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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Grower summary

M 43

Mushrooms: Carbon and nitrogen sources for organic and odourless mushroom composts

Final report 2008

CONTENTS

Grower Summary

Headline

- Replacing 33% of the wheat straw and poultry manure in the compost formulation with spent mushroom compost (with the casing layer removed) has no significant effect on mushroom yield or quality.
- Compost containing vegetable waste produced a higher mushroom yield than barley straw compost, which cropped better than wheat straw compost produced under the same conditions.
- Partially substituting poultry manure with vegetable wastes resulted in a significant reduction in the emission of sulphides and noticeably less compost odour has no significant effect on mushroom yield or quality.

Background

Organic mushroom compost production depends on the availability of organic straw and poultry manure or other approved nitrogen sources. Poultry and other animal manures used in mushroom composting are also the major cause of malodours. The mushroom composting industry, including the organic sector, is still heavily dependent on the supply of broiler poultry manure as a source of nitrogen (N). The mushroom industry has also relied on obtaining plentiful supplies of wheat straw at a sufficiently low price. Increased demand for sustainable energy sources means that coal-fired power stations are now burning some straw, which means that the cost of the material is likely to rise.

Objectives and expected deliverables

01 Identify sources of nitrogen that can be used in organic and conventional mushroom compost in place of poultry and other animal manures.

02 Identify straw types and/or other carbon sources that can be used in organic and conventional mushroom compost.

03 Incorporate the above new materials into compost formulations that result in reduced odours, and reduce the justification for enclosure of compost preparation.

04 Disseminate results to industry; calculate economics and explore commercial feasibility and uptake of results.

Summary of the project

The availability and cost of carbon and nitrogen sources that can be used in organic and conventional mushroom compost formulations in the UK were reviewed. Several materials were identified as potential substitutes for wheat straw and broiler poultry manure.
Carbon sources: green (parks and garden) waste, paper pulp waste, barley straw, rye straw
Nitrogen sources: carpet shearing waste, wool washing waste
Carbon and nitrogen sources: vegetables wastes, spent mushroom compost (without casing) – also available in organically approved forms.
Brewers' grains was also identified as a suitable material but was not included since sufficient work had been conducted on this material and the economics depended on obtaining a low cost local supply.

Composts were first prepared in bench-scale facilities, with some of the materials then progressing to large scale experiments. The above materials were either used to substitute 33 - 40% of wheat straw and poultry manure, to fully replace the wheat straw (with rye and barley straw), or to fully replace the poultry manure (with urea and ammonium sulphate). Organic sources of wheat straw and poultry manure were also compared with conventional sources.

Table 1. Mushroom numbers and yields obtained from bench-scale prepared composts.
Each value is the mean of three replicates (six replicates of wheat control).

Treatment name	Mushroom number/ pot	Mushroom yield, g/ kg compost	
		g/kg fresh weight	g/kg dry weight
Wheat	18.0	186	723
Organic	18.3	191	762
Barley	20.5	233	1077
Rye	27.5	198	775
+Carpet	20.0	153	670
+GW	17.7	151	668
+Paper	20.7	158	572
+SMC	22.0	167	702
+Veg waste	14.7	180	775
+Wool	26.7	193	775
Inorganic	14.0	167	670

In bench-scale experiments, composts prepared from rye straw or containing wool waste resulted in the largest numbers of mushrooms, but produced similar yields to straw + poultry manure composts. Compost prepared from barley straw produced the highest mushroom yield. Yields from composts containing vegetable waste or spent mushroom compost were not significantly different from the wheat + poultry manure compost control treatment. Composts containing carpet, paper or green wastes all produced lower yields than the control treatment. There was no significant difference in mushroom yield between composts prepared from organic sources of wheat and poultry manure and those prepared from conventional sources.

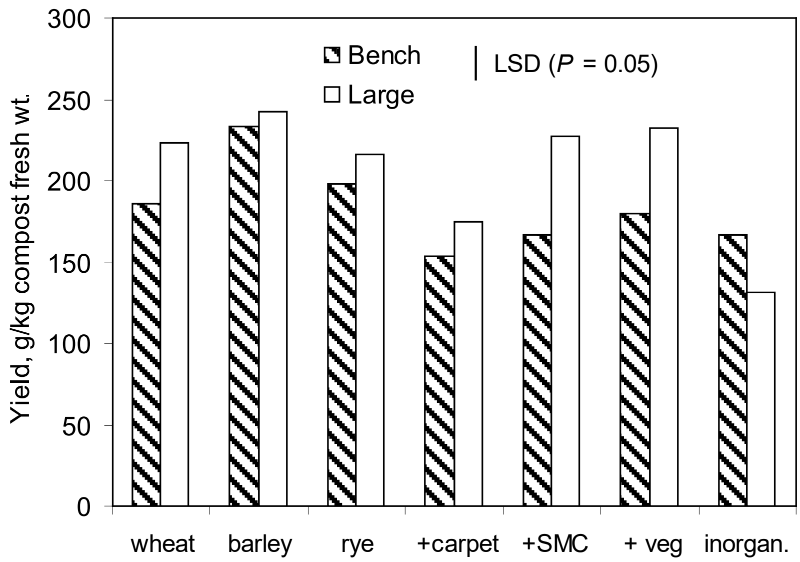

Figure. 1 Mushroom yields obtained using different compost formulations in bench-scale and large-scale experiments. Each value is the mean of three replicates (six replicates of wheat control).

In large-scale experiments, mushroom yield was significantly higher from the barley straw compost than from the wheat straw compost. Yields from composts containing SMC or vegetable waste to partially substitute wheat straw and poultry manure, or prepared from rye straw + poultry manure, were not significantly different from the yield obtained from the wheat straw + poultry manure compost. Yields were significantly lower from composts containing carpet waste or prepared using inorganic nitrogen sources than from the wheat straw + poultry manure compost.

In a commercial cropping test, mushroom yield from compost containing vegetable waste (309 kg/ tonne spawned compost) was higher than from a barley straw compost (258 kg/tonne) and a wheat straw compost (213 kg/tonne).

Main conclusions

1. Mushroom yields from composts prepared from winter barley straw were slightly higher than those from composts prepared from wheat straw. This was confirmed in a commercial cropping test.
2. Compost prepared from rye straw was comparable with that prepared from wheat straw in terms of mushroom yield.
3. Replacing 33-40% of the wheat straw and poultry manure in the compost formulation with vegetable waste or spent mushroom compost (without casing) had no effect on the cropping performance of the compost. In a commercial cropping test, compost containing vegetable waste cropped significantly better than wheat or barley straw composts.
4. Compost prepared only from wheat straw and inorganic nitrogen sources (urea and ammonium sulphate) cropped poorly compared with compost prepared with poultry manure; this was in spite of a longer composting period.
5. Carpet, green waste (parks and garden) and paper waste were unsuitable as straw and/or poultry manure substitutes in mushroom compost. Good mushroom yields were obtained from wool wastes in bench-scale experiments but this material was not tested on a large scale.
6. Substitution of poultry manure with carpet or vegetable wastes resulted in less volatile sulphides and noticeably less compost odour, and composts prepared with inorganic nitrogen produced no volatile sulphides and almost no odour.

Financial and environmental benefits

- Potential use of vegetable wastes and spent mushroom compost as compost ingredients, with a reduction in the cost of wheat straw and broiler poultry manure, particularly for organic composts. Wheat straw currently costs around £30/tonne (More for organic sources) and is likely to rise significantly. Vegetable wastes are a disposal problem – the economics of using them in mushroom compost will depend on proximity to supply.
- Greater availability of straw by incorporating barley and/or rye straw in the compost formulation. Barley straw is 10-20% more expensive than wheat straw due to animal feed value, but the average 9% increase in mushroom yield that was found here would justify using the material.

- Reduction in compost odours resulting from the substitution of poultry manure.
- Potential outlet for spent mushroom compost.

Action points for composters and growers

- Sources of locally available vegetable wastes (peelings, processing wastes, tomato and other plant haulms) should be examined as compost ingredients.
- The feasibility of recycling spent mushroom compost, with the casing layer removed, into the compost formulation should be examined.
- The use of barley straw in compost formulations should be tested.

Science Section

Introduction

Organic mushroom compost production depends on the availability of organic straw and poultry manure or other approved nitrogen sources. Poultry and other animal manures used in mushroom composting are also the major cause of malodours. Recent outbreaks of bird flu highlight the vulnerability of the mushroom composting industry, which is still heavily dependent on the supply of broiler poultry manure as a relatively cheap source of nitrogen (N). The mushroom industry has also relied on obtaining plentiful supplies of wheat straw at a sufficiently low price. In some countries, the use of straw as a biofuel and conversion of land from cereals to biofuel crops has reduced the availability and increased the price of wheat straw for composting. This scenario may also occur in the UK with increased demand for sustainable energy sources and coal-fired power stations now burning some straw.

Alternative raw materials

There has been work on the substitution of broiler poultry manure and wheat straw in mushroom compost in the UK and other countries. Project M 3e showed that composts that included rape straw and inorganic nitrogen sources such as urea and ammonium sulphate produced less odours than composts prepared from only wheat straw and poultry manure, and these ingredients are now used by several composters. In the USA (Pecchia et al. 2000), hay, corn cobs, cocoa wastes and cotton seed meal are used and rice straw is used in Asia, but these are unavailable at low prices in the UK. In the Netherlands, large quantities of locally available slurry manure from egg-laying poultry and horse manure are used. These are odorous wastes that are composted in fully enclosed facilities. High moisture content and bulk limits the distance over which these materials can be economically transported. Most of the above substitute materials are unsuitable for organic composts. Other important criteria in selection of materials are year round availability, value in competitive uses (including potential future uses, such as biofuel), proximity to use, and freedom from contaminants. A number of carbon sources (Table 1) and nitrogen sources (Table 2) have been identified that may have potential for use in mushroom composting in the UK. Some of these materials, highlighted in bold text, are available in sources suitable for organic production.

Nitrogen sources

Broiler poultry manure typically contains about 4.4% N on a dry matter basis. A significant proportion of this N becomes available during composting, as indicated by the high levels of ammonia produced during Phase I and Phase II. For most of the other N sources in Table 1, the proportion of N that becomes available during composting is not established. Previous

Table 1. Nitrogen sources that are currently used or are have a potential use in mushroom composting. Organic sources are available of materials shown in bold.

Material	Dry Matter, %	Nitrogen % of DM	Price £/tonne	Availability K tonnes/year
Poultry manure	**65**	**4.4**	**3**	**700**
Wool and carpet wastes	90	14.0	0.25	3.5
Brassica wastes	**9**	**1.9**	**0**	**30**
Brewers' grains	24	3.0	24	800
Cattle manure	**23**	**2.6**	**0**	**4500**
Digester wastes	27	2.8	0	?
Green wastes	66	1.8	0	>1000
Horse manure	38	1.3	0	>500
Paper pulp waste (raw)	58	2.0	0	25
Tomato, cucumber and pepper plant haulms	**11**	**1.8**	**0**	**?**
Spent mushroom compost (with casing)	**38**	**2.1**	**0**	**300**

work with digester wastes in project M 3d indicates that only a small proportion of the N is available, the rest is locked-up in lignin and other unavailable forms. Feather wastes have been tried as a compost ingredient (R. Barrett, personal communication), but with odours even worse than from poultry manure composts. Cattle manure, although odorous, has been used successfully in mushroom composting and organic sources are available (Ross 1969). It has a high moisture content so that proximity to mushroom composting would be important. Cattle disease outbreaks such as foot and mouth would disrupt supplies of the manure. Pig manure has been used as a compost ingredient, including organic composts, although it is very odorous and cropping results have not always matched poultry manure composts (Van Loon et al. 2004). Brewer's grains and spent hop powder wastes have been used successfully in mushrooms composts; economic viability depends on proximity to supply and alternative value as animal feed. Organic sources of these materials are very limited. Wool wastes are odourless, dry and have traditionally been used as an organic fertiliser for crops due to their high N content. They are available from wool washing plants

and from wool carpet factories. The availability of N in wool wastes and their suitability for mushroom composting has not been previously examined.
Fish wastes have been used in mushroom compost formulations (Schisler & Patton 1974) and there are sources of fish wastes in the UK (Anon 2006). However, contacts with several fish processing companies indicated that fish waste was not a major disposal problem. It is also likely that fish wastes will be odorous, both before and during composting.

Plant based wastes, such as Brassicas and haulms from glasshouse crops, may contain significant amounts of N but they can also be considered as carbon sources and therefore also substitutes for wheat straw in compost. They have high moisture contents and limited storage life so they need to be sourced locally. Significant quantities of paper pulp wastes are produced from paper mills, but only sources from raw pulp are suitable since recycled paper contains contaminants from inks. Potato wastes are usually disposed of as animal feed but other types of vegetable wastes can be a disposal problem for processors and packers. These wastes, which are also generated from imported produce, are available year round. Plant haulm wastes from tomato, cucumber and sweet pepper nurseries are available mainly in the Autumn. Spent mushroom compost (SMC) has been used as a recycled component in mushroom compost in Canada. SMC was found to be unsuitable as a compost ingredient by Gerrits (1991). However, its nutritional value in composting would be improved if the casing layer was removed during emptying. This would also facilitate disposal of spent material since the casing layer, being lower in nitrogen than the underlying compost, can be applied in greater quantities to land than the entire spent compost. The separated casing material could also possibly be recycled into fresh casing material. The spent compost would also need to be cooked-out before emptying to reduce the disease risk of bringing the material back on to the composting site. Green wastes are available in increasing amounts although there can be significant variability in the feedstocks. Work in the Netherlands showed that composted green wastes were unsuitable mushroom compost ingredients (Gerrits 1991), so only the raw green wastes are worth consideration. A consistent supply of raw wastes with the minimum of woody, lignified material would be needed.

Carbon sources

Winter wheat straw is the most widely available cereal straw. Significant amounts of spring and winter barley straw are produced although the price is usually higher than for wheat straw due to value in animal feed. It is often a significant component in horse manure.

Previous results in mushroom composting with straw from spring barley and bean haulms in projects M 3 and M 3a were not very promising.

Microscopically, the structure of wheat and barley straw look similar but barley straw becomes softer during composting more rapidly than wheat straw whereas rape straw retains its structure and is useful for maintaining compost porosity. Rye straw is much longer than wheat straw and has been used in mushroom composting in some other European countries where it is grown more widely. Linseed straw does not degrade sufficiently in mushroom composting.

Table 2. Carbon sources that are currently used or are have a potential use in mushroom composting. Organic sources are available of materials in bold.

Material	Dry Matter, %	Nitrogen % of DM	Price £/tonne	Availability K tonnes/year
Wheat straw	**87**	**0.5**	**29**	**4500**
Rape straw	85	1.2	25	1250
Bean straw	**89**	**0.8**	**35**	**600**
Barley straw	**88**	**0.5**	**36**	**2500**
Rye straw	90	0.6	29	60
Onion waste	**13**	**1.1**	**0**	**30**

Commercial Objectives

04 Identify sources of nitrogen that can be used in organic and conventional mushroom compost in place of poultry and other animal manures.

05 Identify straw types and/or other carbon sources that can be used in organic and conventional mushroom compost.

06 Incorporate the above new materials into compost formulations that result in reduced odours, or reduce the justification for the enclosure of compost preparation.

04 Disseminate results to industry; calculate economics and explore commercial feasibility and uptake of results.

Materials and methods

Bench-scale composting

Wheat straw samples (700 g) were mixed with sieved (5 mm screen) poultry manure, and/or other ingredients (Tables 3 and 4). In two of the treatments, barley or rye straw replaced the wheat straw. Organically produced wheat straw and poultry manure were used in one of the treatments. Paper pulp, carpet shearing, wool and green wastes were as previously described. SMC did not contain spent casing material and was used immediately after cooking-out. Vegetable waste consisted of potatoes and root vegetables (40% w/w), brassica stems and leaves (40% w/w) and tomato plant haulms (20% w/w). Gypsum was added at 4% w/w of the total weight of the compost ingredients. Water (1.5 – 2L) was added to achieve a moisture content of 74.5 ± 0.5% w/w of the ingredients, which were mixed at daily intervals in bins for 3 days. The materials were then composted in 'Quickfit' multiadapter flasks immersed in thermostatically controlled water baths, each holding two 10-L flasks (Noble et al, 1997). The prepared ingredients (about 2 kg samples) were placed on a perforated stainless steel platform within each flask and the flasks immersed in the waterbaths such that the water level was above the level of the enclosed substrate. Each flask was connected to ancillary equipment providing independent aeration of the compost. The oxygen concentration in the substrate was controlled regularly by adjusting the airflow through the compost in each flask within the range 8 - 16 L kg^{-1} substrate h^{-1} by means of flow meters. The temperature of the substrate in the flasks was monitored with Squirrel multipoint temperature loggers (Grant Instruments Ltd, Cambridge, UK).

For the first 48 hours of the composting process, the thermostat of the waterbath was set at 48°C to allow a natural succession and gradual build-up of microorganisms. The substrate temperature was then increased to 72°C for 5 days, after which the substrate was re-mixed and the temperature reduced to 47°C for the remainder of the composting period, which was seven days, or prolonged until the air in the flask was clear of ammonia. The hydrogen sulphide concentration of the air in the flasks was measured daily with Draeger gas detector tubes and an assessment of the odour of the air in the headspace of the flasks was made. An oxygen concentration of 11 (± 1.5)% v/v was maintained in the substrate. The average initial total N and ammonium N contents of the composts were 1.63 (± 0.14) and 0.30 (±0.08)% of DM respectively. Composts containing inorganic N had a higher initial ammonium N content (0.98% of DM). Average initial ash contents of the composts are shown in Table 4.

At the end of the composting period, the material in each flask was weighed. After samples were taken for analysis, 1.5 kg of the residual material was inoculated with mushroom spawn (spawned) at two percent of the fresh weight of compost with *Agaricus bisporus* spawn (Sylvan A15) and filled into plastic pots, 230 mm diameter x 220 mm depth. The pots were placed in polythene bags in an incubator at 25°C and when the substrate was fully colonised with mushroom mycelium, about 15 days after spawning, the containers were cased with a moist mixture of peat and sugar beet lime (900 g) containing casing inoculum of the strain A15 at 1% w/w. When mushroom mycelium was visible on the surface of the casing, the containers were transferred to a controlled environment chamber with an air temperature of 18°C, relative humidity of 90% and a CO_2 concentration of 0.1% to induce fruiting. Mushrooms were harvested daily over a 30 day period (cap diameter 25-30 mm). Three replicate composts were made from each formulation (six replicates from the wheat straw + poultry manure control treatment).

Table 3. Analysis of straw types and other compost ingredients used in the experiments.

Ingredient	DM %	% of DM			pH
		N	NH_4^+	Ash	
Wheat straw	12.0	0.57	0.015	7.0	6.91
Wheat straw (organic)	19.7	0.35	0	9.2	8.35
Barley straw	13.1	0.70	0.034	6.0	7.21
Rye straw	11.9	0.43	0.027	7.3	6.88
Poultry manure	33.3	5.16	1.288	19.6	8.08
Poultry manure (organic)	31.5	3.86	1.958	24.6	7.54
Vegetable waste	71.3	0.86	0.123	64.7	4.43
Carpet waste	9.5	15.60	0.006	0.4	5.0
Wool waste	10.1	15.71	0.008	0.9	5.3
Paper waste	24.3	0.26	0.004	79.2	8.36
Green waste	65.9	1.67	0.007	55.4	8.57
Spent mushroom compost	74.8	2.88	0.343	34.3	8.55
Ammonium sulphate	100.0	21.20	27.270	-	4.66
Urea	100.0	46.70	0	-	8.59

Table 4. Percentage by weight of straw, poultry manure, and other treatment ingredients used in bench-scale composts, excluding added water. Gypsum (or lime for the inorganic treatment) was added at 4% of the total weight of the other ingredients.

Treatment	Straw	Poultry	Other ingredient	Ash, %

name	Type	w/w	manure	Type	w/w	dry matter
Wheat	Wheat	70.6	29.4	none	0	10.0
Organic	Wheat [a]	70.6	29.4 [a]	none	0	13.2
Barley	Barley	70.6	29.4	none	0	9.3
Rye	Rye	70.6	29.4	none	0	10.2
+Carpet	Wheat	77.1	19.9	Carpet waste	3.0	8.8
+GW	Wheat	42.3	17.7	Green waste	40.0	19.9
+Paper	Wheat	42.3	17.7	Paper waste	40.0	36.4
+SMC	Wheat	43.0	16.4	Spent mushroom compost	40.6	14.1
+Veg waste	Wheat	4.2.3	17.7	Vegetable waste	40.0	20.4
+Wool	Wheat	77.6	19.5	Wool waste	2.9	8.8
Inorganic	Wheat	96.3	0	Ammonium sulphate	2.6	6.7
				Urea	1.1	

[a] Organically produced

Table 5. Percentage by weight and initial ash content of ingredients used in large-scale composts, excluding added water. Gypsum (or lime for the inorganic treatment) was added at 4% of the total weight of the other ingredients.

Treatment	Straw		Poultry	Other ingredient		Ash, %
name	Type	w/w	manure	Type	w/w	dry matter
Wheat	Wheat	62.5	37.5	none	0	18.4
Barley	Barley	62.5	37.5	none	0	18.7
Rye	Rye	62.5	37.5	none	0	18.1
+Carpet	Wheat	74.2	21.3	Carpet waste	4.5	18.0
+SMC	Wheat	46.2	25.9	Spent mushroom compost	27.8	19.9
+Veg waste	Wheat	44.4	24.7	Vegetable waste	30.9	23.0
Inorganic	Wheat	92.8	0	Ammonium sulphate	2.6	13.4
				Urea	1.4	

Large-scale composting

Compost ingredients and proportions used in different treatments are shown in Table 5. Straw and nitrogen sources were composted in windrows with standard amounts of gypsum (40 kg/tonne compost ingredients). Straw bales were formed into windrows and wetted on day 0. Poultry manure and/or other nitrogen sources was added on days 3 and 10, gypsum on day 10; windrow turns and water applications if required were made on alternate days during a 18 day period. Due to the slow degradation of composts made with inorganic nitrogen sources, these were composted for a further period of 20 days, with further turns being made every 4 days but without additional wetting. An assessment of the odour emitted from the composts was made at each turning. At the end of Phase I, all the composts had an average moisture content of 77 (±1) % w/w and total nitrogen and ammonium N contents of 2.01 (±0.10) % of dry matter. The ammonium N content was 0.37 (±0.10) % of dry matter, except for composts containing inorganic nitrogen (1.09 % of dry matter). The average initial ash contents of the composts are shown in Table 5.

For the Phase II pasteurisation regime, the tunnels were filled with 2.5 t of material from the Phase I. Following a 20 hour equalisation of compost temperature at 45 - 48°C, the composts were pasteurised at 58 - 60°C for 6 hours. Compost temperatures were then reduced to 46 - 49°C (conditioning). A minimum oxygen concentration of 13% v/v was maintained during Phase II. Composting was completed when the compost temperature had fallen to within 1°C of the air temperature and ammonia could no longer be detected in the compost. Throughout the composting process, the temperature of each individual compost treatment was recorded with three probes and a data logger.

The mushroom cropping procedure is outlined in Noble & Gaze (1998). Composts were spawned with the strain Sylvan A15 at 0.5% w/w. Three flushes of mushrooms were picked. Sixteen replicate trays were prepared from each batch of compost, with eight trays of each compost formulation being cropped in two separate growing rooms. Three replicate composts were prepared from each formulation (six replicates of the wheat straw + poultry manure control treatment).

Commercial cropping tests

Spawn-run composts were prepared as described in the previous section, using the wheat straw, barley straw and +vegetable waste formulations. Samples of compost (500 kg) were transported to Tunnel Tech Ltd and prepared into 20 kg wrapped compressed blocks. The blocks were then sent to Southwell Mushrooms Ltd, Nottinghamshire and cropped in shelves alongside a commercial wheat straw + poultry manure compost. The mushrooms yield in three flushes was recorded.

Compost analysis and volatile emissions

Analyses were conducted on samples of the compost ingredients and of the substrates before and after composting in bench-scale or large-scale experiments. Dry matter (DM), N, ammonium ($NH^+{}_4$) and ash contents and pH were determined as described in Noble & Gaze (1998). An assessment of odour intensity of the composts during Phase I was made according the method described in project report M 3e.

Results

Bench-scale composting

Average moisture and nitrogen contents at spawning were 74% and 2.15% of dry matter and were not significantly different between treatments. The maximum hydrogen sulphide concentration of air above the poultry manure composts prepared from wheat, barley, rye or organic wheat straw, or with spent mushroom compost, were not significantly different (Table 6). Substitution of poultry manure with carpet, vegetable, wool, paper and green wastes all significantly reduced the concentration of hydrogen sulphide and the odours in the flask headspace air. Composts prepared from inorganic nitrogen sources did not produce detectable levels of hydrogen sulphide and had a very faint odour.

Ammonium nitrogen content was slightly higher in composts prepared from conventional poultry manure and wheat straw or barley straw than from rye straw + poultry manure or organic wheat straw and poultry manure. Ammonium nitrogen content was significantly higher and pH was significantly lower in composts prepared from inorganic nitrogen sources than the other treatments (Table 6). Compost prepared with wool waste had a higher pH at spawning than the other treatments. Addition of paper waste to the formulation significantly increased the compost ash content.

Composts prepared from rye straw or containing wool waste resulted in the largest numbers of mushrooms (Table 7). Compost prepared from barley straw produced the highest mushroom yield, expressed as either fresh or dry weight of compost. Yields from composts containing vegetable waste or SMC were not significantly different from the wheat straw + poultry manure compost. Composts containing carpet, paper or green wastes all produced lower yields than the control treatment. There was no significant difference in mushroom yield, expressed either as mushrooms numbers or weight, between composts prepared from organic sources of wheat and poultry manure and those prepared from conventional sources.

Table 6. Maximum hydrogen sulphide concentration of air during bench-scale composting and ammonium nitrogen and ash contents and pH of pasteurised composts. Each value is the mean of three replicates (six replicates of wheat control).

Treatment name	H_2S ppm	NH_4^+ % of DM	Ash % of DM	pH
Wheat	16	0.216	17.86	7.65
Organic	12	0.076	18.70	7.45
Barley	13	0.240	14.05	7.49
Rye	14	0.072	17.72	7.63
+Carpet	4	0.104	17.45	7.37
+GW	3	0.140	23.39	7.26
+Paper	3	0.059	32.72	7.17
+SMC	12	0.069	22.17	7.30
+Veg waste	6	0.274	21.61	7.57
+Wool	5	0.083	17.85	7.79
Inorganic	0	0.491	16.72	7.09
LSD (*P*=0.05)	4.1	0.128	3.92	0.13

Table 7. Mushroom numbers and yields obtained from bench-scale prepared composts. Each value is the mean of three replicates (six replicates of wheat control).

Treatment name	Mushroom number/ pot	Mushroom yield, g/ kg compost	
		g/kg fresh weight	g/kg dry weight
Wheat	18.0	186	723
Organic	18.3	191	762
Barley	20.5	233	1077
Rye	27.5	198	775
+Carpet	20.0	153	670
+GW	17.7	151	668
+Paper	20.7	158	572
+SMC	22.0	167	702
+Veg waste	14.7	180	775
+Wool	26.7	193	775
Inorganic	14.0	167	670
LSD (P=0.05)	4.92	19.9	66.3

Large-scale composting

There was no significant difference in the maximum Phase I compost temperatures or the time taken to reach the maximum temperature between the treatments, except for compost prepared with inorganic nitrogen sources. This treatment resulted in a lower maximum compost temperature, and a much longer duration to reach this maximum (Table 8). The odours of composts prepared from wheat, barley and rye straw or with spent mushroom compost were not significantly different. Substitution of poultry manure with carpet or vegetable wastes resulted in noticeably less compost odour, and composts prepared with inorganic nitrogen produced almost no odour.

Average moisture content at spawning was 72.5 (±0.6) %. The composts at spawning had similar nitrogen contents, except for composts containing carpet waste and inorganic nitrogen sources which significantly higher and lower nitrogen contents respectively (Table 9). Ammonium nitrogen contents at spawning were significantly higher in composts containing SMC and inorganic nitrogen than in the other composts. Ash contents were highest in composts containing SMC or vegetable waste and lowest in composts containing inorganic nitrogen. Ash content increased by about 7% of dry matter during Phases I and II (Tables 5 and 9), with the exception of compost containing SMC which increased in ash content by 10.4% of dry matter.

Table 8. Maximum Phase I compost temperatures and durations required to reach the maximum temperature. Each value is the mean of 3 temperature probe values. Each value is the mean of three replicates (six replicates of wheat control).

Treatment name	Max. temperature °C	Time to reach max. temperature, days
Wheat	72.8	7.3
Barley	70.3	8.9
Rye	74.7	7.7
+Carpet	71.1	6.2
+SMC	74.5	7.5
+Veg waste	72.8	7.4
Inorganic	66.5	36.5
LSD (*P*=0.05)	2.54	1.77

Table 9. Total nitrogen, ammonium nitrogen and ash contents and pH of pasteurised composts prepared in large-scale windrows. Each value is the mean of three replicates (six replicates of wheat control).

Treatment name	Total N % of DM	NH_4^+ % of DM	Ash % of DM	pH
Wheat	3.04	0.059	27.0	7.56
Barley	2.95	0.075	24.8	7.71
Rye	2.82	0.048	25.5	7.72
+Carpet	3.46	0.047	24.6	7.69
+SMC	3.19	0.134	30.3	7.56
+Veg waste	2.85	0.078	29.8	7.66
Inorganic	2.66	0.632	20.7	7.42
LSD (*P*=0.05)	0.231	0.0758	2.608	0.152

Table 10. Mushroom yields from large-scale composts. Each value is the mean of three replicates (six replicates of wheat control).

Treatment	Mushroom yield, g/ kg compost	
name	kg/t fresh weight	kg/t dry weight
Wheat	223.0	847.8
Barley	242.7	855.6
Rye	215.9	844.7
+Carpet	175.0	646.5
+SMC	227.1	798.6
+Veg waste	232.0	800.7
Inorganic	131.0	672.7
LSD (*P*=0.05)	20.8	87.7

Mushroom yield, expressed per tonne of compost fresh weight, was significantly higher from the barley straw compost than from the wheat straw compost (Table 10). Yields from composts containing SMC or vegetable waste, or prepared from rye straw, were not significantly different from the yield obtained from the wheat straw compost.

Mushrooms yields expressed per tonne of compost dry weight were not significantly different from composts prepared from wheat, barley or rye straws, or from composts containing SMC or vegetable wastes (Table 10). Yields, expressed on either a compost fresh or dry weight basis, were significantly lower from composts containing carpet waste or prepared using inorganic nitrogen sources than from the wheat straw + poultry manure compost.

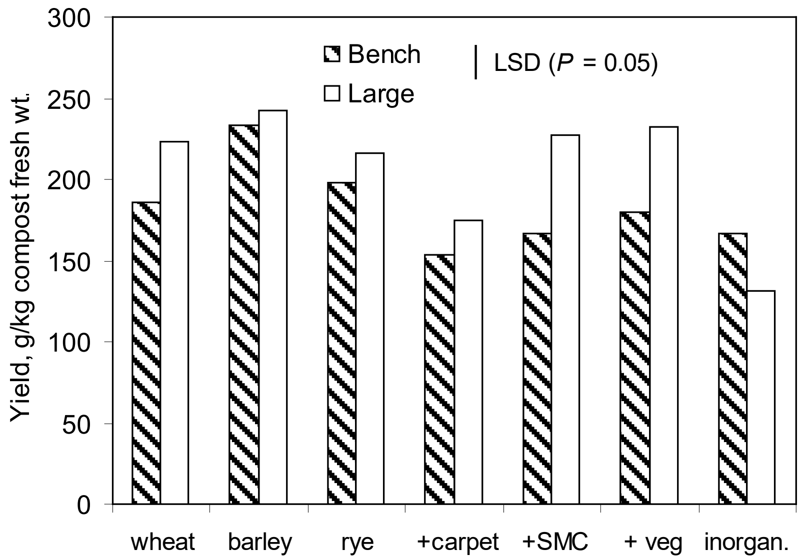

Fig. 1 Mushroom yields, expressed on a compost fresh weight basis, obtained using different compost formulations in bench-scale and large-scale experiments. Each value is the mean of three replicates (six replicates of wheat control).

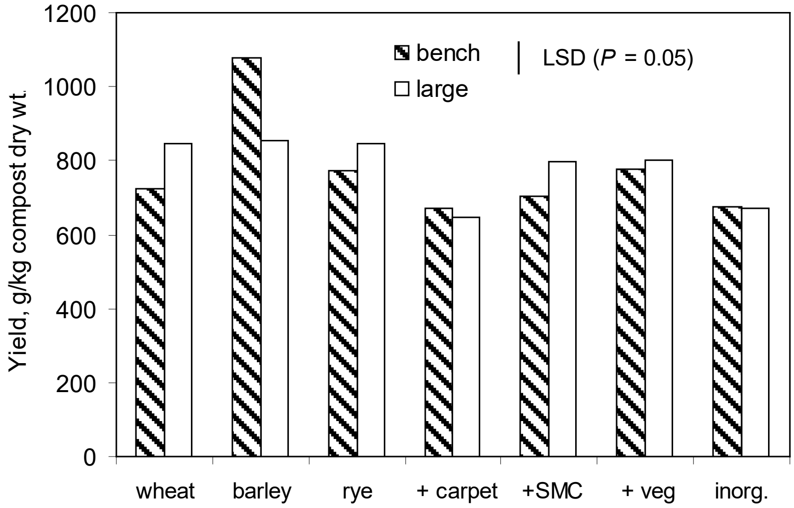

Fig. 2 Mushroom yields, expressed on a compost dry weight basis, obtained using different compost formulations in bench-scale and large-scale experiments. Each value is the mean of three replicates (six replicates of wheat control).

Mushroom yields obtained from bench-scale and large-scale composts are compared in Figs.1 and 2. Generally there was good agreement between yields obtained in bench and large-scale facilities for similar compost formulations. Most of the formulations resulted in a slightly higher yield from the large-scale composts than from the bench-scale composts. The exceptions were for composts prepared using inorganic nitrogen sources (Fig.1), and yields from barley straw compost expressed on a compost dry weight basis (Fig. 2).

Commercial cropping tests

Mushroom yields obtained from the composts (kg mushrooms/ tonne Phase III) were: wheat straw compost 213; barley straw compost 258; +veg waste compost 309. The main difference between the compost appeared to be in the third flush.

Discussion

There was generally good agreement between results obtained in bench-scale and large-scale experiments for similar compost treatments. The better mushroom yields from the large-scale experiments may be due to the better degradation of materials; this is reflected in the higher ash contents of large-scale composts with those of compost prepared on a bench-scale (Tables 6 and 9). The level of poultry manure substitution was slightly higher in the bench-scale experiments (40%) than in the large-scale experiments (33%). The compost moisture was also higher in composts prepared in the bench-scale facilities than in large-scale experiments, although previous experiments have shown that higher moisture content is required in bench-scale prepared composts (Noble et al. 1997; Noble et al. 2002). Results obtained in bench-scale facilities can be used as a preliminary screening of materials for larger-scale experiments.

In contrast to earlier work (Noble & Gaze 1994) which showed barley straw to be inferior to wheat straw for mushroom composting, the results here have shown that barley straw is at least as good as wheat straw in terms of mushroom yield. This may be due to the different barley cultivars used, with spring barley being used for the earlier work and winter barley being used for the present work. Compost prepared from rye straw produced a mushroom yield equivalent to that produced from wheat straw, which agrees with Gerrits (1998).

The results have shown that 33% of the wheat straw and poultry manure used in compost can be replaced with vegetable waste or spent mushroom compost (with the casing layer removed) without affecting mushroom yield. Both of these materials are available in sources suitable for organic production. A method is needed for separating the casing layer from the underlying compost on emptying. A range of vegetable wastes were used in these experiments. These materials included tomato plant haulms, root vegetables and brassica leaves. The analysis of these wastes was fairly similar and it is likely that a wide range of vegetable waste scan be used. Results obtained with green wastes in bench-scale experiments were less good than for vegetable wastes and it is likely that the presence of a significant amount of woody material would reduce the suitability of green wastes for mushroom composting. Paper waste, which had high ash content, also produced poor yields in bench-scale experiments.

Results obtained in the bench-scale composting facilities showed that mushroom yields obtained from organic wheat straw and poultry manure were equivalent to those obtained from conventional sources. The organic poultry manure used in these experiments had a more strawy texture than the conventional broiler poultry manure.

Although containing high nitrogen content, carpet shearing waste was not a suitable substitute for poultry manure in either bench-scale or large scale-experiments. It is possible that the wool in the carpet waste requires a longer composting period for the nitrogen to become available. This could be achieved in a period of ‘pre-composting’ the material before it is added to the other compost ingredients. However, composts produced with wool waste in bench-scale facilities produced a good mushroom yield but this material was not tested in large-scale experiments.

Compost prepared only with straw and inorganic nitrogen sources (urea and ammonium sulphate) cropped poorly compared with composts prepared using poultry manure and other forms of organic nitrogen. The results obtained with inorganic nitrogen in bench-scale facilities were better than in large-scale experiments. This was probably due to compost being heated in the bench-scale equipment, whereas in the large-scale windrows, the inorganic nitrogen sources produced little self-heating and compost degradation for the first 30 days. However, inorganic nitrogen sources have been shown to be suitable as partial substitutes for poultry manure (up 25%) (Noble et al. 2002). Further work is needed on using combinations of inorganic nitrogen sources and readily available carbon sources such as vegetable wastes as substitutes for poultry manure in compost formulations.

Although not examined in this project, brewers' grains have been successfully used in compost formulations, particularly in the USA and in a previous HDC project (M3d). The economics of using this material depend on proximity to local supplies (it is fairly wet) and alternative value as animal feed.

Conclusions

- Mushroom yields from composts prepared from winter barley straw were slightly higher than those from composts prepared from wheat straw. This was confirmed in a commercial cropping test.
- Compost prepared from rye straw was comparable with that prepared from wheat straw in terms of mushroom yield.
- Replacing 33% of the wheat straw and poultry manure with vegetable waste or spent mushroom compost (without casing) had no effect on the cropping performance of the compost. In a commercial cropping test, compost containing vegetable waste cropped significantly better than wheat or barley straw composts.
- Compost prepared only from wheat straw and inorganic nitrogen sources (urea and ammonium sulphate) cropped poorly compared with compost prepared with poultry manure; this was in spite of a longer composting period.
- Carpet, green (parks and garden) and paper wastes were unsuitable as straw and/or poultry manure substitutes in mushroom compost. Good mushroom yields were obtained from wool wastes in bench-scale experiments but this material was not tested on a large scale.
- Substitution of poultry manure with carpet or vegetable wastes resulted in less volatile sulphides and noticeably less compost odour, and composts prepared with inorganic nitrogen produced no volatile sulphides and almost no odour.
- There was generally good agreement between results obtained in bench-scale and large-scale experiments for similar compost treatments. Results obtained in bench-scale facilities can be used as a preliminary screening of materials for larger-scale experiments.

Technology transfer

The promising results obtained with barley straw compost and compost containing vegetable waste at Warwick HRI were confirmed in cropping tests at Southwell Mushrooms. Vegetable wastes (beetroot peelings, lettuce leaves) are now being tested in compost formulations at Rothwells Mushrooms Ltd, Ormskirk. The promising results obtained with spent mushroom compost (with the casing layer removed) should be tested on a commercial scale. A method is needed for separating the casing layer from the compost on emptying. The casing material could also be recycled, either in casing material or other horticultural growing media.
HDC News article Ralph Noble & Andreja Dobrovin-Pennington (2007) Organic and odourless. No. 139: 28-29.

Glossary

Carpet	Carpet shearing waste, a by-product from wool carpet production
DM	Dry matter
Inorganic	Inorganic nitrogen sources (urea and ammonium sulphate)
N	Total nitrogen, determined by Kjeldahl
Paper	Paper sludge waste, a by-product of virgin paper production
SMC	Spent mushroom compost (the casing layer was removed after cooking –out)
Veg waste	Mixed vegetable waste (tomato plant haulms, root vegetables, brassica leaves)
Wool	Wool waste, a by-product from wool washing plants

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