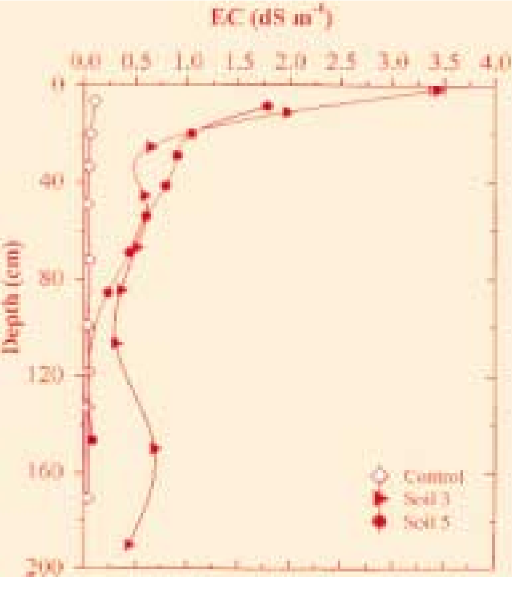

Fig. 3. Electrical conductivity profiles (soil to water = 1:5) of soils as influenced by spent mushroom substrate weathering (Guo *et al.*, 2001)

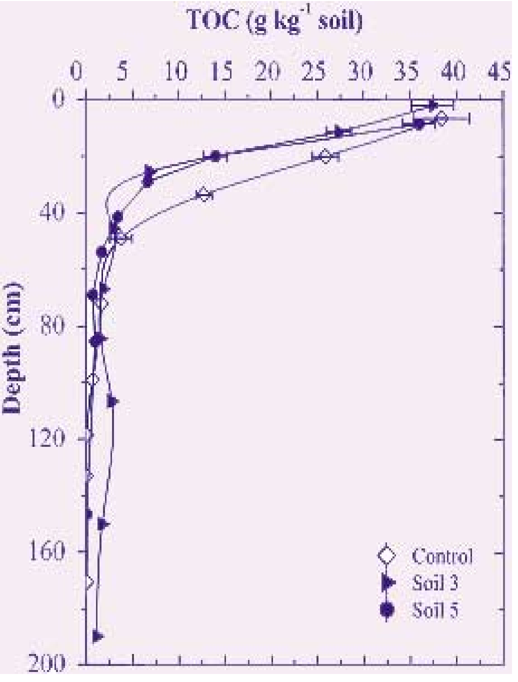

Fig. 4. Total organic carbon profiles of soils as influenced by spent mushroom substrate weathering (Guo *et al.*, 2001)

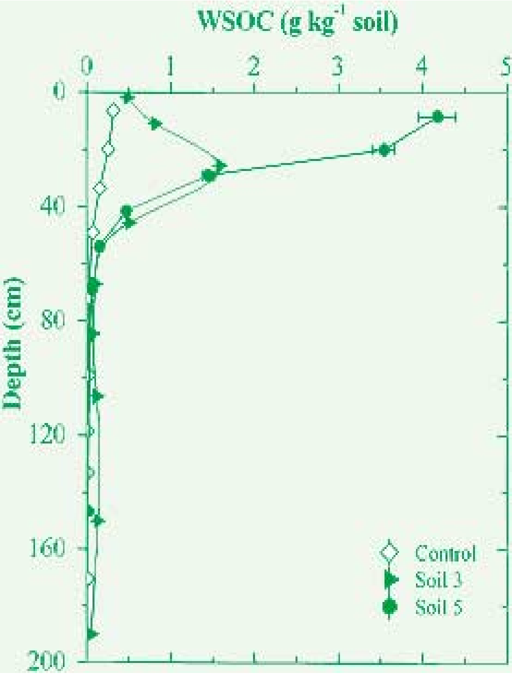

Fig 5. Water-soluble organic carbon profiles of soils as influenced by spent mushroom substrate weathering (Guo *et al.*, 2001)

climatic conditions like varied temperature and rainfall, which is called as weathering of SMS. Weathering makes required improvement in the characteristics of SMS but at the same time it also releases leachate containing nitrates and other nutrients.

During field weathering process, leachate percolates into the underlying soils. The leachate from 24 months old naturally weathered piles of 3' and 5' SMS depth contains 0.8-11.0 g l^{-1} of dissolved organic carbon (Fig. 5); 0.1-2.0 g l^{-1} of dissolved organic nitrogen and organic salts. The values of pH, electrical conductivity and acid neutralizing capacity are 6.6 to 9.0, 21 to 66 dsm^{-1} and 10 to 75 mmol l^{-1}, respectively (Fig. 3). Ionic forms of potassium, chlorine and sulphate are the main inorganic elements in the leachate.

Organic acids below 1000 Da form the major component of dissolved organic carbon. In 24 months of SMS weathering, the 5 feet high pile releases about 2.8 kg dissolved organic carbon, 0.7 kg dissolved organic nitrogen and 13.6 kg of inorganic salts, while 3 feet pile releases about 3.0 kg dissolved organic carbon, 1.6 kg dissolved organic nitrogen and 26.6 kg of inorganic salts. The 5 feet pile retains more water and exhibits lower net nitrification compared with the 3 feet pile. The top 3 feet of soil retains 20 to 89% of the leachate solutes and 3 feet pile is more effective for efficient weathering than 5 feet pile (Guo *et al.*, 2001). Aeration during weathering fastens the process of weathering by reducing the time for biological activity within the SMS (Iteinemann *et al.*, 2002).

CHAPTER - III

Recomposting of SMS

Studies have revealed that SMS being rich in organic matter adds nutrients to the soils, helps in neutralizing acidic soils, facilitates plant growth in barren areas and in some cases, it improves water quality along with bioremediation of contaminated soils/industrial sites. In order to improve the physico-chemical characteristics of SMS for its use as manure, following recomposting methods can be employed.

1. RECOMPOSTING METHODS

a) Natural

In natural weathering process, the kachcha pit of 5^3 feet is filled up to the top with SMS and left for natural recomposting process for next 2 years (Fig. 6).

Fig. 6. SMS filled in a pit and left for decomposition

b) Aerobic

A perforated base is first prepared in the bottom of a kachcha pit of 5^3 feet with the help of waste wooden material (Fig. 7). The perforated bottom of the pit is connected perpendicularly with 2 inch diameter hollow plastic pipes placed at a distance of 1^2 feet. Holes of 0.5 inch diameter are also provided in the plastic pipes at a distance of 15 cm each in a circular fashion. The pit is filled with SMS up to the brim and

Fig. 7. Perforated base of the pit connected with hollow pipes

left for recomposting for a period of 2 years (Fig. 8).

Fig. 8. Aerobic method of SMS recomposting

c) Anaerobic

In anaerobic process, the kachcha pit of 5^3 feet is filled with SMS upto the brim and is covered with 1 feet thick layer of normal soil to create anaerobic conditions and left as such for 2 years.

2. PHYSICO-CHEMICAL PROPERTIES OF RECOMPOSTED SPENT MUSHROOM SUBSTRATE

a) Oyster and paddy straw mushroom spent substrate

The paddy straw mushroom spent substrate has pH in the range of 8.82 to 9.16; while oyster mushroom spent substrate has pH between 6.51 to 7.69. The values of electrical conductivity, total dissolved solids and nitrogen content are lower in paddy straw mushroom spent substrate than oyster mushroom spent substrate. The oyster mushroom SMS contains higher nitrogen (1.82%) as compared to paddy straw mushroom (1.06% to 1.46%). The other nutrients like organic carbon and phosphate are higher in paddy straw mushroom spent substrate than in oyster mushroom spent substrate. However, contents of potassium, magnesium and calcium are at par in two types of SMS. The ingredients used and method of substrate preparation employed always have bearing on the properties of two types of SMS.

b) Effect of recomposting methods on physico-chemical properties of oyster, button and paddy straw mushroom SMS

With the increasing recomposting period, pH decreases in SMS of all mushrooms, while conductivity increases in oyster and paddy straw mushroom spent substrates but not in button mushroom substrate. Nitrogen content, porosity, water holding capacity, total dissolved oxygen and microbial count increase during recomposting by all the methods in all the mushrooms. The contents of phosphorus, potassium, sodium, calcium, carbon, nitrate, total dissolved solids, particle density and bulk density decrease with the time in SMS of all mushrooms. Recomposting of SMS plays vital role in reducing the residue level of various fungicides, insecticides and heavy metals. Among different fungicides, insecticides and heavy metals, residues of only carbendazim (Bavistin) and deltamethrin (Decis) are detected in the fresh SMS but not in six months old weathered SMS.

c) Button mushroom SMS

i. Naturally weathered

In SMS samples of different age, pH ranges between 6.72 in 9 months old sample to maximum of 7.50 in 48 months old sample. Conductivity decreases with time and it varies between lowest of 0.24 mS cm^{-1} in 48 months old sample and highest of 6.22 mS cm^{-1} in 6 months old sample. Dissolved oxygen level and bulk density remain almost same in SMS of different age. Particle density decreases with time with lowest of 1.03 g cm^{-3} in 48 months old sample and highest in 12 months old sample. Porosity and water holding capacity vary between 14.50% to 26.20% and 28.00% to 41.00%, respectively in different samples with nonsignificant difference among SMS of different age. Nitrogen, phosphorus, carbon and calcium decrease continously with increasing time of weathering. None of the SMS sample contains sodium and lead. Nitrate content also decreases from 12.80 ppm in 6 months old sample to 1.95 ppm in 48 months old sample (Table 3).

ii. Button mushroom SMS recomposted in a pit

The SMS recomposted in a pit of 5^3 feet shows more variation in its properties than SMS left as such for open recomposting. The parameters like pH, electrical conductivity, particle density, porosity and total dissolved solids decrease after 30^{th} day of recomposting. Bulk density and water holding capacity remain consistant up to 180^{th} day. The contents of nitrogen, phosphorus and potassium increase after 30^{th} day, while carbon, sodium, calcium, chloride and nitrate

Table 3. Physico-chemical properties of button mushroom SMS of different age

S.No	Parameter	Properties of SMS of different age (Months)					
		6	9	12	24	36	48
1.	pH	7.30	6.72	7.20	7.45	6.90	7.50
2.	Conductivity (mS cm^{-1})	6.22	0.95	2.73	2.94	3.34	0.24
3.	Total dissolved solids (ppm)	2.70	0.462	2.03	0.14	1.72	0.11
4.	Dissolved oxygen (ppm)	0.64	0.54	0.56	0.64	0.63	0.84
5.	Bulk density (g cm^{-3})	0.69	0.71	0.62	0.75	0.75	0.73
6.	Particle density (g cm^{-1})	1.20	2.00	2.50	1.57	1.20	1.03
7.	Porosity (%)	25.80	14.50	15.20	15.90	20.80	26.20
8.	Water holding capacity (%)	41.00	30.00	28.00	32.00	36.00	38.00
9.	Nitrogen (%)	2.73	1.96	2.90	1.45	1.70	0.70
10.	Phosphorus (%)	0.31	0.20	0.20	0.17	0.16	0.10
11.	Potassium (ppm)	31.40	0.00	11.70	0.00	16.00	0.00
12.	Carbon (%)	2.51	1.46	1.46	0.84	0.45	0.41
13.	Sodium (ppm)	0.00	0.00	0.00	0.00	0.00	0.00
14.	Calcium (ppm)	0.56	0.58	0.41	0.34	0.52	0.27
15.	Lead (ppm)	0.00	0.00	0.00	0.00	0.00	0.00
16.	Chloride (ppm)	46.50	0.86	20.00	1.45	14.10	1.54
17.	Nitrate (ppm)	12.80	4.31	9.90	2.43	8.92	1.95

Gupta *et al.*, 2004

decrease. During 180 days of recomposting, significant changes occur in EC, total dissolved solids, bulk density, porosity, water holding capacity and contents of potassium, carbon, sodium, calcium, chloride and nitrate (Table 4).

Table 4. Physico-chemical properties of button mushroom SMS recomposted in a pit for different durations

Parameter	Properties of SMS recomposted for different duration (month)						
	0	**1**	**2**	**3**	**4**	**5**	**6**
pH	8.41	8.03	7.67	7.30	7.27	7.17	7.15
Conductivity mmho cm^{-1}	7.50	5.09	4.64	3.44	1.08	0.18	0.14
Nitrogen (%)	2.71	2.17	1.66	1.47	1.00	0.87	0.83
Phosphorus (%)	1.08	1.10	0.85	0.65	0.32	0.29	0.27
Potassium (ppm)	231.00	103.00	76.20	52.70	17.01	1.97	7.50
Sodium (ppm)	260.00	231.00	124.00	28.00	11.01	2.09	0.27
Carbon (%)	4.90	2.70	2.10	1.07	0.91	0.66	0.61
Calcium (ppm)	543.00	360.00	159.00	73.00	17.00	4.10	3.97
Chloride (ppm)	146.00	65.00	43.50	20.30	1.54	1.20	1.13
Nitrates (ppm)	12.80	6.56	4.19	2.30	2.51	2.10	2.07
Cadmium (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total dissolved solids (ppm)	1910.00	1263.00	613.00	409.00	247.00	93.0	0.81
Dissolved oxygen (DO) (ppm)	0.83	0.97	1.10	1.57	1.59	1.63	1.63
Bulk density (g cm^{-3})	0.57	0.28	0.26	0.24	0.24	0.23	0.23
Particle density (g cm^{-3})	2.20	2.00	1.67	1.97	1.97	1.70	1.70
Porosity (%)	20.00	36.00	44.31	44.01	44.01	42.39	42.39
Moisture (%)	59.0	67.0	67.5	67.5	68.20	69.00	68.10

3. Button mushroom SMS recomposted by different methods

Initially the pH increases and then decreases after 30th day in all recomposting methods. Anaerobic recomposting of SMS leads to lower electrical conductivity (0.02 mS cm^{-1} to 0.49 mS cm^{-1}) in comparison to aerobic process (1.21 mS cm^{-1} to 4.62 mS cm^{-1}). Total dissolved solids also decrease (2740 ppm to 885 ppm) in aerobic SMS, while these increase in both anaerobic and naturally weathered SMS. The other parameters like bulk density, porosity and water holding capacity increase with the time in aerobic process, remain constant in anaerobic process and show minor changes in natural recomposting process. The contents of nitrogen, potassium, carbon, sodium, calcium, chloride and nitrate decrease with the time in all processes of recomposting, however, the rate is fastest in anaerobic process followed by aerobic and then natural process. Phosphorus content shows an increase with the time in aerobic/ anaerobic processes, which is an exception in natural recomposting process, where it decreases with the time (Table 5).

d) Microbiological properties

The bacterial population in spent mushroom substrate ranges between lowest of 14.33 x 10^{-7} in *Volvariella volvacea* (paddy straw mushroom) to highest of 59.33 x 10^{-7} in oyster mushroom spent substrate. Spent substrate from *P. florida* (oyster mushroom) harbours 5 to 23 fold higher fungal population than other spent substrates. Among different fungi, *Trichoderma* spp. followed by *Aspergillus* spp. and *Mucor* spp. dominate in different spent substrates. *Trichoderma* dominates in all spent substrates, while *Mucor* in paddy straw mushroom and *Aspergillus* in both paddy straw mushroom and oyster mushroom spent substrates.

e) Enzyme activity

Oyster mushroom spent substrate exhibits highest activity of exoglucanase, endoglucanase and xylanase. The spent substrate from oyster mushroom also shows higher activity of laccase, manganese peroxidase and arylalcohol oxidase in comparison of SMS of button and paddy straw mushrooms. Button mushroom spent substrate shows higher activity of lignin peroxidase only (Ahlawat *et al.*, 2004a).

Table 5. Physico-chemical properties of button mushroom SMS recomposted by different methods

S.No.	Parameter	Physico-chemical properties of SMS recomposted by different methods for different duration (days)												
		Aerobic					Anaerobic				Natural			
		0	15	30	45	60	15	30	45	60	15	30	45	60
1.	pH	8.30	8.56	8.81	8.13	8.00	8.77	8.61	8.12	8.22	7.17	8.43	7.88	8.19
2.	Conductivity (mS cm^{-1})	3.51	4.62	1.39	1.21	1.55	0.02	0.35	0.49	0.49	0.32	0.90	2.26	2.28
3.	Total dissolved solids (ppm)	2740.00	1230.00	682.00	747.00	885.00	8.80	203.00	221.00	272.00	53.10	432.00	1390.00	1580.00
4.	Dissolved oxygen (ppm)	-0.18	0.02	-0.10	-0.19	0.00	0.00	-0.20	-0.09	0.00	-0.10	-0.09	-0.11	0.00
5.	Bulk density (g cm^{-3})	0.22	0.30	0.39	0.33	0.35	0.25	0.31	0.33	0.38	0.28	0.19	0.22	0.22
6.	Particle density (g cm^{3})	10.00	1.33	2.50	0.91	0.63	2.00	3.33	1.42	1.38	2.50	1.67	2.00	1.91
7.	Porosity (%)	7.80	52.60	24.40	73.62	73.62	37.50	20.72	47.18	35.30	28.80	48.50	39.00	36.25
8.	Water holding capacity (%)	20.00	20.00	33.30	41.18	49.00	40.00	23.07	33.33	35.25	20.00	44.44	54.55	52.60
9.	Nitrogen (%)	2.10	2.10	1.19	1.82	1.23	1.75	1.51	1.58	1.14	2.03	1.72	1.72	1.44
10.	Phosphorus (%)	0.57	0.97	0.94	1.05	1.11	1.05	1.30	1.24	1.25	1.37	1.20	1.14	1.14
11.	Potassium (ppm)	138.00	283.00	336.00	41.40	34.60	236.00	72.70	18.30	19.60	256.00	223.00	43.80	76.80
12.	Carbon (%)	5.43	5.34	5.84	4.50	0.60	5.70	5.83	5.22	1.50	5.52	5.57	4.74	0.60
13.	Sodium (ppm)	402.00	120.00	91.60	4.46	0.00	0.00	20.40	0.00	0.00	54.00	61.80	0.00	6.85
14.	Calcium (ppm)	1380.00	19.90	0.00	22.30	8.12	70.10	0.00	21.10	5.46	22.70	23.80	30.80	11.70
15.	Lead (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.	Chloride (ppm)	115.00	111.00	56.30	51.00	21.80	13.30	15.90	31.00	17.40	59.50	30.20	107.00	36.10
17.	Nitrate (ppm)	4.80	13.60	9.90	4.92	10.20	2.28	3.18	0.48	4.01	2.66	5.38	11.30	30.80

CHAPTER - IV

Recycling of SMS

The addition of spent mushroom substrate in nutrient poor soil improves its health by improving the texture, water holding capacity and nutrient status (Kaddous and Morgans, 1986; Maher, 1991; Beyer, 1996). However, it reduces the soil's thermal conductance, bulk density and water stable aggregates (>0.25 mm). Spent mushroom substrate incorporation in soil leads to an increase in both pH as well as the organic carbon content (Kaddous and Morgans, 1986). The experiments carried out for studying the effect of SMS on several crops have shown that the dry matter content of plants increases with incorporation of increasing amount of weathered or unweathered SMS in soil (Chong *et al.*, 1987). The phosphorus and potassium requirements of the crop plants can be fully met by incorporating 5% of SMS by volume, while nitrogen requirement by 25% of SMS by volume (Maher, 1991). The mixing of spent mushroom substrate in soil has shown plant growth promoting activity in several plant species.

Spent mushroom substrate not only improves soil health but also helps in the turf establishment which, however, depends on the rate of SMS application in soil (Landschoot and McNitt, 1994).

1) FARMERS' INDIGENOUS KNOWLEDGE ABOUT USES OF SMS

Mushroom growers are recycling spent mushroom substrate naturally and using it in agricultural and horticultural crops as manure at their own. They have gained a lot of experience in it and are sharing their knowledge within a specified locality. The data collected at NRCM, Solan (HP) reveals that SMS is being used as manure in several crops viz. capsicum, tomato, cauliflower, pea, potato, ginger, garlic, wheat, paddy, maize and apple (Table 6). Wide variation exists in age of SMS applied in different crops and it ranges between 0 month (fresh) to 3 years old. Similarly, quantity of SMS applied also varies between a minimum 4.75q ha^{-1} to maximum 1000 q ha^{-1} in field crops and 4-6 kg pl^{-1} in apple.

Spent compost also improves the physical and chemical structure of the soil. Mushroom growers have the observation that spent compost considerably increases the level of soil fertility, water holding capacity, porosity and texture on applying as manure.

Both mushroom growers and researchers have noticed that the application of SMS in soil enhances the crop yield and manages diseases in agricultural and horticultural crops, in addition to improvement in soil physical conditions. On the basis of empirical data and experiences gained during the process of verification and refinement of ITKs about use of SMS as manure in crops; it can be concluded that SMS should be decomposed for atleast 12 months either by natural weathering in pits or aerobic/anaerobic recomposting instead of disposing off in open on road side. Similarly, the doses of recomposted SMS for various crops should be worked out on the basis of total nutrient (N.P.K.) requirement of the respective crop and the nutrient status of the soil/SMS. The recomposted SMS can be used singly as basal application or in combination with inorganic fertilizers.

2) RESEARCHERS' OUTCOME

a) Horticulture

Spent mushroom substrate makes the soil suitable for raising vegetables (Kaddous and Morgans, 1986). Suitable treatments of SMS like rapid salt leaching (Chong *et al.*, 1991) and weathering in open for two to three years make SMS more suitable for either complete or partial substitution of growing media for flowers, vegetables, fruits, saplings, ornamental shrubs and other horticultural plants of economic importance (Beyer, 1996) (Table 6). The spent mushroom substrate being rich in N, P and K, acts as a good growing medium for vegetables like cucumber, tomato (Fig. 9), broccoli, tulip, cauliflower, peppers, spinach etc., but the

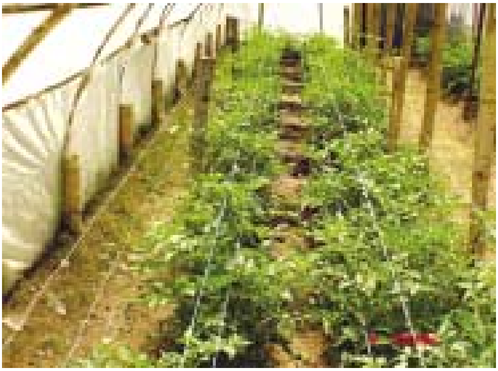

Fig. 9. Tomato crop raised on SMS amended soil

response of the plants vary at different levels of SMS incorporation. There are varied reports available regarding the effect of SMS on plant growth and yield of vegetables, but the study carried out at National Research Centre for Mushroom, Solan (HP) for the last 4 years has shown definite advantage with SMS. In earlier studies also the incorporation of spent mushroom substrate @ 25% and 37.5% with the growing medium has shown growth promoting effect on lettuce, marigold and tomato. There is a long list of vegetables viz; *Cucurbita pepo*, *Capsicum annuum*, spring broccoli, autumn broccoli, aubergines, sweet corn cv. Seneca gold, snapbeans (*Phaseolus vulgaris*) cv. provinder and *Pennisetum glaucum* cv. HGM–100, which show enhanced yield on amendment of the soil with SMS. However, the aged mushroom compost is preferable over the fresh compost (Lohr and Coffey, 1987). The use of SMS as manure has also been found to increase the quality of the produce in several crops. In a study, 50t ha^{-1} of SMS incorporation in soil gave the maximum yield of onion bulbs with higher content of P, K, Ca and Mg in the bulbs (Wisniewska and Penkiewicz, 1989) and in tomato it improved the firmness and ascorbic acid content (Dundar *et al.*, 1995).

Besides vegetables, greenhouse and nursery crops, the woody ornamental and forage crops including, *Cotoneaster dammeri* cv Coral Beauty, *Deutzia gracilis*, *Cornus alba*, *Argenteo marginata*, *Forsythia* x *intermedia* cv. Lynwood, *Juniperus sabina* cv. Blue Danube, *J. virginiana* cv. Hetzii, *Physocarpus opulifolius*, *Potentilla fruticosa* cv. Red Ace, *Ligustrum vulgare*, *Rosa indica* cv. John Franklin, *Weigela* cv. Bristol Ruby and *W. florida* cv. Variegata Nana also show good growth in different levels (33%, 67% & 100%) of SMS mixed with bark (Chong and Rinker, 1994). In addition to the above mentioned plant species, spent mushroom substrate also increases the total spear FW and number m^{-2} in white asparagus (Pill *et al.*, 1993), while total height in mountain persimmon (*Diospyros oldhamii*) as well as non-astringent persimmon (*D. kaki*) cv. Fuyu (Nee *et al.*, 1994). The fresh SMS properly sized by sieving, leached of salts and blended with vermiculture acts as an ideal growth medium for plants and offers exceptional aeration, porosity, water holding capacity and nitrogen. It acts as a conceivable alternate to peat in soil less mixer (Romaine and Holcomb, 2001). The research carried out in this direction at NRCM, Solan has also shown very encouraging results with respect to effect of SMS on plant growth, fruit yield and quality along with diseases management (Ahlawat *et al.*, 2004b, 2005a, 2005b, 2006a, 2007a, 2007b; Dev Raj *et al.*, 2005). The detailed findings of work carried out with different crops is presented in the following text.

i) TOMATO (*Lycopersicon esculentum*):

Amendment of aerable land with 18.5 ton ha^{-1} of 6-24 months old naturally weathered SMS followed by recommended package of practices leads to far superior vegetative growth of plants and yield of 746q ha^{-1} (Fig. 10) in comparison to tomato yield of 456.53q ha^{-1} in FYM mixed soil. Similarly, the mixing of soil with 12 months old anaerobically recomposted SMS leads to superior tomato yield of 658.89 q ha^{-1} to that of FYM (547.04q ha^{-1}).

Fig. 10. Tomato crop raised on SMS amended soil

Mixing of soil with anaerobically recomposted SMS also enhances the tomato quality (Fig. 11) with respect to superior fruit weight (59.32 g), ascorbic acid content (33.89 mg g^{-100} fresh weight), dry matter (8.40%), total soluble solids (TSS, 5.17 ^{o}Brix) & acidity (2.05%).

Fig. 11. Quality fruits on tomato plants

Anaerobically recomposted SMS as manure in tomato crop is found to lower incidences of blossom end rot, buck eye rot and leaf curl with no effect on fruit borer incidence (Fig. 12).

Fig. 12. Fruit borer infestation on tomato crop

ii) SHIMLA MIRCH (*Capsicum annuum*)

Amendment of aerable land with 25 ton ha^{-1} of 6-18 months old naturally weathered SMS enhances plant growth (49 cm) and fruit yield (171 q ha^{-1}) (Fig. 13) in comparison to farm yard manure (152.53 q ha^{-1}) and the recommended dose of fertilizers. Similarly, the amendment of

Fig. 13. Effect of SMS on plant growth of Capsicum

aerable land with 12 months old aerobically recomposted SMS followed by recommended package of practices leads to far superior plants growth (51 cm) and fruit yield of 212.27 q ha^{-1} (Fig. 14).

Fig. 14. Capsicum raised on SMS amended soil

Amendment of soil with 12 months old naturally weathered SMS also enhances the fruit quality with respect to fruit length (53.74 mm), fruit width (44.15 mm), dry matter (9.40%), total soluble solids (4.82 °Brix) & ascorbic acid content (23.70 mg g^{-100} fresh weight). Similarly the aerobically recomposted SMS also stimulates the quality of the fruits with respect to their length (51.08 mm), width (43.48 mm), dry matter (9.41%), total soluble solids (4.80 °Brix) & ascorbic acid content (25.37 mg g^{-100} fresh weight).

Amendment of soil with 24 months old naturally weathered and aerobically recomposted SMS also leads to 2-4% lower incidence of fruit rot, 15-20% lower incidence of chilli veinal mottle virus and about 4% lesser grasshopper attack on plants in comparison to recommended dose of fertilizers and FYM.

iii) PEA (*Pisum sativum*)

Amendment of aerable land with 12 months old anaerobically recomposted SMS @ 20 ton ha^{-1} enhances plant height to 110.50 cm and pod yield to 120.26q ha^{-1} (Fig. 15) in comparison of pod

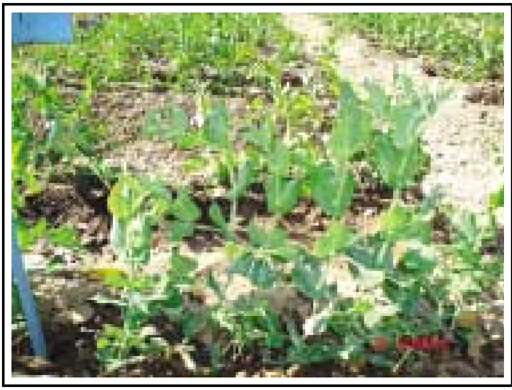

Fig. 15. Healthy crop of pea on SMS amended soil

yield of 92.40q ha^{-1} in FYM mixed soil.

Anaerobically recomposted SMS also improves the quality of pea (Fig. 16) with respect to its contents of protein (4.88%), ascorbic acid (11.90mg g^{-100} of fresh weight), dry matter (73.80%)

Fig. 16. Quality pea pods on plants grown of SMS amended soil

and total soluble solids (16.9° Brix).

The mixing of SMS also reduces *Fusarium* wilt and powdery mildew score incidences by 3-4 folds both on plants and the pods.

iv) CAULIFLOWER (*Brassica oleracea* L. var. *botrytis*)

The mixing of 12 months old anaerobically recomposted SMS @ 25 ton ha^{-1} along with chemical fertilizers in nutritionally poor soil before transplantation of the seedlings followed by recommended package of practices enhances the vegetative growth (Fig. 17) and total yield of cauliflower (186.56 q ha^{-1}) in comparison to yield obtained from FYM manured field (119.35 q ha^{-1}).

Fig. 17. Cauliflower raised on SMS mixed aerable soil

Mixing of 12 months old anaerobically recomposted SMS along with chemical fertilizers leads to superior stalk length (5.10 cm), curd length (12.25 cm), curd dia (15.17cm), dry matter (7.84%), ascorbic acid content (57.60mg g^{-100} fresh weight) and curd appearance (Fig. 18).

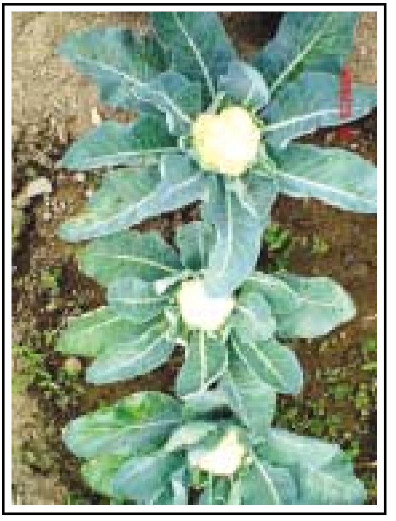

Fig. 18. Superior quality curd of cauliflower on SMS amended plot

The extent of incidence of black rot (Fig. 19) and caterpillar are lowered by 60% and 40%, respectively in anaerobically recomposted SMS manured soil in comparison to FYM mixed plots.

Fig. 19. Diseased plant from FYM mixed plot

Fig. 20b. Enhanced plant growth in SMS amended plots

v) ZINGER (*Zingiber officinale*)

The amendment of nutritionally poor soil with 30-32 ton ha^{-1} of 18 months old aerobically recomposted SMS + chemical fertilizers enhances plant growth (Figs. 20a & 20b) and ginger yield upto 144.44q ha^{-1} in comparison to 120.9q ha^{-1} in FYM mixed field.

Fig. 20a. Healthy crop of ginger raised on SMS mixed soil

The mixing of 18 months old aerobically/anaerobically recomposted SMS along with chemical fertilizers not only stimulates the yield but also enhances the quality with respect to rhizome length (10.20cm), breadth (5.15cm), thickness (3.1cm), dry matter (15.83%), total soluble solids (6.0 °Brix), fibre (4.54%) and non-soluble solids (NSS) (9.49%).

Lowest rhizome rotting occurs in FYM and anaerobically recomposted SMS, followed by aerobic and natural SMS amendments as compared to the recommended dose of fertilizers.

vi) ONION (*Allium cepa* L.)

The mixing of 12 months old anaerobically recomposted SMS + chemical fertilizers @ 25 ton ha^{-1}

in aerable land stimulates the vegetative growth (38.49 cm) and the yield of onion bulbs (222.00q ha^{-1}) in comparison to FYM (148.00q ha^{-1}) and recommended dose of fertilizers (206.00q ha^{-1}) (Fig. 21).

Fig. 21. Onion crop on SMS amended plots

The amendment of soil with anaerobically recomposted SMS along with chemical fertilizers leads to an enhancement in quality parameters of onion bulbs with respect to length (4.30 cm), diameter (5.55 cm), total soluble solids (12.3 °Brix), dry matter (17.46%), pyruvic acid (0.416) and ascorbic acid (29.45) contents in comparison to FYM and recommended dose of fertilizers.

vii) BRINJAL (*Solanum melongena*)

The mixing of 12 and 24 months old anaerobically recomposted SMS @ 25 ton ha^{-1} enhances the growth of the plants (Fig. 22) as well as the fruit yield (251.42q ha^{-1}) in comparison to FYM manured plots (236.66 q ha^{-1}).

Fig. 22. Brinjal crop raised on using SMS as manure

The fruits obtained from SMS mixed plots, FYM and recommended dose of fertilizers do not vary in quality with respect to their size and weight.

b) Cereal Crops

Studies have been conducted on several crops, out of which maize has shown promising results in most of the studies. In one case, SMS incorporation @ 100, 200 and 400 tons (Fresh weight) ac^{-1} in nutrient poor soil like silty clay loam, shows positive effect on the silage and grain yield of corn crop. The silage production in this case increases by 33% to 68% depending upon the weather conditions after SMS incorporation. Similarly, the grain yield is also influenced by weather conditions. None of the studies has shown any adverse effect on quality of the ground water and run off, and the quality of water matches with water from the non fertigated plots (Wuest and Fahy, 1991).

The amount of protein in stover and grains increases with SMS incorporation in the field and in study carried out by Wuest *et al.*, (1995), the grain as well as stover were found to contain significantly higher level of nitrogen. The incorporation of SMS along with peat stimulates the growth of diazotrophs in the field (Gronborg, 1990). Further, annual incorporation of SMS upto 90 kg m^{-2} area has not been found to degrade the quality of surface water, and the run-off has been found to contain very low amount of ammonia-N, biological oxygen demand (BOD) and chloride. The study carried out with wheat (*Triticum aestivum*) at National Research Centre for Mushroom, Solan (HP) has also shown encouraging results.

i) WHEAT (*Triticum aestivum*)

Field application of 12 months old anaerobically recomposted SMS + basal dose of chemical fertilizers (Urea, DAP and Murate of Potash) enhances vegetative growth of plants (86.60cm) and yield (49.80q ha^{-1}) of wheat (Fig. 23) in comparison (35.20q ha^{-1}) to FYM mixed plots.

Fig. 23. Wheat crop raised using different SMS treatments

Amendment of soil with 12 months old anaerobically recomposted SMS + chemical fertilizers stimulates the ear quality with respect to length (cm), no of grains ear^{-1}, test weight of grains (gm) and grain: straw ratio in comparison to control and FYM mixed treatments.

c) Mushrooms

Production of second crop of mushroom from the spent substrate can prove more efficient utilization of the substrate ingredients and can also ameliorate the problem of solid waste disposal in the mushroom industry (Fahy and Wuest, 1984). Re-spawning of *Agaricus* spent compost together with the addition of spawn mate (delayed - release nutrient) and Bonaparte peat (adsorbent material) can give good yield of second *Agaricus* crop.

The shiitake spent mushroom substrate supplemented with 10% wheat bran and 10% millet can be utilized for *Pleurotus sajor-caju* cultivation, after air-drying, grinding, supplementation, pasteurization and spawning of spent substrate. In one case higher yield of *P.sajor-caju* (79% Biological Efficiency) was obtained by supplementing the spent shiitake basal medium with 12% soybean and 1.0% $CaCO_3$ (Royse, 1993).

Another use of SMS in mushroom cultivation is as casing material for button mushroom. The use of aerobically fermented spent mushroom substrate as casing material gives mushroom yield at par with peat based casing material with an additional advantage of less bacterial blotch (*Pseudomonas tolaasii*) infection on fruiting bodies than those from peat-based casing material (Szmidt, 1994; Ahlawat and Vijay, 2004). The casing prepared from SMS, EDTA and peat has also been found most productive (Sharma *et al.*, 1999).

Casing of button mushroom bags with one year old aerobically recomposted SMS supports about 2-3 days early crop of button mushroom (Fig. 24) along with mushroom yield at par with coir pith and superior than 2 year old FYM with non-significant differences in fruiting body

Fig. 24. Button mushroom crop using SMS based casing

Table 6. Response of different plant species towards different doses and age of SMS

Crop	Age of SMS	Quantity ($q\ ha^{-1}$)	Impact			Source of information
			Yield	Quality	Diseases/ insect-pests	
Capsicum	6-12 months	100-150	Increased	NR	Normal	Mushroom growers
	6 months mixed with FYM	125	Increased		Normal	
	24-36 months	25-37.5	Increased		Decreased	
	24 months	250	Increased		NR	
Tomato	0-6 months	100 -125	Increased	NR	No diseases	Mushroom growers
	6 months mixed with FYM	125	Increased		Normal	
	2-6 months	12.5	Increased		NR	
	24 months	250	Increased		NR	
	24-36 months	25-37.5	Increased		Decreased	
Cauliflower	6 months mixed with FYM	125	Increased	NR	Normal	Mushroom growers
	6-12 months	100-125	Increased		Decreased	
	24-36 months	25-37.5	Increased		NR	
Ginger	2-6 months	25	Increased	NR	Decreased	Mushroom growers
	6 months	100-125	Increased		Increased	
	12 months	250	Increased		Increased	
	18 months	37.5-50	Increased		Decreased	
Garlic	1 month	312.5	Increased	NR	Increased	Mushroom growers
	6 months	100-125	Increased		Increased	
	12 months	62.5-75	Increased		Normal	
Wheat	2-3 months	87.5	Increased	NR	NR	Mushroom growers
	1-6 months	125-150	Increased		Decreased	
	6 months	25 -37.5	Increased		Decreased	
	4 months	12.5	Increased		Decreased	
	7-8 months	4.75-12.5	Increased		Decreased	
	12 months	250	Increased		NR	

Crop	Age of SMS	Quantity ($q\ ha^{-1}$)	Impact			Source of information
			Yield	Quality	Diseases/ insect-pests	
	12 months	12.5-37.5	Increased		Decreased	
	12 months	11.25	Increased		Decreased	
Maize	0-6 months	50-150	Increased	NR	No diseases	Mushroom growers
	2-6 months	4.375	Increased		Decreased	
	6 Months	25-37.5	Increased		Decreased	
	12 months	11.25	Increased		Decreased	
	12 months	62.5-75	Increased		Normal	
	24-36 months	25-37.5	Increased		Decreased	
	3-15 months	10	Increased		NR	
	12 months	250	Increased		NR	
Paddy	Fresh	62.5	Increased	NR	Decreased	Mushroom growers
	1 month	62.5	Increased		Increased	
	12 months	12.5-37.5	Increased		Decreased	
	1-2 months	125	Increased		Decreased	
Potato	0-6 months	18.75	Increased	NR	NR	Mushroom growers
	6 months	100-125	Increased		Decreased	
	4 months	12.5	Increased		Decreased	
	12 months	250	Increased		Decreased	
	24 months	100	Increased		Normal	
Pea	0-6 months	100	Increased	NR	No diseases	Mushroom growers
	6 months	100-125	Increased		Decreased	
	12 months	62.5-75	Increased		Normal	
	12 months	93.75	Normal		Normal	
	12 months	250	Increased		NR	
Apple	1 month	5-6 $kg\ pl^{-1}$	Normal		Normal	Mushroom growers
	5 months	4 $kg\ pl^{-1}$	Increased		Normal	
	8-12 months	4-6 $kg\ pl^{-1}$	Increased		Decreased	
Cucumber, Tomato,	Varied age	Varied dose	Enhanced	NR	NR	Beyer, 1996

Crop	Age of SMS	Quantity ($q\ ha^{-1}$)	Impact			Source of information
			Yield	Quality	Diseases/ insect-pests	
Broccoli, Tulip, Cauliflower, Pepper, Spinach						
Lettuce, Marigold, Tomato	Aged mushroom compost	25-37.5% of the growing medium	Enhanced	NR	NR	Lohr and Coffey, 1987
Cucurbita pepo, Capsicum annuum, Spring broccoli, Autumn broccoli, Aubergines, Sweet corn, Snapbeans, *Pennisetum glaucum*	Varied age	Varied dose	Enhanced	NR	NR	Maynard, 1994; Steffen *et al.*, 1994; Rhoads and Olson, 1995
Onion	Aged SMS	500	NR	Higher content of P, K, Ca and Mg	NR	Wisniewska and Penkiewicz, 1989
Tomato	Button mushroom SMS	NR	NR	Improved firmness and ascorbic acid	Restricted root knot infestation	Dundar *et al.*, 1995; Verma, 1986
Woody ornamental and forage crops	NR	33, 67, 100% mixed with bark	Superior growth	NR	NR	Chong and Rinker, 1994
White asparagus	NR	NR	NR	Total spear FW and number m^{-2}	NR	Pill *et al.*, 1993

Crop	Age of SMS	Quantity ($q\ ha^{-1}$)	Impact			Source of information
			Yield	Quality	Diseases/ insect-pests	
Mountain persimmon, Non-astrigent persimmon	NR	NR	Total height	NR	NR	Nee *et al.*, 1994
Apple	Spraying with aqueous extract of SMS	Weekly and biweekly	NR	NR	Controls apple scab	Yohalem *et al.*, 1994
Tomato	6-24 months naturally weathered and 12 months anaerobically recomposted	185	Enhanced plant growth and fruit yield	Superior quality	Lesser diseases and insect-pests infestation	NRCM, Solan
Shimla mirch (Capsicum)	6-18 months naturally weathered and 12 months aerobically recomposted	250	Enhanced plant growth and fruit yield	Superior quality	2-20% lower diseases and insect-pests infestation	NRCM, Solan
Pea	12 months anaerobically recomposted	200	Enhanced plant growth and pod yield	Superior quality	3-4 folds lower diseases incidence	NRCM, Solan
Cauliflower	12 months anaerobically recomposted SMS + chemical fertilizers	250	Enhanced plant growth and curd yield	Superior quality	40-60% lower diseases and insect-pests infestation	NRCM, Solan
Zinger	18 months aerobically recomposted SMS + chemical fertilizers	300-320	Enhanced plant growth and rhizome yield	Superior quality	Lesser rotting of rhizome	NRCM, Solan

Crop	Age of SMS	Quantity ($q\ ha^{-1}$)	Impact			Source of information
			Yield	Quality	Diseases/ insect-pests	
Onion	12 months anaerobically recomposted SMS + chemical fertilizers	250	Enhanced plant growth and bulb yield	Superior quality	NR	NRCM, Solan
Brinjal	12-24 months anaerobically recomposted SMS	250	Enhanced plant growth and fruit yield	Superior qualtiy	NR	NRCM, Solan
Wheat	12 months anaerobically recomposted SMS + chemical fertilizers	300 q + chemical fertilizers (N, P, K @ 80 kg, 60 kg, 50 kg ha^{-1})	Enhanced plant growth and grain yield	Superior qualtiy	NR	NRCM, Solan
Maize	Fresh	1000-4000	Enhanced silage and grain yield	Superior protein content in silage and grains	NR	Wuest and Fahy, 1991
White button mushroom	Button mushroom SMS + spawn mate and bonaparte peat	Full	Good second crop	NR	NR	Fahy and Wuest, 1984
Oyster mushroom	Shiitake mushroom waste + 10% wheat bran + 10% millet	Full	Good yield	NR	NR	Royse, 1993

Crop	Age of SMS	Quantity ($q\ ha^{-1}$)	Impact			Source of information
			Yield	Quality	Diseases/ insect-pests	
Oyster mushroom	Shiitake mushroom waste + 12% soyabean + 1% $CaCO_3$	Full	79% BE	NR	NR	Royse, 1993
Button mushroom	Aerobically fermented SMS	As casing	Mushroom yield at par with peat	NR	Lower bacterial blotch infection	Szmidt, 1994
Button mushroom	SMS + EDTA + peat	As casing	Superior mushroom yield	NR	Lower bacterial blotch infection	Sharma *et al.*, 1999
Button mushroom	Aerobically fermented SMS	As casing	Early and mushroom yield at par with coir pith	NR	Lower dry bubble infection	NRCM, Solan

weight. The SMS based casing also lowers dry bubble disease incidence in comparison to coir pith.

d) Bioremediation of contaminated soil

The uncontrolled release of industrial wastes in the open and poor availability of pre-treatment facilities contribute towards the increased level of contaminants in the soil. The degradation of these contaminants mainly depends upon the physical and chemical conditions of the soil and the nature of microorganisms thrive in the soil. In addition to being a rich nutrient source for various field crops, spent mushroom substrate originated from different edible mushrooms possesses unique physico-chemical and biological properties, which make SMS an ideal bioremediative agent for various environmental protection activities. SMS adsorbs the organic and inorganic pollutants and harbours diverse category of microbes, which have the capability of biological break down of the organic xenobiotic compounds. The microbes, especially actinomycetes (*Streptomyces* sp. and *Thermomonospora* sp.) present in spent mushroom substrate also have strong pollutants catabolizing capabilities which result in decreased level of pollutants in contaminated soil after incubation with SMS (Ahlawat *et al.*, 2007c) (Table 7).

In laboratory experiments, the mixing of pentachlorophenol (PCP) contaminated sterile soil with aliquotes of spent sawdust cultures of shiitake mushroom, supplemented with nutrient solution of glucose, thiamine and mineral salt result in disappearance of about 44.4-60.5% of pentachlorophenol in 21 days of incubation. (Okeke *et al.*, 1993). However, during the same incubation period, Buswell (1995) reported 50% break down of PCP on mixing of spent shiitake substrate with sterile PCP contaminated soil. The addition of spent oyster mushroom substrate in contaminated soil also results in 50% to 87% reduction in 3-ring compounds in first 12 weeks of addition and these further increase to 87% to 99% on re-inoculation of SMS followed by further incubation for 3 weeks. The effect on 4-ring compound is less and it ranges between 34 to

43%, which again increases to 51% to 59% on re-inoculation of SMS after 12 weeks of first addition (Leopold, 2002). The spent mushroom substrate also has the decontamination potential for land sites used for disposal of hazardous wastes (Buswell, 1994). Similar studies but with diverse category of chemicals were conducted by Fermor *et al*. (2000) and reported a significant potential of phase II compost in remediation of lands contaminated with xenobiotic pollutants like chlorophenols (PCP), polycyclic aromatic hydrocarbons (PAHS) and aromatic monomers. The crude and partially purified extract from SMS also degrade variety of dyes and it has found uses as a bleaching and deinking aide (Fig. 25) during recycling of paper waste (Hanson, 2002; Ahlawat *et al.,* 2006b).

Fig. 25. Laboratory study for dyes decolourization by using enzyme extract from SMS

The second category of chemical contaminants affecting the soil are the man made fungicides, herbicides and insecticides, which are being in use for protecting the crops from different categories of pathogens, competitors and pests. Five percent, W/W spent mushroom compost incorporation in soil having 5 ppm alachlor concentration, increases the alachlor disappearance and protects garden pea cv. Taichung from root injury. It has also been observed that SMS stimulates the microbial population (10^8-10^9) and maintains it for 28 days. The stimulated microbial population of *Aspergillus* sp., *Penicillium* sp., *Trichoderma* sp., *Aeromonas* sp. and *Bacillus* sp., has been found to degrade alachlor within 7 days of incubation under *in vitro* conditions (Huang *et al*., 1995, 1996).

Use of spent mushroom substrate also stabilizes the abandoned mine sites, pipeline construction sites and commercial/industrial sites. The mixing of SMS in soil degrades different pesticides at varied rates with the involvement of physical structure of SMS and microbes it harbours.

i) Bioremediation of pesticides:

The mixing of spent mushroom substrate @ 10, 20 & 30%, w/w in soil, results in faster degradation of Decis, Malathion, Bavistin and Mancozeb in comparison to soil without any amendment of SMS. Mixing of soil @ 30% gives best results and the effect is at par in 20% SMS amendment treatment (Fig. 26).

Fig. 26. Experiment on pesticides biodegradation by using SMS

The concentration of insecticides (Malathion and Deltamethrin) reduces to just half of its initial concentration just after one month of SMS mixing and to negligible level after six months of SMS mixing. However, in Decis (deltamethrin), the degradation occurs at much faster rate and it reaches to undetectable limit after 5 months of SMS application. In case of fungicides also (Carbendazim and Mancozeb), maximum degradation occurs on 30% SMS mixing. The residue level of carbendazim reduces to 6% of its initial concentration after 6 months of SMS mixing in soil. Twenty percent SMS mixing gives results at par with 30% SMS treatment. The degradation of Mancozeb occurs at a faster rate in 20% SMS treatment. In control, degradation of different pesticides occurs at slower rate and is far less as compared to SMS incorporated soil.

During the study, the lignolytic enzymes have been found to play major role in pesticides bioremediation. Among different microflora of SMS, *Trichoderma* sp., *Aspergillus* sp., *Mucor* sp. and B-I bacterial isolate possess higher pesticides biodegradation potential under *in vitro* conditions. The bioremediation of pesticides in sterilized SMS occurs at a very slow rate as compared to pure or mixed inoculum of different fungi or bacteria (Gupta *et al.*, 2006a; Ahlawat *et al.*, 2007c)

Table 7. Additional advantages of using SMS in different types of soils

Type of soil/waste	Type of SMS	Advantage	Source of information
Arable soil	Button mushroom SMS	Enhanced fertility level, water holding capacity, porosity and soil texture	Mushroom growers
Nutrient poor soil	Button mushroom SMS	Enhanced texture, water holding capacity and nutrient status	Kaddous nad Morgans, 1886; Maher, 1991; Beyer, 1996
Nutrient poor soil	Button mushroom SMS	Enhanced pH and organic carbon, while reduced thermal conductance and bulk density	Kaddous nad Morgans, 1886
Pentachlorophenol contaminated soils	Shiitake spent substrate	44.4-60% breakdown of PCP	Okeke *et al.*, 1993)
Pentachlorophenol contaminated soils	Shiitake spent substrate	50% breakdown of PCP	Buswell, 1995
Three and 4-ring compounds contaminated soils	Oyster mushroom spent substrate	50-87% reduction in 3-ring and 34-43% reduction in 4 ring compounds	Leopold, 2002
Land sites used for hazardous wastes disposal	Button mushroom SMS	Reduction in chlorophenols, polycyclic aromatic hydrocarbons and aromatic monomers	Buswell, 1994; Fermor *et al.*, 2000
Mine, pipe construction, commercial and industrial sites	Button mushroom SMS	Stabilization of the sites	Buswell, 1994
Alachlor contaminated soil	Button mushroom SMS	Increased disappearance of alachlor	Huang *et al.*, 1995
Fungicides, pesticides and heavy metals contaminated soils	Button mushroom SMS @ 20% w/w	Increased degradation of the pesticides and heavy metals	NRCM, Solan
Paper waste	Extract from SMS	Deinking of paper waste	Hanson, 2002

ii) Bioremediation of heavy metals

The mixing of spent mushroom substrate @ 10, 20 & 30%, w/w, results in faster degradation of lead and cadmium in soil in comparison to soil without any amendment of SMS. It has been recorded that metals decrease at sharpest rate in 30% SMS, w/w, mixed soil. The level of cadmium & lead reduces to undetectable limit after six months of SMS mixing in soil under *in situ* conditions. However, the decrease in levels of these heavy metals in control plot occurs at a very slow rate, where no SMS is mixed. The sharp decrease in level of heavy metals in SMS mixed soil occurs because of the isolated biomass of SMS which works as an ion exchanger.

The microflora thrive on SMS has been found to be responsible for faster heavy metals bioremediation in SMS mixed soils. In sterilized SMS, initially the metal level decreases quite fast but become gradual after the zero day of analysis (Gupta *et al.*, 2006b).

e) Vermicomposting

Decomposition of SMS takes minimum of six months and quality manure from SMS can only be prepared by long term decomposition. The duration of SMS decomposition can be shortened to few weeks by vermicomposting of SMS. Farm yard manure is the most preferred food material for worms, but recent studies conducted at National Research Centre for Mushroom, Solan have shown that spent substrate from paddy straw, oyster and button mushrooms are also suitable for vermicomposting. Fresh as well as 15-20 days old rotten spent mushroom substrate from white button, oyster, milky and paddy straw mushrooms is an acceptable material for the worms to multiply and to convert it into manure for field crops. The SMS can be used as a vermicomposting medium either alone or in

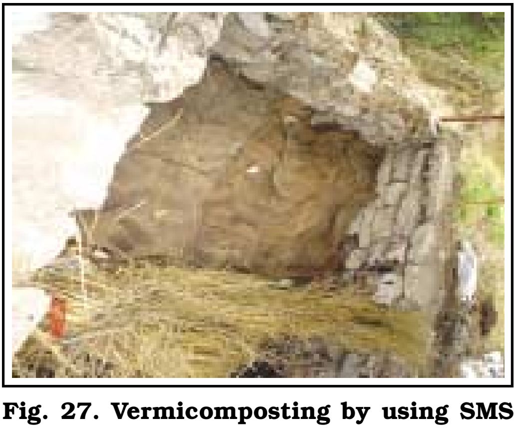

Fig. 27. Vermicomposting by using SMS as feeding material

different combinations either with FYM, agricultural or vegetable farming wastes depending upon their availability. Effective vermicomposting can be followed by following the standard protocol as adopted for FYM, agricultural and domestic wastes (Fig. 27). The time for vermicomposting with SMS varies between 2 to 2.5 months.

f) Spent mushroom substrate as organic fertilizer

Spent mushroom substrate is still nutrient-rich and contains about 80% of the total nitrogen in bound form with high molecular weight fractions of lignin and humic substances (Grabbe, 1982). Nitrogen release from the SMS is very low; therefore, plant nutrition is insufficient, which can, however, be achieved by the addition of some easily available form of nitrogen source. On the other hand phosphorus, potassium, micro-nutrients and the growth substances in SMS are present in sufficient quantity and in the available form. Availability of nutrients from SMS can be enhanced by preparing an organic-mineral fertilizer from the spent mushroom substrate. The absorption capacity of stable 'humus' available in SMS helps in retention of nitrogen in the top soil (Grabbe, 1978). Conversion of SMS into an organic-mineral fertilizer is an alternative way of using spent mushroom compost for soil amelioration and to make it a balanced source of nutrition for plant growth. The organic mineral fertilizers prepared with three different formulae, having 2, 7 and 10% nitrogen and each supplemented with 2% phosphate (P_2O_5) and 2% of potassium (K_2O) have the potential of a balanced organic fertilizer for spinach and give yields of spinach equal to the standard fertilization. In addition, the organic mineral fertilizer also improves the quality and dry matter of spinach as compared to mineral fertilizer treatment (Sochtig and Grabbe, 1995). Preparation of the organic mineral fertilizer from the SMS has also been patented in USA (Robinson, 1988).

g) Spent mushroom substrate for disease management

Due to the unique chemical constitution and the microflora present in SMS, its application can be more diversified than what is normally predicted. The actinomycetes, bacteria and fungi inhabiting the compost, not only play role in its further decomposition but also exert antagonism to the normal pathogens surviving and multiplying in the soil ecosystem. The amendment of soil with spent mushroom substrate restricts the root knot infestation of tomato plants caused by *Meloidogyne incognita*. It shows higher efficacy than the application of carbofuran (2kg ai ha^{-1}), a common nematicide used to combat the above organism (Verma, 1986). Under *in vitro* conditions, the anaerobically fermented aqueous extract of the SMS inhibits the conidial germination of *Venturia inaequalis*, the causal agent of apple scab. The extract also inhibits the conidial germination of *Cochliobolus carborum* and *Sphaeropsis sapinea* (*Diplodia pinea*) causing diseases on maize and red pine (*Pinus resinosa*), respectively. The aqueous extract obtained after 5 to 9 days of incubation in the ratio of 2:1 to 4:1 (water: SMS) maintains its efficacy for about 4 months on storage at -20^{0}C, 4^{0}C and room temperature. The biological analysis of SMS extract shows that it contains a *Pseudomonas* and a *Bacillus*. SMS obtained from different growers harbours different mycoflora and shows differences in its effect on inhibition of conidial germination and disease suppression. The inhibitory properties of SMS remain unaffected even after autoclaving and filter sterilization (Yohalem *et al*., 1994) of aqueous extract. Weekly or bi-weekly application of spreader/sticker amended SMS extract, starting from green tip to petal fall of apple tree reduces the scab-affected leaf area. It maintains higher population of bacteria even after 1 month of the final spray which is the reason of less scab affected leaf area in SMS sprayed treatment (Yohalem *et al*., 1996). The field application of SMS along with a soil fumigant 'Basamid' results in suppression of the fungus *Cylindrocladium scoparium*, an ubiquitous pathogen of varied plant hosts throughout the world (Hunter *et al*., 1997).

CHAPTER - V

Conclusion

SMS has the potential of solving several agriculture related problems. However, it requires some early treatments like desalting/prolonged leaching and recomposting for added advantages. The conductivity of SMS, which is taken as a criteria of high salt concentration can be tested before using SMS for raising crops. However, the ions which contribute to high conductivity in recomposted SMS are highly water soluble and their leaching is possible. SMS is also not part of the list of wastes which are required to fulfill the legal hygienic conditions in respect of load of heavy metals and phosphate. The model way of agrowastes utilization in Israel (Table 8), can be adopted for recycling of SMS without leaving any residue in the end.

The exploitation of spent mushroom substrate for the management of environment, agriculture and production of recyclable energy requires strict watch on its physical, chemical and microbiological properties. Yes, its diversified uses in agriculture, environment and recycling energy (Fig. 28) forces us to change its name from spent mushroom substrate to "used mushroom substrate".

Table 8: Recycling mushroom substrates and wastes

Recycling Course	Product	Waste
Cultivation of cotton	Fibres	Plant residue cotton straw
Cultivation of oyster mushroom on straw	Oyster mushrooms	Spent substrate (SMS)
SMS used as cattle feed	Meat and milk	Manure
Manure fermented to produce biogas	Methane energy	Residue ("Cabutz")
Cabutz used as casing soil for champignons	Champignons	SMS
SMS composted for organic farming	Organic food crops	No further waste

(Levanon and Danai, 1997)

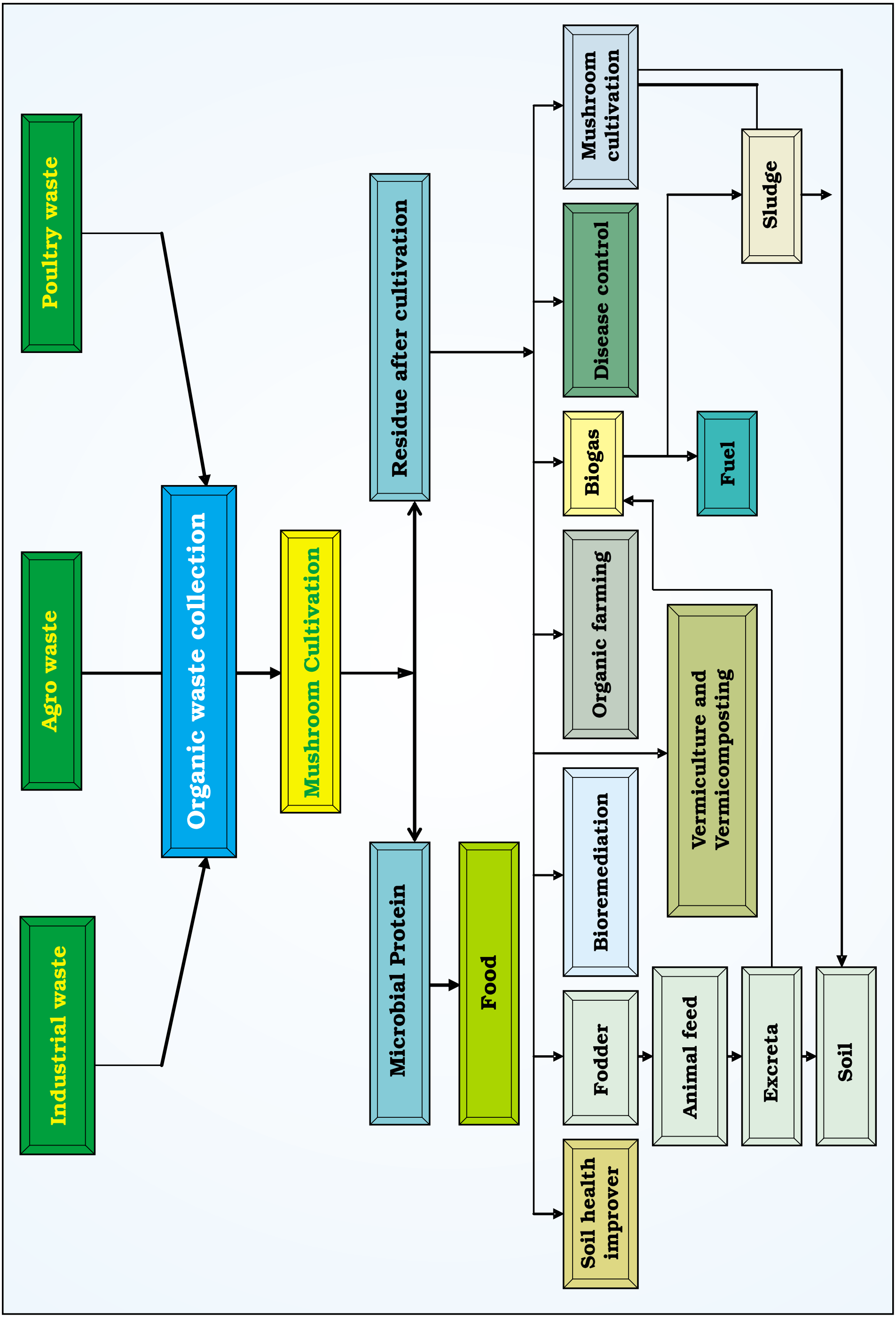

Fig. 28. Recycling of spent mushroom substrate

References

1. Ahlawat OP, Ahlawat Kusum, Indurani C, Vijay B and Dhar BL (2004a). Chemical composition and enzymatic activity of spent paddy straw and oyster mushroom substrates. Mushroom Science XVI : 553-559.

2. Ahlawat OP, Dev Raj, Sagar MP, Gupta Pardeep and Vijay B (2006a). Effect of recomposted spent mushroom substrate on yield and quality of cauliflower (*Brassica oleracea* L. var. *botrytis*). Mushroom Research 15(2): 149-152.

3. Ahlawat OP, Dev Raj, Sagar MP, Gupta Pardeep and Vijay B (2007a). Effect of recomposted button mushroom spent substrate on growth, yield and quality of Ginger (*Zingiber officinale*). Indian Journal of Mushrooms (accepted).

4. Ahlawat OP, Gupta Pardeep, Dev Raj and Vijay B (2006b). Dye decolorization potential of spent substrates from *Agaricus bisporus* and *Pleurotus* sp.- a laboratory study. Mushroom Research 15(1): 75-82

5. Ahlawat OP, Indurani C and Sagar MP (2005a). Spent mushroom substrate-properties and recycling for beneficial purposes. In: *Frontiers in Mushroom Biotechnology* (R.D. Rai, R.C. Upadhyay and S.R. Sharma, Eds.). Pp. 314-334. National Research Centre for Mushroom (HP), India.

6. Ahlawat OP, Sagar MP, Dev Raj, Indurani C, Gupta Pardeep and Vijay B (2005b). Effect of spent mushroom substrate of different age and recomposted by different methods on growth, yield and quality of *Capsicum annuum*. Indian J. Horticulture (communicated).

7. Ahlawat OP, Sagar MP, Dev Raj, Gupta Pardeep and Vijay B (2007b). Effect of recomposted button mushroom spent substrate

on growth and yield attributes of Wheat (*Triticum aestivum* L.). Mushroom Research (accepted).

8. Ahlawat OP, Gupta Pradeep, Kumar Satish and Sharma DK (2007c). Evaluation of bioremedation potential of button mushroom spent substrate against selected insecticides from soil system. Current Science (communicated).

9. Ahlawat OP, Sharma Vibhuti, Indurani C and Vijay B (2004b). Physico-chemical changes in button mushroom spent substrate recomposted by different methods. In: *International Workshop on "Recent Trends in Environmental Science"* from 24-26th April, 2004 at National Environmental Science Academy, New Delhi.

10. Ahlawat OP and Vijay B (2004). Effect of casing material fermented with thermophilic fungi on yield of *Agaricus bisporus*. Indian J. Microbiol 44(1): 31-35.

11. Beyer M (1996). The impact of the mushroom Industry on the environment. Mushroom News 44(11): 6-13.

12. Beyer DM (1999). Spent mushroom substrate fact sheet. http:/mushroom spawn.cas.psu.edu/ spent.htm.

13. Bisaria R, Madan M and Mukhopadhyay SN (1983). Production of biogas from residues from mushroom cultivation. Biotechnology Letters 5(12): 811-812.

14. Buswell JA (1994). Potential of spent mushroom substrate for bioremediation purposes. Compost - Science and Utilization 2(3): 31-36.

15. Buswell JA (1995). Potential of spent mushroom substrate for bioremediation purposes. Mushroom News 43(5): 28-34.

16. Chong C, Cline RA, Rinker DL (1987). Spent mushroom compost and papermill sludge as soil amendments for containerized nursery crops. Combined Proceedings - International Plant Propagators Society 37: 347-353.

17. Chong *et al* (1988). Proc. Ontario Hort. Crops Conf., Mushroom Session 8 P.

18. Chong C and Wickware M (1989). Hort Rev 7(6): 10, 11, 13.

19. Chong C, Cline RA and Rinker DL (1991). Rapid leaching of salts - key to successful plant growth in spent mushroom compost potting mixes. Mushroom News 39(10): 12-13.

20. Chong C, Rinker DL and Cline RA (1991). A comparison of five spent mushroom composts for container culture of ornamental shrubs. Mush Sci XIII : 637-644.

21. Chong C and Rinker DL (1994). Use of spent mushroom substrate for growing containerized woody ornamentals: an overview. Compost - Science and Utilization 2(3): 45-53.

22. Dann MS (1996). The many uses of spent mushroom substrate. Mushroom News 44 (8): 24-27.

23. Devonald VG (1987). Spent mushroom compost, a possible growing medium ingredient. In: Compost: Production, Quality and Use. Els., April. Sci. London. 785-791.

24. Dev Raj, Indurani C, Sagar MP, Gupta Pardeep, Ahlawat OP and Vijay B (2007). Effect of spent mushroom substrate recomposted by different methods and of different age on vegetative growth, yield and quality of tomato (*L. esculentum*).). *The Indian Journal of Agricultural Sciences* (communicated).

25. Dundar O, Paksoy M and Abak K (1995). Quality changes during cold storage of tomato fruits grown in different substrates. In: First International Symposium on Solanacea for fresh market, from 28-31 March, 1995, Malaya, Spain.

26. Fahy HK and Wuest PJ (1984). Best practices for environmental protection in the mushroom farm company. Chester County Planning Commission West Chester, PA, p. 65.

27. Femor T, Wastls N, Duncombe T, Brooke R, McCarthy A, Semple K and Reid B (2000). Bioremediation: Use of composts and composting technologies. Mushroom Sci. XV(II): 833-839.

28. Fox R and Chorover J (1999). Seeking a cash crop in spent substrate. http:/

aginfo.psu.edu/psa/sgg/mushrooms.html.

29. Gerrits JPG (1987). Compost for mushroom production and its subsequent use for soil improvement. In M.de Bertoldi, MP Ferranti, PL Hermite and F Zucconi (eds.). Els. April. Sci. London. pp. 431-439.

30. Grabbe K (1978). Verfahren zur Herstellung eines Dung emittels. BRD - Patent Nr. 2831583.

31. Guo M, Chorover J, Rosario R and Fox RH (2001). Leachate chemistry of field-weathered spent mushroom substrate. J Environ Quality 106(8): 208-209.

32. Guo M, Chorover J and Fox RH (2001). Effects of spent mushroom substrate weathering on the chemistry of underlying soils. J Environ Quality 30: 2127-2134.

33. Grabbe K (1982). Prinzipien des mikrobiellen Stoffumsatzes bie der Aufbereitung Flussiger and fester Reststoffe und ihre Bedeutung fur die Substratherstellung im Champignonanbau Wissenschaft and Umwelt 4: 210-218.

34. Gronborg H (1990). Trials at the advisory centre. Gartner Tidende. 106(8): 208-209.

35. Gupta Pardeep, Indurani C, Ahlawat OP, Vijay B and Mediratta V (2004). Physico-chemical properties of spent mushroom substrates of *Agaricus bisporus*. Mushroom Research 13(2): 84-94.

36. Gupta Pardeep, Ahlawat OP, Kumar Satish, Sharma DK and Dev Raj (2006a). Studies on bioremediation of pesticides using spent mushroom substrate. In: XIXth Annual Conference of National Environmental Science Academy on Solid Waste Management on 16th – 18th October, 2006 at Punjab University, Chandigarh.

37. Gupta Pardeep, Ahlawat OP, Kumar Satish, Sharma DK and Dev Raj (2006b). Bioremediation of heavy metals through spent mushroom substrate. In: XIXth Annual Conference of National Environmental

Science Academy on Solid Waste Management on 16th – 18th October, 2006 at Punjab University, Chandigarh

38. Huang JW, Hu CK and Shih SD (1996). The role of soil microorganisms in alleviation of root injury of garden pea seedlings by alachlor with spent golden mushroom compost. Plant Pathology Bulletin 5(3): 137-145.

39. Huang JW, Hu CK, Tzeng DDS and Ng KH (1995). Effect of soil amended with spent golden mushroom compost on alleviating phytotoxicity of alachlor to seeling of garden pea. Pl. Pathology Bulletin 4(2): 76-82.

40. Hunter BB, Hall T, Lysons MT and Bell TK (1997). Field application of sewage and spent mushroom composts in conjuction with basamid, a fumigant to control the root pathogen, *Cylindrocladium scoparium* nursry soil. www.epa.gov/docs/ozone/mbr/aire/1997/045 hunter.

41. Iteinemann P and Robert (2002). Processing of mushroom substrate. Mushroom News 50(5): 3-13.

42. Kaddous FGA and Morgans AS (1986). Spent mushroom compost and deep litre fowl manure as a soil ameliorant for vegetables. In Proc. of Surface Soil Management Rotorua, New Zealand, pp. 138-147.

43. Landschoot P and McNitt A (1994). Improving turf with compost. Biocycle 35(10): 54-57.

44. Leopald D (2002). Use of edible and medicinal oyster mushroom (*Pleurotus ostrearus* (Jacq:Fr) kumm.7 spent compost in remediation of chemically polluted soils. International J Medicinal Mushrooms 4(3):

45. Levanon D and Danai O (1997). Recycling agricultural residuals in Isreal. Biocycle 38(6): 56-57.

46. Lohr VI, Brien RGO and Coffey DL (1984). Spent mushroom compost in soil less media and its effects on the yield and quality of transplants. J. Amer. Soc. Hort. Sci. 109(5): 693-697.

47. Lohr VI, Wang SH and Wolt JD (1984). Physical and chemical characteristics of fresh and aged spent

mushroom compost. Hort Science 19(5): 681-683.

48. Lohr VI and Coffey DL (1987). Growth responses of seedlings to varying rates of fresh and aged spent mushroom compost. Hort Science 22(5): 913-915.

49. Maher MJ (1991). Spent mushroom compost (SMC) as a nutrient source in peat based potting substrate. Mushroom Science XIII (Part II): 645-650.

50. Nee CC, Chou WY and Chen S (1994). Study on compost of winter mushroom - a reused medium for persimmon potting. J Agriculture and Forestry 43(4): 39-44.

51. Okeke BC, Smith JE, Paterson A and Watson - Craik IA (1993). Aerobic metabolism of pentachlorophenol by spent sawdust culture of "shiitake" mushroom (*Lentinus edodes*) in soil. Biotech. Let. 15: 1077-1080.

52. Pill WG, Evans TA and Garrison SA (1993). Forcing white button asparagus in various subs under cool and warm regimes. Hort. Science 28(10): 996-998.

53. Robinson EC (1988). Fertilizer and Method. United - States - Patent, U.S. 4, 743, 287.

54. Romaine P and Holcomb E (2001). Spent mushroom substrate a noval multifunctional constituent of a potting medium for plants. Mushroom News 49(11): 4-6.

55. Royse D J (1993). Recycling of spent shiitake substrate for production of the oyster mushroom (*Pleurotus sajor-caju*). Mushroom News 41 (2): 14-18.

56. Rupert DR (1995). Use of spent mushroom substrate in stabilizing disturbed and commercial sites. Compost Science and Utilization 3(1): 80-83.

57. Sagar MP, Ahlawat OP, Dev Raj, Vijay B and C Indurani (2007). Identification, documentation, verification and refinement of indigenous technical knowledge about use of spent mushroom substrate. Indian J Traditional Knowledge (communicated).

58. Sharma HSS, Furlan A and Lyons G (1999). Comparative assessment of chelated SMS as casing material for production of *Agaricus bisporus*. Applied Microbiology and Biotechnology 52(3): 366-372.

59. Sochtig H and Grabbe K (1995). The production and utilization of organic-mineral fertilizer from spent mushroom compost. Mushroom Science XIV (Part II): 907-915.

60. Szmidt RAK (1994). Recycling of spent mushroom substrates by aerobic composting to produce novel horticultural substrates. Compost Science and Utilization 2(3): 63-72.

61. Verma RR (1986). Efficacy of organic amendments against *Meloidogyne incognita* infesting tomato India J Nematology 16(1): 105-106.

62. Wisniewska GH and Pankiewicz T (1989). Evaluation of the suitability of spent mushroom substrate for tulip cultivation. Prace - Instytute - Sadownictwa-i-Kwiaciarstwa- w.-Skierniewicach. Seria-B,-Rosliny -Ozdobne, 14: 7 -14.

63. Wuest PJ and Fahy HK (1991). Spent mushroom compost traits and uses. Mushroom News 39 (12): 9-15.

64. Wuest PJ, Fahy HK and Fahy J (1995). Use of spent mushroom substrate (SMS) for corn (maize) production and its effect on surface water quality. Compost Science and Utilization. 3(1): 46-54.

65. Yohalem DS, Harris RF and Andrews JH (1994). Aqueous extracts of spent mushroom substrate for foliar disease control. Compost Science and Utilization 2(4): 67-74.

66. Yohalem DS, Nordheim EV and Andrews JH (1996). The effect of water extracts of spent mushroom compost on apple scab in the field. Phytopathology 86(9): 914-922.

67. Zang CK, Gong F and Li DS (1995). A note on the utilization of spent mushroom composts in Animal feeds. Bioresource Technology 52: 89-91.