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MUSHROOMS: CONTROLLED ENVIRONMENT COMPOSTING

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CONTENTS

REVIEW OF PROJECT ACHIEVEMENTS

This report describes a series of experiments in which a controlled environment composting process was developed. The major achievements have been:

1. The development of a single bulk tunnel stage process, avoiding the need for a compost transfer used in partially controlled composting systems.
2. The elimination of odour and water pollution.
3. Consistent yields of good quality mushrooms, averaging over 200 kg/tonne compost at spawning, with yields of up to 250 kg/tonne compost.
4. The production of compost with a bulk density of 85-90% of conventional compost.
5. The establishment of optimum nitrogen and moisture contents of the compost ingredients and methods for their preparation (mixing and blending).
6. Reduction in the duration of bulk tunnel processing to 8-9 days.
7. The evaluation of supplementation, which was found to produce a consistent increase in mushroom yield (10.1-13.6%).
8. A saving in raw materials (about 30% of dry weight) compared with conventional composting.

SUMMARY

Odour and water pollution are major problems associated with traditional methods of preparing mushroom compost. The aim of the present project was to develop a system of composting which will be as pollution-free as possible, while maintaining a high yield of good quality mushrooms per unit of cropping area and minimising the capital resources required. The project consisted of two

parts: firstly an evaluation of two partially controlled composting systems, and secondly a series of experiments on fully controlled environment composting which involved a single tunnel stage process.

The two partially controlled composting systems were the 'Agrifung' method, which involves a re-mixing of the compost in a two tunnel stage process, and the 'Minskip' method, developed in 'deep troughs' which includes a high temperature (>70 °C) and low oxygen phase. Mushroom yields which were obtained from composts supplied by Agrifung and Minskip were significantly lower than those which were achieved with standard mushroom compost from commercial producers in the UK. A simulated Agrifung process also resulted in a significantly lower mushroom yield and quality than standard mushroom compost. A direct transfer of the Minskip composting process from deep troughs to bulk tunnels was not shown to be possible, since a stable, selective substrate could not be produced in the latter facility using a similar temperature regime.

A series of experiments on controlled environment compost preparation were conducted to determine the effects of the degree of straw chopping and straw type (wheat or barley), initial substrate nitrogen content, substrate preparation and tunnel treatment on the following factors: (i) mushroom productivity (ii) substrate bulk density (iii) evolution of gaseous pollutants. The experiments were conducted in bulk composting tunnels, each filled with a 16t of compost.

The results of these experiments have shown that by preparing compost ingredients over a four-day period and by optimising the initial N content to 2.5-2.9% of DM, controlled environment composts capable of producing over 200 kg of good quality mushrooms per tonne at spawning can be prepared without significant odour. This yield represents *c.* 80% of that obtained from

conventional pre-wet/Phase I mushroom composts under the same cropping conditions. The bulk density of controlled environment compost was increased by straw chopping and by extending the period of preparation from 2 to 5 days to 85-90% of conventional compost. The bulk density of the compost was increased further by a period at low oxygen in the bulk tunnel. However, this treatment had a negative effect on mushroom yield.

A conventional Phase II bulk tunnel regime, i.e. pasteurization at 58-61 °C for 6 h, followed by conditioning at 47 °C produced the best results. Increasing the duration and temperature of 'pasteurization' in the bulk tunnel prolonged the clearance of ammonia from the substrate. Increasing or decreasing the temperature of the pasteurization decreased the mushroom yield from the substrate. However, composts were produced with an extended pasteurization of 20 h which resulted in mushroom yields close to 200 kg/tonne. The use of Sporavite in the substrate had no effect on mushroom yield compared with substrates of equivalent N content. Replacing wheat straw with barley straw, or poultry manure with ammonium sulphate in the substrate ingredients both had negative effects on mushroom yield. Supplementation of prepared substrates with Betamyl 1000 increased yields by an average of 10.2%.

Further work needs to be conducted into increasing the degradation of the substrate and the effect of extending the initial pasteurization phase to 42 h is currently being investigated. The use of low cost cellulase enzymes may also be of value. Conversion of nitrogen in the substrate appears to be an important factor determining mushroom yield and the duration of the composting process. Preliminary work has shown that this may be improved by inclusion of a prepared compost inoculum in the compost ingredients. This treatment has also been shown to further increase compost bulk density.

INTRODUCTION

Mushroom compost is traditionally made from wheat straw with horse litter and/or poultry manure. The initial process of wetting, blending and composting these materials takes up to three weeks in open or roofed yards, firstly in large 'prewet' heaps and secondly in long, windrow composting stacks (Phase I). However, the odour and water pollution resulting from this process has resulted in strong environmental pressure against many composting yards in the UK.

In addition to the prewetting and Phase I, modern composting includes a controlled composting phase, carried out in bulk tunnels under controlled temperature and aeration (Phase II). The objective of the present work was to utilize and modify this controlled, pollution free Phase II process whilst reducing or eliminating the uncontrolled, polluting prewet and Phase I.

The project consisted of two parts: firstly an evaluation of two partially controlled composting systems, developed with a view to minimising pollution, and secondly, a series of experiments on fully controlled environment composting with the following objectives:

1. To develop a system of composting which will be as pollution-free as possible. The major pollutants concerned are odour and liquid run-off, although ammonia and noise may become greater problems in the future.

2. To produce compost with a yield potential of at least 250 kg mushrooms/tonne at spawning, within a four flush cropping duration (about 28 days of picking).

3. To maintain a high yield of good quality mushrooms per unit of cropping area, either by maintaining current commercial compost density, or a high productivity in terms of yield/tonne compost.

4. To minimise the loss of raw materials for compost production.

5. To minimise capital resources

   a) machinery for compost preparation

   b) bulk tunnels, by minimising the composting duration in the tunnel, ideally to a period of one week or less.

PART 1. EVALUATION OF THE PARTIALLY CONTROLLED AGRIFUNG AND MINSKIP COMPOSTING SYSTEMS

EXPERIMENT 1.1. COMPARISON OF COMPOSTS OBTAINED FROM CONVENTIONAL PHASE I/II PRODUCERS WITH COMPOSTS OBTAINED FROM AGRIFUNG AND MINSKIP.

Introduction

Two methods of 'short duration', partially controlled composting have been commercially developed with a view to minimising pollution. These are the Agrifung process developed in Italy and the Minskip process developed in Yorkshire. The aim of this experiment was to compare samples of compost from these sources with conventional composts produced by three different UK producers. The mushroom yields and compost filling densities obtained with these composts would also provide a 'benchmark' for further experiments.

Materials and Methods

Treatments

The following composts were compared:

1. Agrifung

Wetted, chopped straw, poultry manure, ammonium sulphate and gypsum were mixed and wetted in a screw conveyor and filled in an open tunnel. The temperature was allowed to rise naturally with a low air flow through the compost. After 3-4 days, the compost was transferred to a standard bulk tunnel and pasteurised and conditioned for 6 days (temperatures were not disclosed by the producer).

2. Minskip

A mixture of wetted straw, pig bedding and gypsum was loaded into bulk containers ('troughs') and allowed to rise naturally to 70 °C (± 5 °C). A low air flow was introduced at intervals to prevent any compost reaching 80 °C. Oxygen levels in the compost at this stage were < 1%. The initial high temperature phase was terminated after 30-36 hours. The compost temperature was reduced to 50-52 °C for 24 hours and then 46-48 °C for a further 7-8 days.

3. Standard 'A'

The basic mixture consisted of pre-wetted straw, hay and pig, horse and poultry manures. Oil seed meal, gypsum and further water were added during the stacking process (Phase I), which lasted for 7 days. The compost was then pasteurised (57-60 °C) and conditioned (47-48 °C) in bulk for 6 days (Phase II).

4. Standard 'B'

The basic mixture consisted of a 60%/40% prewetted blend of straw and horse litter, together with poultry manure. Gypsum, compost activator (Sporavite) and further water were added during the Phase I stacking stage, which lasted for 7 to 8 days. Phase II was similar to Compost 3.

5. Standard 'C'

As compost 4, except straw was used in place of a straw/horse litter mixture.

Cropping procedure

Composts 1, 4 and 5 were transported to HRI Littlehampton in compressed, polythene wrapped, 20 kg blocks. Composts 2 and 3 were transported in 25 kg polythene bags. The compost was emptied and pressed into 0.55 m^2 wooden trays during spawning. Each tray contained 50 kg compost, spawned at 0.5% w/w with the strains Hauser A9.3 or Somycel S609. During a 14-day spawn-running period, the compost temperature was maintained at 25-26°C. The trays were then cased with an Irish brown peat/chalk casing to a depth of 45 mm. Casing spawn (Growmaster A 9.3 or Somycel Pellet Spawn S609) was added to the casing before application. After a further 6 days, fresh air was introduced into the cropping shed and the air temperature was reduced to 17-18°C. Mushrooms were harvested at the large button stage (30-40 mm diameter) over a 42-day period (about 5 flushes of mushrooms).

Experimental design

The experiment consisted of two 'replicate' trial crops. The first trial comprised a 5 compost x 2 spawn strain factorial, although lack of Compost 2 led to the omission of one of the factorial treatments (Compost 2, strain S609). The second trial comprised a 4 compost x 2 spawn strain factorial. Compost 2 arrived too late to be included in the main design, although trays of Compost 2 were included in the same cropping shed. The layouts for the two trials were each based on row x column designs, with eight replicate trays of each compost/strain treatment. The mushroom yields for each of the two trials were analysed separately.

Compost analysis

Samples of each compost were analysed for moisture, total nitrogen, NH_4^+-nitrogen and ash contents and pH. The bulk density of each compost was assessed by determining the weight of compost which was required to fill a 0.91 x 0.61 x 0.18 (deep) m wooden cropping tray, after a pressure of 1.03 x 10^7 Pa had been applied.

Results

Compost analysis of the two batches of composts are shown in Table 1. The standard Phase I/II composts had higher nitrogen contents than the Agrifung or Minskip composts. The ash contents of the composts varied between batches, although both batches of Agrifung compost had a high ash content. The Minskip compost had the highest C:N ratio. The standard

Table 1. Compost analysis at spawning, Experiment 1.1

Compost	Batch	Percentage of dry weight		C:N ratio	Moisture %	pH (wet)	Bulk density kg/m^3
		N	Ash				
A	I	2.25	30.9	12.3	67.2	7.5	575
	II	2.38	30.0	11.8	70.2	7.8	575
B	I	2.15	24.9	14.0	68.6	7.4	450
	II	1.97	19.4	16.3	72.4	7.4	525
C	I	2.80	24.5	10.8	70.6	7.6	650
	II	2.84	21.8	11.0	69.9	7.8	625
D	I	2.65	28.1	10.9	66.3	7.7	575
	II	2.50	21.9	12.5	65.8	7.8	600
E	I	2.55	23.7	12.0	64.5	7.6	650
	II	2.75	30.7	10.1	63.1	7.4	625

NH_4N of all composts was less than 0.10% of dry weight

Table 2. Yield of mushrooms (kg/tonne compost at spawning) from Agrifung, Minskip and Standard Composts. Experiment 1.1. Each value is the mean of 8 trays.

Compost	Trial Crop 1		Trial Crop 2	
	Strain A9.3	S609	A.93	S609
1. Agrifung	222	191	151	135
2. Minskip	178	-	186	-
3. Standard 'A'	314	284	280	300
4. Standard 'B'	296	290	288	274
5. Standard 'C'	287	270	266	248
s.e.d.	15.9		9.5	

composts 'B' and 'C' had lower moisture contents than the other materials.

The Minskip compost was the least dense whereas standard composts 'A' and 'C' had the highest densities. Mushroom yields from the three standard composts were significantly higher than from the Agrifung and Minskip composts. Higher yields were obtained from the first batch of Agrifung, Standard 'B' and Standard 'C' composts than from the second batch.

EXPERIMENT 1.2. SIMULATION OF THE AGRIFUNG AND MINSKIP COMPOSTING SYSTEMS

The aim of this experiment was to simulate, as far as possible, the Agrifung and Minskip composting systems described in Experiment 1.1, using the bulk tunnel facilities at HRI Littlehampton.

Materials and Methods

Compost ingredients

The ingredients of the substrates were new season chopped wheat straw, deep litter poultry manure, Sporavite (molassed fibrous meal containing 26% sugar w/w DM) and gypsum. An analysis of the ingredients is shown in the Appendix. Poultry manure, Sporavite and gypsum were added at 160, 100 and 29 kg per tonne of initial compost ingredients. Water was added in four applications (c. 4900 litres/tonne fresh compost) to stacks which were turned five times in a three-day period on the compost yard. Maximum stack temperatures were c. 63°C. The analysis of the compost at the

time of filling in the tunnels is shown in Table 3.

Composting tunnels

Two bulk composting tunnels, consisting of modified insulated cargo containers with internal dimensions 11.8 x 2.2 x 2.4 (high) m (volume 62.3 m^3) were used for the experiments. A slatted steel bar floor with 40% air space was mounted 0.23 m above the base of the tunnel, providing an air plenum through which air could be blown upward through the compost. The tunnels were filled with 16 t of compost through double doors situated at one end using an oscillating head conveyor, and emptied using a 'Bobcat' front end loader (12 t of compost was used for the Agrifung simulation). The ventilation system, mounted at one end of the tunnel, provided a controlled flow of air into the plenum and through the compost before being recirculated through the plenum or exhausted through a vent at the far end of the tunnel. An automatic temperature controlled damper regulated the proportion of cooler fresh air to warmer recirculated air to maintain a specified input air temperature. Fresh air was filtered with a tunnel filter (95% efficiency at 2 μm). Steam was injected into the air supply when the temperature fell more than 1°C below the input air temperature set point. The steam supply was regulated by a motorized valve and step-less controller.

The air flow capacity of the fan ventilation system was variable within the range 0-4000 m^3/h, at a back pressure of 40 mm water, and was automatically regulated to maintain a specified temperature difference (normally 2-3 °C) between the top and bottom of the composting mass. Platinum resistance temperature sensors were mounted in the air space above and below the compost, and in the compost at four equally spaced positions along the tunnel. Up to twelve additional air and compost temperatures were monitored using squirrel data loggers. Ammonia,

carbon dioxide, oxygen and hydrogen sulphide levels in the air above the compost were monitored through an access port with a Draeger gas detector and appropriate sample tubes (CG20501, CH31401, 6728081 and 8101831 respectively). Air pressure in the plenum was monitored with tube manometers (Type SJ-8, Airflow Developments Ltd., High Wycombe, UK).

Compost treatments

1. Agrifung

Compost (12 tonnes) was filled into a tunnel to a non-uniform depth (min. 1 m, max. 2 m), and the end doors were left open. The airflow was set at 20 m^3/tonne compost/hour. After four days, the compost was emptied from the tunnel, mixed and re-wetted and then filled back into the tunnel to a uniform height of 1.5 m. A conventional Phase II bulk tunnel composting regime was then used as follows:

i) air input temperature set at 43 °C, with compost temperatures being allowed to rise to 45-50 °C during a 16-20 h period (temperature equalization)

ii) air input temperature set at 56-57°C, with compost temperature being maintained at 58-61 °C for 6 h (pasteurization),

iii) compost temperature reduced to 47-49 °C allowing ammonia to clear (conditioning).

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.

2. Minskip

Compost was filled to a uniform depth of 1.5 m and the tunnel doors were closed. The compost temperature was equalised at 40-50 °C using a limited amount of fresh air and airflow (*c.* 15 m^3/tonne compost/hour). The compost temperature was then allowed to rise, firstly tp 60-65 °C using intermittent fresh air, and then to 70-75 °C with steam for 8 hours. The compost temperature was then reduced, firstly to 60 °C using recirculated air, and then to 45-50 °C with fresh air. The compost was maintained at this temperature for a further 9 days for conditioning.

Cropping procedure and experimental layout

The cropping procedure was similar to that described in Experiment 1.1. Half of the compost spawned with each strain was supplemented with the soya meal-based Betamyl 1000 at a rate of 1% of compost fresh weight.

Trays were stacked four high in cropping sheds, with 12 replicate trays of each spawn strain and supplement subtreatment. A randomized block design was used, with each block

containing 2 strain x 2 supplement treatments.

Samples of each compost were also filled into six 1.83 x 1.22 x 0.20 (deep) m trays (220 kg compost/tray) and spawned with the strain Hauser A9.3 at a rate of 0.5% of fresh weight. No supplement was added to the compost. The trays were then transported to a commercial farm where they were cropped in houses with standard mushroom compost. The cultural conditions were similar to those at HRI Littlehampton.

Results

Temperature measurements

During the initial tunnel phase of the 'Agrifung' simulation, compost temperature ranged from around 25 °C close to the air plenum (Fig. 1, probe 1) to a maximum of around 75 °C in the upper centre of the composting mass (Fig. 1, probe 4).

Temperatures in the Minskip simulation are shown in Fig. 2. Compost temperature was initially increased at a rate of 2 °C/h and then at 0.5 °C/h to a peak of 75 °C. No oxygen could be detected with a Draeger tube in the tunnel at this stage. Compost temperatures varied by less than 5 °C.

Compost analysis

The Agrifung process resulted in a compost at spawning with a higher total nitrogen content

Table 3. Compost analysis at filling of bulk tunnels; Expt 1.2 (± S.D.)

Percentage of DM			C:N ratio	Moisture %	pH
N	NH_4^+-N	Ash			
1.80 (0.137)	0.42 (0.137)	11.0 (0.57)	19.9 (1.53)	78.3 (1.03)	7.9 (0.12)

Table 4. Compost analysis at spawning, Expt 1.2

Treatment	Rep.	Percentage of DM			C:N Ratio	Moisture %	pH	Bulk Density kg/m^3
		N	NH_4-N	Ash				
'Agrifung'	1	2.25	0.01	14.3	15.2	74.1	7.5	450
	2	2.50	0.02	15.9	13.4	78.6	7.3	475
'Minskip'	1	2.12	0.12	16.1	15.8	74.0	7.8	450
	2	2.06	0.40	16.4	16.2	72.5	8.1	475

Table 5. Mushroom yields at HRI Littlehampton and on a commercial farm, Agrifung simulated process, Expt 1.2

Rep.	Strain S609		Strain A93		Commercial Farm*
	Control	+ Betamyl	Control	+ Betamyl	
1	179	193	182	186	190
2	172	190	161	197	115

* Commercial farm - strain A9.3, no supplement added

Fig.1 Agrifung simulation,Exp 1.2

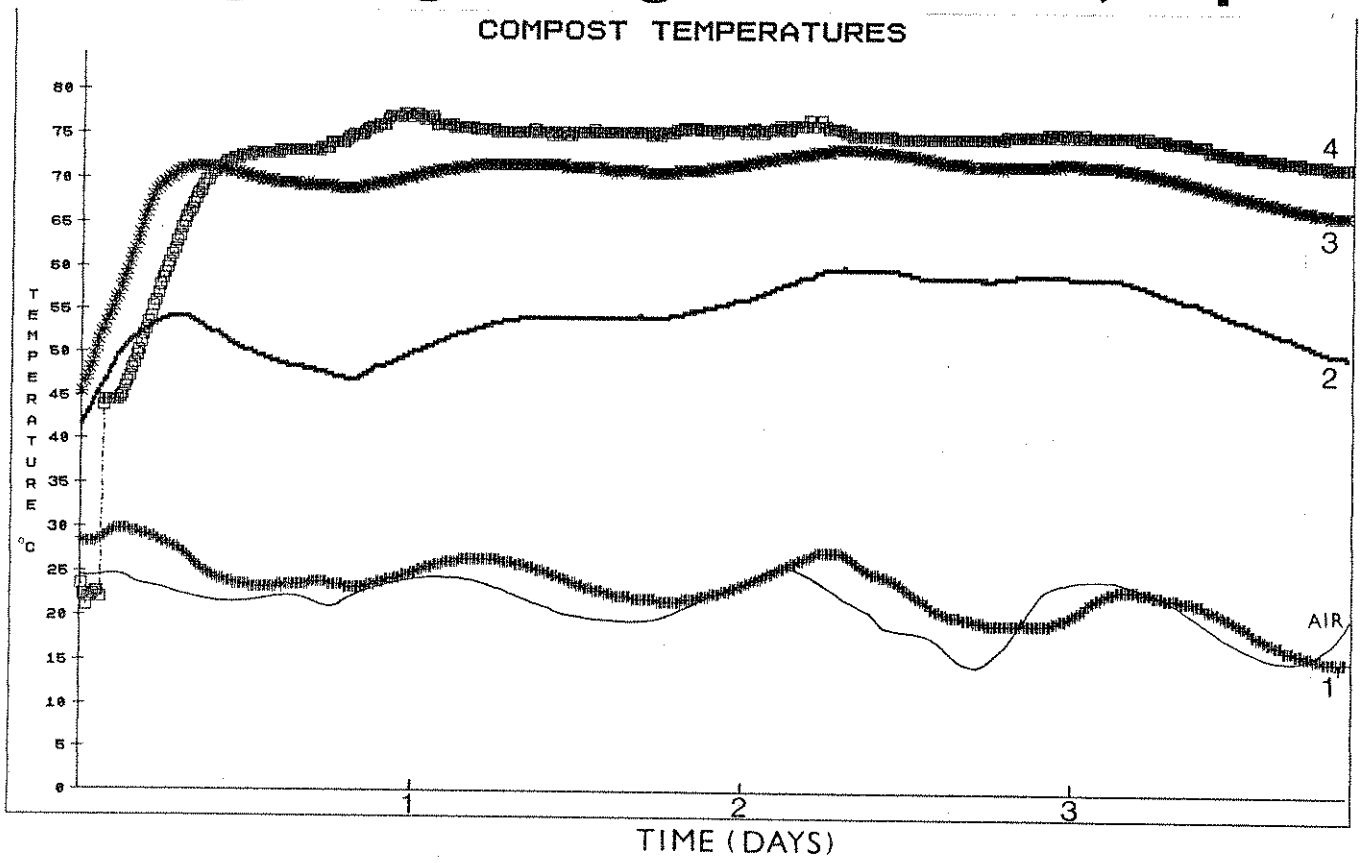
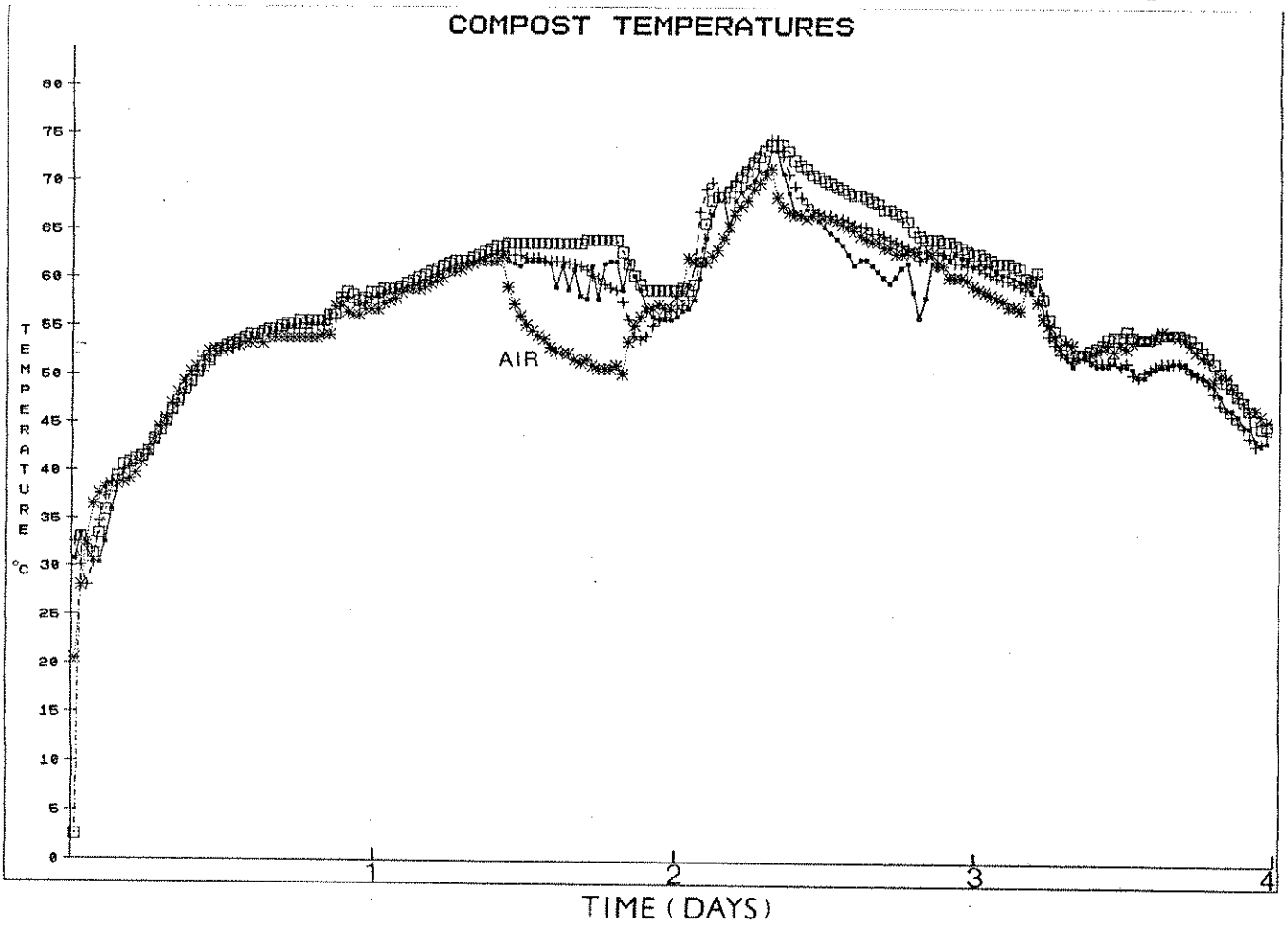


Fig.2 Minskip simulation, Exp 1.2



than the Minskip process, although the Minskip process compost had a higher NH_4^+ nitrogen content and pH (Table 4). There was no difference in the bulk densities of the composts.

Mushroom yields

Secondary heat and ammonia production occurred during spawn-running in both the Minskip simulation composts. These composts were therefore discarded before casing at HRI Littlehampton although very low yields of 16-20 kg mushrooms/tonne compost were obtained on the commercial farm.

Yields from the two Agrifung simulation composts were similar at HRI Littlehampton, although the yield from the second replicate was much lower than from the first on the commercial farm (Table 5). The use of the supplement 'Betamyl 1000' resulted in an average 11.8% yield increase. The quality of mushrooms from the simulated Agrifung compost was generally poor with mushrooms opening prematurely.

CONCLUSIONS - PART 1

Mushroom yields which were obtained from Agrifung and Minskip composts and the simulated Agrifung process (Expts 1.1 and 1.2) were significantly lower than those which were achieved with standard mushroom compost from commercial producers in the UK. The density of the composts was also lower, which would reduce the compost filling weight in trays or shelves, thus further limiting yield per unit of cropping area. The quality of mushrooms from the Agrifung composts was low. The simulated Agrifung process did not result in strong odours, although it necessitated

an additional filling and emptying of the tunnels. Recent experiments with this type of composting process indicate that an initial six-day tunnel phase results in higher mushroom yields than an initial three-day phase (Gerrits *et al.*, 1993; Overstijns, 1993). The yield and compost bulk density obtained in the present experiments with an initial four-day tunnel phase may therefore be improved by prolonging this stage. It is not clear whether the partially controlled Phase I can be conducted in a lower cost facility than a bulk tunnel. A simple aerated stack, possibly contained within side walls, may produce a similar result at much lower cost. This would also provide the opportunity for aeration and wetting by intermittent turning.

Odour was produced for 6-8 hours during the initial temperature rise of the simulated Minskip process. A direct transfer of the Minskip composting process from deep troughs to bulk tunnels was not shown to be possible, since a stable, selective substrate could not be produced in the latter facility using a similar temperature regime. This may be due to the more uniformly high temperatures which occur in a bulk tunnel compared with a deep trough (Doble, 1991).

PART 2: CONTROLLED ENVIRONMENT COMPOSTING: SUBSTRATES BASED ON STRAW AND DEEP LITTER POULTRY MANURE

Introduction

The aims of this series of experiments on controlled environment compost preparation were to determine the effects of the degree of straw chopping and straw type (wheat or barley), initial substrate nitrogen content, substrate preparation and tunnel treatment on the following factors:

(i) mushroom productivity

(ii) substrate bulk density

(iii) evolution of gaseous pollutants, specifically ammonia and odorous compounds.

Materials and Methods

Tunnel temperature regime

A standard temperature regime, based on conventional Phase II bulk tunnel composting was used for Experiments 2.1, 2.2 and 2.3. The procedure was as follows:

(i) air input temperature set at 43 °C, with compost temperatures being allowed to rise to 45-50 °C during at 16-20 h period (temperature equalization),

(ii) air input temperature set at 56-57 °C, with compost temperature being maintained at 58-61 °C for 6 h (pasteurization),

(iii) compost temperature reduced to 47-49 °C allowing ammonia to clear (conditioning).

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.

Preparation of materials

The ingredients of the substrates were new season chopped wheat straw, deep litter poultry manure, gypsum and Sporavite (in Expt 2.1 only). Barley straw was used in place of wheat straw in part of Expt 2.2. Bales of straw were chopped in a bale chopper (model 6-10, Kidd Farm Machinery Ltd, Devizes, Wilts, UK), wetted and formed into stacks using a compost turning machine. Further water was added to the chopped straw in a separate turn to achieve a moisture content of 70%. After 24 h, deep litter poultry manure, Sporavite (in Expt 2.1) and gypsum at 30 kg/t fresh compost ingredients were mixed into the stack. In Expts 2.1, 2.2 and 2.3 water was added in a further two turns to achieve a moisture content of 78% (± 1.5%) and the total compost preparation time, before filling into the tunnels, was 2 days. In later experiments the compost was given a further two turns and the preparation time increased to 4 days.

Cropping procedure

The cropping procedure was similar to that described for Experiment 1.2. Compost treatments

were produced in pairs in the two tunnels. The paired treatments were then brought together in the same spawn-running room and cropping shed.

Compost analysis was the same as for Expt 1.2.

EXPERIMENT 2.1. EFFECT OF STRAW CHOP LENGTH

Substrates were produced with wheat straw from three treatments:

(i) unchopped straw (median and mean straw lengths 85 and 165 mm)

(ii) 'long' chop length, produced with the standard chopping blades on the bale chopper (median and mean straw lengths 40 and 60 mm)

(iii) 'short' chop length, produced by attaching a short chop kit (Kidd Farm Machinery Ltd) to the bale chopper (median and mean straw lengths 30 and 47 mm).

The above median and mean straw lengths exclude straw pieces < 30 mm length. The percentages by weight of straw pieces < 30 mm length were 5, 24 and 49% for treatments (i), (ii) and (iii).

Following chopping, most of the hollow straw stems were also broken open and split lengthways. Controlled environment composts produced with the above straw chop lengths were also compared with a fourth treatment, namely GCRI 'Formula 2' mushroom compost (Randle 1974) prepared

with unchopped straw in a 13-day Phase I stacking period (treatment iv).

Poultry manure applications were adjusted in treatments (i) to (iii) to achieve a compost N content between 2.2-2.5% of DM at the time of filling of the bulk tunnels. The Formula 2 compost (treatment iv) had an N content between 1.8-2.1% of DM and a moisture content of 75-76% when filled into the tunnels.

The experiment was conducted as a series of six paired treatments in the two tunnels, with each treatment paired once with each of the other treatments. This balanced incomplete block design gave three replicates of each treatment paired as follows:

Pair	1	2	3	4	5	6
Tunnel 1	iv	iii	i	ii	iii	iv
Tunnel 2	i	iv	ii	iii	i	ii

Results

Although the Formula 2 compost (treatment iv) had a lower pH and lower N, NH_4^+-N and moisture contents than the other treatments (i-iii) before filling in the tunnel, these factors were similar in all treatments after emptying from the tunnel (Table 6). There were only small differences in ash content between the treatments, with the greater addition of ash from the higher poultry manure applications in treatments i-iii probably compensated by the greater carbon losses during the 13-day Phase I composting of treatment iv. The C:N ratios of the composts at emptying were similar for all the treatments. The bulk density of controlled environment compost prepared with unchopped

straw was significantly lower than that prepared with chopped straw (Table 7). The bulk densities of the two chop length treatment composts were not significantly different from that of the Formula 2 compost.

There was no significant difference in yield between the mushroom strains A9.3 and S609; the mean values are therefore shown (Table 7). The Formula 2 compost produced a significantly higher yield of mushrooms than the controlled environment composts. Although there was a trend for mushroom yield to increase with shorter straw chop length, differences between straw chop length treatments (i-iii) were not significant at $P = 0.05$. Supplementation of the compost with Betamyl 1000 significantly increased the mushroom yield from the Formula 2 compost but yield differences between supplemented and unsupplemented controlled environment composts were not significant. The quality of mushrooms was high from all the treatments (see Photograph 1 in the Appendix).

Table 6. Compost analysis at filling and emptying of bulk tunnels, Expt 2.1. Each value is the mean of three replicates.

Straw chop treatment		% of dry matter					
		N	NH_4^+ -N	Ash	C:N	Moisture %	pH
Filling	(i) Unchopped	2.26	0.55	16.1	14.8	77.4	8.1
	(ii) Long	2.37	0.46	15.5	14.3	78.5	8.5
	(iii) Short	2.46	0.58	14.6	13.9	78.3	8.2
	(iv) Formula 2	1.97	0.19	14.3	17.4	75.5	7.7
Emptying	(i) Unchopped	2.16	0.05	17.6	15.3	74.9	7.5
	(ii) Long	2.18	0.09	17.0	15.2	74.3	7.8
	(iii) Short	2.24	0.07	16.0	15.0	73.5	7.6
	(iv) Formula 2	2.23	0.09	17.7	14.8	74.6	7.5

Table 7. Yield of mushrooms (kg per tonne of compost at spawning) and compost bulk density. Expt 1.

Straw chop treatment	Yield,* kg/tonne		Bulk density kg/m^3
	Unsupplemented	+ Betamyl	
(i) Unchopped	117	133	470
(ii) Long chop	126	138	544
(iii) Short chop	169	169	548
(iv) Formula 2	213	250	539
S.E. (24 D.F.)	17.2	17.2	12.2

* Mean of strains A9.3 and S609

EXPERIMENT 2.2 EFFECT OF COMPOST N CONTENT

Introduction

Previous experiments with controlled composting systems have been conducted with substrates with initial N contents of 1.4-2.3% of DM (Beck, 1978; Smith, 1983; Laborde *et al*, 1986; Perrin and Gaze, 1987; Miller *et al*, 1990). The aims of the present experiment were to examine a wider range in initial substrate N content (1.1-2.75% of DM) and to compare the use of wheat and barley straw.

Materials and Methods

Compost N content was varied by altering the ratio of poultry manure to chopped straw, taking into account the N and moisture contents of the poultry manure and straw using the equation:

$$\frac{W2}{W1} = \frac{D1\ (n\text{-}N1)}{D2\ (N2\text{-}n)}$$

n = required nitrogen content of the mixed substrate ingredients (% of DM)

W = fresh weight

D = percentage dry matter

N = nitrogen content (% of DM)

Suffixes 1 and 2 refer to straw and poultry manure respectively.

Composts with calculated or 'target' N contents varying between 1.1 and 2.75% of DM at the time

of filling of the tunnels were produced with the range in target N content divided into seven subdivisions, each covering a range of *c.* 0.25% N. Two composts with calculated N contents within each subdivision were produced. Composts within each target N content subdivision were randomly paired with other target N content treatments, such that each treatment was produced once in each tunnel. A total of 14 substrates were prepared with wheat straw (short chop length).

Two further substrates were prepared with barley straw in place of wheat straw with the following N contents at the time of filling: 2.34 and 2.54% of DM.

Results

Increasing the initial N content of the compost ingredients at the time of filling of the tunnels lengthened the duration needed to clear ammonia from the substrate. The ammonia concentration in the tunnels and the total ammonia losses were also significantly increased. A substrate with a high initial N content of 2.75% of DM resulted in a maximum ammonia concentration of 1200 μl/l in the air in the tunnel, and 0.53 kg ammonia/t compost were evolved during a period of 15 days. Conversely, a substrate with a low initial N content of 1.13% of DM was clear of ammonia in 4 days, and produced only 0.02 kg ammonia/t compost, with a maximum ammonia concentration of 100 μl/l in the air.

There was a close correlation between the initial N content of the compost and that calculated from the analyses of the ingredients; differences between the two assessments were due to the heterogeneity of the sampled materials. Compost N contents at filling and emptying of the tunnels were closely correlated; the N content at emptying was usually greater than that at filling, although

the difference decreased with increasing N content. There was also a close correlation between the compost N content at filling and the C:N ratio at emptying.

A higher initial compost N content increased the DM and ash contents at emptying due to the longer duration in the tunnel required to clear the ammonia, resulting in greater moisture and carbon losses. The increasing moisture loss with higher initial compost N content resulted in a significant negative correlation between compost N content and bulk density. Compost NH_4^+ -N content and pH at emptying of the tunnels were only weakly correlated with compost N content at filling. There was no significant correlation between the compost NH_4^+ -N contents at filling and emptying of the tunnels.

Substrates with an initial N content of 2.7% of DM or higher could not be completely cleared of ammonia within 20 days, leading to desiccation of the substrate and mushroom yields of less than 100 kg/t compost at spawning. Large numbers of fruitbodies of *Coprinus* spp. developed in these composts after casing. Within the range of compost N content of 1.6-2.6% of DM at spawning (initial compost N content 1.1-2.5% of DM) there was a significant positive correlation between compost N content and mushroom yield (Fig. 3). Mushroom yield was more closely correlated with the compost N content at spawning than with that at the time of filling of the tunnels (r = 0.606 and 0.552 respectively, $P < 0.05$). The addition of the supplement 'Betamyl 1000' increased the yield by an average of 13.6% above that from the unsupplemented compost ($P <$ 0.01). There was no significant interaction between the effects of compost N content and supplementation with Betamyl 1000 on mushroom yield.

There was a weak but significant correlation (r = 0.557) between mushroom yield and compost

DM content over a range in DM content of 25-33% at spawning; this was probably due to the positive relationship between DM and N contents. However, composts desiccated as a result of prolonged conditioning (DM content ≥35%) produced yields of < 100 kg mushrooms/t compost at spawning. There were no significant correlations between mushroom yield and compost pH or NH_4^+-N and ash contents.

Mushroom yields in Expts 1 (short chop treatment) and 2, at equivalent substrate N contents at spawning, were similar (compare Table 7, treatment (iii) with Fig. 3). The Sporavite compost activator used in Expt 1 therefore had no effect on mushroom yield.

The mean mushroom yield from composts prepared with barley straw was 112 kg/t compost at spawning and was significantly lower ($P < 0.01$) than those prepared with wheat straw, at equivalent N contents. The duration required for ammonia to be cleared from the substrate was not significantly different from that for substrates prepared with wheat straw. The bulk density of substrates prepared with wheat or barley straw were not significantly different. The quality of mushrooms in this experiment was high, and there were no differences between treatments.

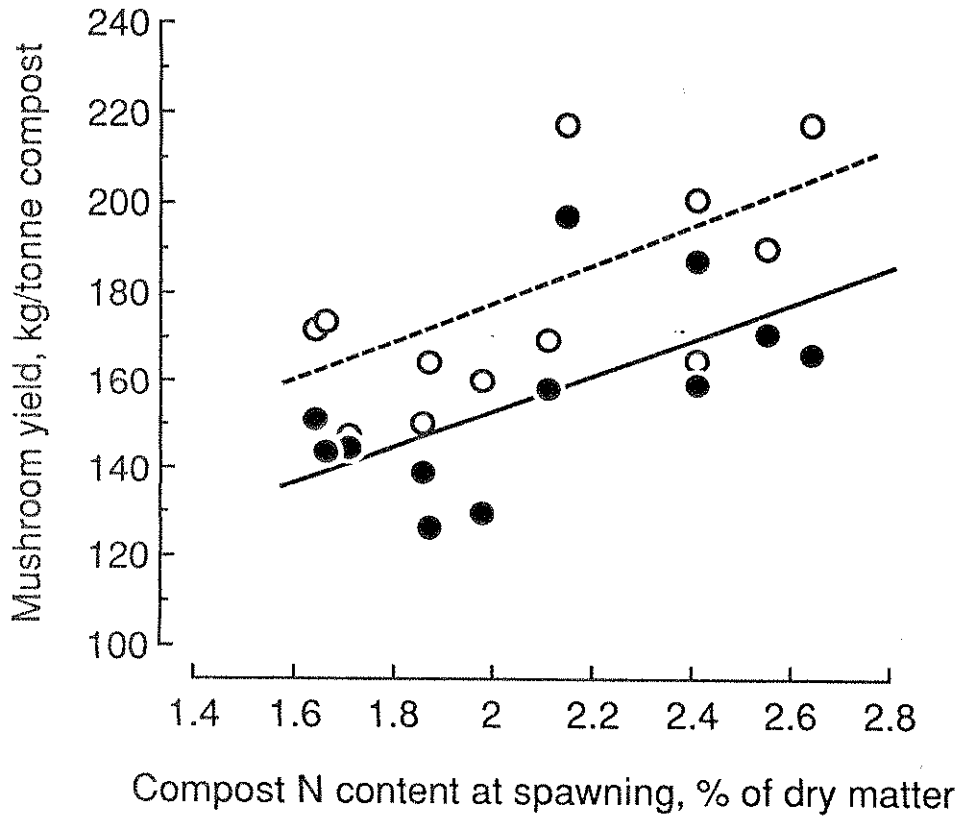


Fig. 3 Relationship between compost N content at spawning and mushroom yield per tonne of compost at spawning: unsupplemented compost, (●) and solid line; compost supplemented with Betamyl 1000, (⊙) and broken line. Expt 2.1.

EXPERIMENT 2.3 EFFECT OF COMPOST YARD STACK DURATION

In Expts 2.1 and 2.2, controlled environment composts were prepared on the compost yard for a two or three day period. The aim of the present experiment was to determine how the duration of compost preparation in the stack on the compost yard affects:

(i) mushroom yield and quality

(ii) compost bulk density

(iii) compost odour

Materials and Methods

Compost ingredients and durations of stacking

The ingredients of the stacks and quantities used are shown in the Appendix. Stacks were prepared with an initial N content of about 1.75% of DM and a moisture content of about 78% when the first material was filled into the tunnel after 2 days. The compost continued to be turned at daily intervals and further material was filled into the tunnels after 5, 9 and 13 days. Water was added to the stack to maintain a constant moisture content at the time of each filling.

Four replicate stacks were prepared. In each case, the 2 and 5 day treatments and 9 and 13 day treatments were paired in the tunnels and subsequent spawn-run and cropping sheds. The allocation

of the two tunnels to each of the paired treatments was alternated for each replicate run.

The cropping procedure and compost analysis were similar to those described previously in Expts 1.2 and 2.1.

Compost odour assessment

Compost odour was assessed by a randomly selected group of ten people on stack days 2, 5, 7, 9 and 13 when the compost was turned. The odour was assessed on a 0 (odourless) to 10 (highly pungent and offensive) scale.

Results

Ammonia cleared in the tunnels from all the stack duration treatments in an average of 6 days. The average processing time in the tunnel was 7 days for all treatments.

Compost analysis

At the time of filling, N content increased from 1.75% of DM after 2 days to 2.31% of DM after 13 days, whereas NH_4^+ declined from 0.56 to 0.40% of DM (Table 8). Ash content increased during stacking, whereas the pH remained constant (*c.* 8.1). At the time of spawning, the N and ash contents of the substrate also increased with lengthening duration of stacking, whereas NH_4^+ content and pH were unaffected. The compressed bulk density was significantly increased by extending the preparation of the materials in the stack (Table 9). Photographs 2-6 in the Appendix

show the gradual darkening of the materials with time.

Compost odour

Compost odour increased with increasing number of days on the yard, up to day 7, with the threshold for an 'acceptable' level of odour being exceeded after day 5. Although the odour changed from predominantly ammonical to anaerobic, the intensity of the odour declined after day 9 (Fig. 4).

Mushroom yields

Due to a severe infestation of sciarid flies, no reliable yield data was obtained from replicates 2, 3 and 4 at HRI (Table 9). Yields were obtained from all four replicates on the commercial farm. However, the experiment was conducted during the summer without cooling facilities so that the overall level of yields was low. Average mushroom yield in the same cropping sheds using a standard Betamyl supplemented compost was 189 kg/t compost at spawning. This compares with an average yield of 285 kg/t compost during Expts 1.2, 2.1 and 2.2.

At HRI the highest mushroom yield was obtained from a 9-day stack compost, whereas 13-day stack composts produced the highest yield on the commercial farm. Mushroom yields from the 5-day stack compost were 19.2% and 5.4% higher than from the 2-day stack compost at HRI and the commercial farm respectively.

Table 8. Compost analysis at filling and emptying of bulk tunnels, Expt 2.3. Each value is the mean of four replicates.

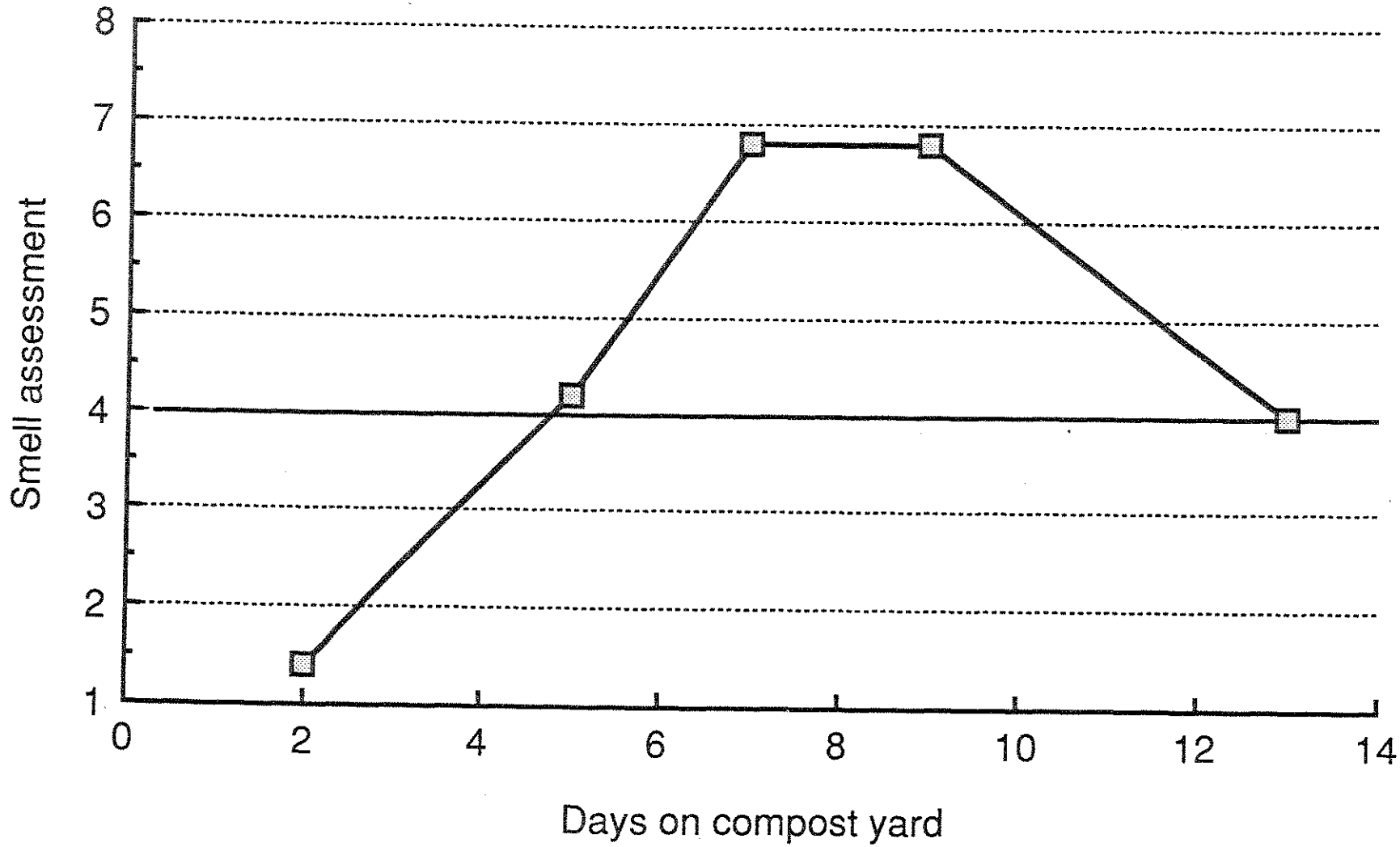
	N Source	Percentage of DM			C:N Ratio	Moisture %	pH	Bulk Density
		N	NH_4^+-N	Ash				kg/m^3
Filling	2	1.75	0.56	11.8	20.2	77.6	8.1	-
	5	2.11	0.47	13.4	17.5	78.5	7.9	-
	9	2.25	0.41	14.1	16.1	77.3	8.1	-
	13	2.31	0.40	15.8	14.8	77.0	8.2	-
	L.S.D. (5%)	0.27	0.18	2.6	2.8	2.3	0.4	-
Emptying	2	2.11	0.20	13.8	16.6	73.3	7.5	444
	5	2.26	0.20	17.9	14.0	75.5	7.5	481
	9	2.50	0.19	17.1	13.4	73.5	7.8	506
	13	2.62	0.22	20.2	12.3	73.3	7.7	563
	L.S.D. (5%)	0.24	0.04	1.4	1.5	2.1	0.3	39

Table 9. Mushroom yields at HRI Littlehampton and on a commercial farm, Expt 2.3

Stack duration, days	Strain S 609[1] Control	Strain S 609[1] + Betamyl	Strain A 9.3[1] Control	Strain A 9.3[1] + Betamyl	Commercial Farm[2]
2	123	128	100	148	114.0
5	157	176	101	161	120.2
9	167	208	199	223	128.8
13	158	172	150	167	178.5

[1] First replicate only
[2] Mean of 4 replicates, Strain A9.3, no supplement added

Compost smell assessment



EXPERIMENT 2.4 EFFECT OF BULK TUNNEL TEMPERATURE AND AERATION REGIME

In the previous experiments, the temperature and oxygen levels in the bulk tunnel were based on a conventional Phase II bulk tunnel regime. In this experiment, the temperature, oxygen level and duration of the initial higher temperature phase were varied. The term pasteurization has been designated to the higher temperature phase, although this normally applies to compost temperatures of at least 56 °C.

In a preliminary trial, compost was pasteurized at 71-74 °C for 3 hours before conditioning at 47 °C. However, ammonia could not be cleared from this substrate. A maximum temperature of 65-68 °C was therefore used in this experiment.

Materials and Methods

Bulk tunnel treatments

Following an initial temperature equalization period in which compost temperatures were allowed to rise to 45-50 °C during 16-20 h, the following treatments were imposed:

1. 'Pasteurization' compost temperature, °C : (i) 51-54 (ii) 58-61 (iii) 65-68.
2. Oxygen concentration in the compost, %: (i) <1 (ii) 7-9.
3. Duration of pasteurization, h (i) 6 (ii) 20.

The higher oxygen level tratment (2, ii) was achieved by maintaining a continuous airflow through the compost to control the compost temperature throughout the period of pasteurization. The low oxygen level treatment (2, i) was achieved by closing the fresh air damper and exhaust vent and turning off the ventilation fan when the compost was *c.* 5 °C below the desired temperature. The compost temperature then rose to the desired level, at which point the limitation in oxygen supply prevented a further increase in temperature.

All the treatments were conditioned at 47-49 °C under controlled aeration (minimum of 14% 0_2). Two replicates of each of the 12 treatments (3 temperature x 2 oxygen x 2 duration) were prepared. The treatments were prepared in pairs, with treatments paired differently for the first and second replicate runs.

Compost ingredients

Compost ingredients were prepared in four-day stacks with an initial N content of about 2.35% of DM and a moisture content of about 79.5% (Table 11). The straw and poultry manure ingredients of the stacks are shown in the Appendix.

Results

Ammonia cleared from all the 51-54 °C treatments and 6 h 58-61 °C treatments in an average of 6.5 days. The 20 h 58-61 °C and 6 h 65-68 °C treatments required 8 days and the 20 h 65-68 °C treatments required 10.5 days for ammonia to be cleared.

Hydrogen sulphide (H_2S) could only be detected in the low oxygen treatments, and the highest levels were recorded at 51-54 °C (500 ppm). At 65-68 °C, a H_2S level of 35 ppm was recorded.

Compost analysis

The N content of the substrates at spawning was not significnatly different between treatments; the aveage N content was 2.59% of DM. NH_4^+ content was slightly higher in composts given a 20 h pasteurization (0.27 and 0.32% of DM for 6 and 20 h pasteurization). The ash content of substrate pasteurizated at 60 °C, 7-9% 0_2 for 20 h was significantly higher than that of the other treatments (Table 11). The moisture content of substrates pasteurized at 65 °C for 20 h was significantly lower than of the other treatments, due to the extended conditioning period required. The pH of the substrates at spawning was not affected by the treatments. The bulk density of compost pasteurized at low oxygen was significantly higher than that of compost pasteurized at 7-9% 0_2 (overall means 523 kg/m^3 and 483 kg/m^3).

Mushroom yield

Mushroom yield was significantly higher from the 58-61 °C temperature treatments than from the 51-54 °C and 65-68 °C treatments (Table 12). The 7-9% oxygen level also resulted in a significantly higher mushroom yield than the low oxygen concentration treatment. The duration of 'pasteurisation' (6 or 20 h) had no significant effect on subsequent mushroom yield. There were no significant interactions between the bulk tunnel treatments. Supplementation of the compost with Betamyl resulted in an average 10.1% yield increase.

Three individual replicates of 20 h pasteurization treatments resulted in mushroom yields close to 200 kg/tonne compost. These treatments were 20 h at 51-54 h (low oxygen), 58-61 °C and 65-68 °C (7-9% oxygen). The effect of extending these pasteurization treatments to 42 h is currently being investigated.

Table 10. Compost analysis at filling of bulk tunnels; (± S.D.). Expt 2.4

Replicate	Percentage of DM					
	N	NH_4^+N	Ash	C:N Ratio	Moisture %	pH
1.	2.42 (0.270)	0.55 (0.139)	12.2 (2.01)	14.5 (2.08)	79.4 (1.54)	7.8 (0.49)
2.	2.27 (0.462)	0.66 (0.258)	12.4 (1.44)	16.1 (3.13)	79.7 (1.58)	7.8 (0.47)

Table 11. Ash and moisture contents and bulk density of composts at emptying of bulk tunnels, Expt 2.4

	Pasteurisation treatment				Moisture %	Bulk Density kg/m^3
	Temp °C	O_2, %	time, h	Ash % of DM		
(i)	51-54	<1	6	15.1	75.7	500.0
(ii)		7-9	6	16.9	73.5	487.5
(iii)		<1	20	15.3	76.7	537.5
(iv)		7-9	20	16.9	73.3	487.5
(v)	58-61	<1	6	14.0	73.9	537.5
(vi)		7-9	6	15.0	73.2	462.5
(vii)		<1	20	14.4	79.0	500.0
(viii)		7-9	20	18.6	74.6	525.0
(ix)	65-68	<1	6	16.8	74.4	525.0
(x)		7-9	6	13.1	77.1	475.0
(xi)		<1	20	15.9	73.0	537.5
(xii)		7-9	20	16.5	71.9	462.5
L.S.D. (5%)				2.6	4.0	56.1

Table 12. Effect of bulk tunnel treatments on mushroom yield, kg/tonne compost at spawning. Expt 2.4. Mean of strain and supplement treatments.

Compost temperature °C	Oxygen conc. %	Duration, h 6	20	Mean
51-54	<1	164	140	152
	7-9	164	165	165
58-61	<1	143	151	147
	7-9	213	181	197
65-68	<1	125	107	116
	7-9	106	175	141
L.S.D. (5%)				54

EXPERIMENT 2.5 HIGH NITROGEN CONTENT SUBSTRATES PREPARED IN 4-DAY STACKS

The results of Expt 2.2 showed that within a range of compost N content of 1.6 - 2.6% of DM at spawning, there was a significant positive correlation between compost N content and mushroom yield. However, substrates with an initial N content of 2.7% of DM or higher could not be completely cleared of ammonia. The aim of this experiment was to determine whether substrates with high N contents (*c.* 3% of DM at spawning) could be prepared by extending the initial stack preparation of the materials from 2 to 4 days.

Materials and Methods

Compost ingredients

Substrates with initial N contents of 2.2 - 3.0% of DM were prepared in a 4-day stack using three N source treatments:

(i) Poultry manure

(ii) Poultry manure + Sporavite

(iii) Poultry manure + Ammonium sulphate

The quantities of the ingredients used are shown in the Appendix. Compost analyses at filling are

shown in Table 13.

Four replicate stacks of treatment (i) and a single replicate of treatments (ii) and (iii) were prepared. A conventional Phase II bulk tunnel treatment (Expts 2.1 - 2.3) was used.

Results

The substrates were clear of ammonia after 8 days and were spawned after 9 days.

The different N source treatments resulted in similar total N and NH_4^+ contents at spawning (Table 14). The poultry manure + ammonium sulphate treatment (iii) had a lower ash content, due to the lower addition of poultry manure, and a lower pH than the poultry manure treatment (i). Treatments (ii) and (iii) were drier and wetter respectively than treatment (i) at spawning.

Mushroom yields of over 200 kg/tonne compost at spawning were achieved, although the addition of Sporavite appeared to have little or no effect (Table 15). The addition of ammonium sulphate appeared to be detrimental to yield, although this result is based on only one replicate. Betamyl 1000 increased the yields of treatments (i) and (ii) by 10.1%.

Table 13. Compost analysis at filling of bulk tunnels; Expt 2.5.

	N source	Percentage of DM N	NH_4^+	Ash	C:N Ratio	Moisture %	pH
(i)	Poultry manure	3.04	1.14	15.7	11.1	77.3	8.3
(ii)	Poultry manure + Sporavite	2.93.	1.02	16.4	11.4	75.0	7.6
(iii)	Poultry manure + Ammonium sulphate	2.23	1.18	12.9	15.6	80.4	7.6
(iv)	Poultry manure	2.65	0.57	13.2	13.1	79.4	8.2
(v)	Poultry manure	2.97	1.01	12.8	11.7	77.1	8.1
(vi)	Poultry manure	2.20	0.86	16.7	15.1	72.1	8.0

Table 14. Compost analysis at spawning, Extp 2.5.

	N Source	Percentage of DM N	NH_4^+-N	Ash	C:N Ratio	Moisture %	pH	Bulk Density kg/m^3
(i)	Poultry manure	3.37	0.48	24.4	8.97	68.0	7.8	450
(ii)	Poultry manure + Sporavite	3.14	0.39	23.5	9.75	61.4	8.0	525
(iii)	Poultry manure + Ammonium sulphate	2.95	0.30	18.7	11.02	75.1	6.7	525
(iv)	Poultry manure	3.58	0.07	19.9	8.95	72.6	7.9	475
(v)	Poultry manure	3.35	0.36	18.2	9.80	67.8	7.1	470
(vi)	Poultry manure	2.52	0.16	15.9	13.30	74.7	7.8	450

Table 15. Yield of mushrooms (kg per tonne of compost at spawning).

	N source	Yield, kg/tonne	
		Unsupplemented	+ Betamyl
(i)	Poultry manure	185	210
(ii)	Poultry manure + Sporavite	184	205
(iii)	Poultry manure + Ammonium sulphate	131	138
(iv)	Poultry manure	201	209
(v)	Poultry manure	239	249
(vi)	Poultry manure	211	224

CONCLUSIONS - PART 2

The results of these experiments have shown that by preparing compost ingredients over a four-day period and by optimising the initial N content to 2.5-2.9% of DM, controlled environment composts capable of producing over 200 kg of good quality mushrooms per tonne at spawning can be prepared without significant odour. This yield represents *c.* 80% of that obtained from conventional pre-wet/Phase I mushroom composts under the same cropping conditions. The bulk density of controlled environment compost was increased by straw chopping and by extending the period of preparation from 2 to 5 days to about 85% of conventional compost. The bulk density of the compost was increased further by a period at low oxygen in the bulk tunnel. However, this treatment had a negative effect on mushroom yield.

A conventional Phase II bulk tunnel regime, i.e. pasteurization at 58-61 °C for 6 h, followed by conditioning at 47 °C produced the best results. Increasing the duration and temperature of 'pasteurization' in the bulk tunnel prolonged the clearance of ammonia from the substrate. Increasing or decreasing the temperature of the pasteurization decreased the mushroom yield from the substrate. However, three individual replicates of the 20 h pasteurization treatments resulted in mushroom yields close to 200 kg/tonne compost. These were 20 h at 51-54 °C (low oxygen), 58-61 °C and 65-68 °C (7-9% oxygen). The effect of extending these pasteurization treatments to 42 h is currently being investigated.

The use of Sporavite in the substrate had no effect on mushroom yield compared with substrates of equivalent N content. Replacing wheat straw with barley straw, or poultry manure with ammonium sulphate in the substrate ingredients both had negative effects on mushroom yield.

Supplementation of prepared substrates with Betamyl 1000 increased yields by an average of 10.2%.

Further work needs to be conducted into increasing the degradation of the substrate, and the use of low cost cellulase enzymes may be of value. Conversion of nitrogen in the substrate appears to be an important factor determining mushroom yield and the duration of the composting process. Preliminary work has shown that this may be improved by inclusion of a prepared compost inoculum in the compost ingredients. This treatment has also been shown to increase compost bulk density.

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APPENDIX

Table A1. Analysis of organic ingredients used in the composts (± S.D.).

Ingredient	% dry matter	% of dry matter	
		N	Ash
Wheat straw	89.2 (± 2.76)	0.5 (± 0.12)	5.4 (± 2.37)
Barley straw	91.9 (± 3.15)	0.5 (± 0.18)	4.6 (± 2.73)
Poultry manure	66.3 (± 5.34)	5.4 (± 0.75)	15.8 (± 2.19)
Sporavite	74.7 (± 4.41)	7.4 (± 0.60)	15.7 (± 1.86)

Table A2. Compost ingredients, per tonne of original fresh weight excluding water added, mean values.

Expt		Wheat* straw	Barley* straw	Poultry manure	Sporavite	Ammonium sulphate	Gypsum	water litres/t
(treatment)		kg	kg	kg	kg	kg	kg	
1.2		711	0	157	103	0	29	4913
2.1	(i)-(iii)	597	0	287	87	0	29	3646
2.1	(iv)	731	0	146	101	0	22	3859
2.2		344-722	598	243-621	0	0	35	3548
2.3		589	0	381	0	0	30	3160
2.4		608	0	362	0	0	30	3657
2.5	(i)	413	0	558	0	0	29	3242
2.5	(ii)	364	0	519	90	0	27	2847
2.5	(iii)	537	0	397	0	37	29	3905

* Wheat and barley straw were used separately