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## HDC Project M3c

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# Reduction of Pollution from Mushroom Composting

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## Summary

Odour and water pollution are major problems associated with traditional methods of preparing mushroom compost. Two enclosed composting processes were compared in terms of mushroom yield, compost density, odour pollution and implications for cost and management. The processes were a single tunnel system, based on a Phase II pasteurization, and a two tunnel system, where a Phase II tunnel process was preceded by a six-day, low aeration, 'high' temperature phase (compost temperature exceeding 75°C).

For both systems, compost ingredients were prepared in a four-day stacking period. The affects of adding a cellulase enzyme and recycled, processed compost (15% of the dry matter) to the compost ingredients on subsequent mushroom yield and compost density were also investigated.

There were no significant odour emissions from either the single or 2-tunnel composting systems. The 2-tunnel process resulted in a compost with a higher bulk density and mushroom yield potential than the single tunnel process. Total processing times for the single tunnel and 2-tunnel systems were 9 and 12 days respectively. Control of compost temperatures in the single tunnel system was more difficult due to the greater activity of the compost. In the 2-tunnel system, significant compost energy was dissipated during the high temperature phase.

The addition of a low rate of cellulase enzyme did not affect the bulk density or mushroom yield potential of the compost. Adding recycled compost in the initial ingredients improved the water absorption and resulted in a small improvement in subsequent compost density but did not affect mushroom yield. Mushroom quality (size grades and firmness) were not affected by any of the treatments. Mushroom yield and quality and substrate density from the 2-tunnel process were similar to those obtained from conventional compost.

## Recommendations for future work

1. Straw chopping is a costly and time consuming procedure. The process has been developed for a single tunnel system. The effects of using coarsely chopped and unchopped straw in the 2-tunnel system should be explored. The need for fine chopping in a 2-tunnel system may be further reduced by the inclusion of recycled substrate, in the compost ingredients.

2. The effect of reducing the rate of recycled compost in the ingredients should be investigated (rates lower than 15% of the dry matter).

3. The optimum tunnel regime for the low aeration, high temperature phase of the 2-tunnel process should be determined.

4. The optimum compost N and moisture contents for the 2-tunnel process should be determined.

5. The use of a wider range of compost supplements, at spawning and at casing (spawn-run compost) should be investigated.

6. An aerated outdoor phase or other techniques to allow odour free degradation prior to the use of a single tunnel regime should be considered.

## Introduction

The successful development of a controlled composting process would alleviate the environmental pressure facing the mushroom industry and could also result in a more consistent and reliable method of substrate preparation. Recent developments in reducing pollution have followed two main approaches:

- A single tunnel system, preceded by a period of outdoor stacking.
- A two tunnel system whereby compost is first filled into a basic, low aeration tunnel, followed by a conventional tunnel pasteurization. Either blended ingredients or pre-stacked material have been used for this system.

Single tunnel system

The HRI approach (funded by HDC and MAFF) has been to explore tunnel regimes, compost ingredients and non-polluting preparation techniques to avoid the need for the additional 'basic' tunnels. Progress in large-scale bulk tunnel experiments has produced the following achievements:

- Control of odour and water pollution.
- High mushroom quality.
- Mushroom yield 70-80% of conventional compost (in 4-5 flushes).
- Compost density 80-90% of conventional compost.

To increase yields and compost density to conventional compost levels, it would appear that further straw softening and degradation is needed without added pollution. Recent work using flask composting equipment has shown that the addition of recycled, processed compost and cellulase enzymes can increase substrate density and mushroom yield.

Two tunnel system

The approach adopted in Italy and some enterprises in Holland and Belgium has been to fill

compost ingredients into basic, low-aeration tunnels before re-mixing and/or inoculating and filling into a standard phase II tunnel. An initial study of this process was included in the HDC project.

Information on this system has given the following conclusions:

- Yields are reported in some instances to be better than from a single tunnel system. Mushroom quality (soft, small mushrooms) may be lower. Little information is available concerning this aspect.

- Filling raw ingredients into the basic tunnel results in lower yields than when a stacking period of 2-5 days is used before filling.

- A six-day basic tunnel phase appears to give better results than a three-day phase.

## Scientific/Technical Target of the Work

1. To compare the yield and quality of mushrooms and the substrate density of compost produced using the two-tunnel system with those of the single tunnel system and conventional mushroom compost.

2. To further develop non-polluting stack preparation techniques for both the single tunnel and two tunnel systems.

3. To further optimise the substrate ingredients for both systems.

4. To assess the pollution implications of both approaches.

A schematic of the project proposal is shown in Figure 1.

## Materials and Methods

Composting tunnels

Six bulk composting tunnels, four of which consisted of insulated polythene tunnels (internal dimensions 3 x 2.05 x 2.5 (high) m) and two consisting of modified insulated cargo containers were used for the experiment. A slatted steel bar floor with 75% air space was mounted 0.5 m above the base of the tunnel, providing an air plenum through which air could be blown upwards through the compost. The tunnels were filled with 4 t of compost to a height of 1.5 m through double doors situated at one end using an oscillating head conveyor. A 'Bobcat' front end loader was used to empty the tunnels. 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 either recirculated through the plenum or discharged from the tunnel through a vent. An automatic temperature - controlled damper regulated the proportion of cooler fresh air to warmer recirculated air to maintain a specified air input temperature. Temperature control of the air damper was overridden if the oxygen concentration in the recirculated air fell below 14% v/v, in which case the air damper was opened, reaching a maximum proportion of fresh air at 12% v/v $O_2$. The air flow capacity of the fan ventilation system was variable within the range 0-2000 $m^3/h$, at a back pressure of 40 mm water. The air flow could be automatically regulated to maintain a specified temperature difference (normally 2-3°C) between the top and bottom of the composting mass. 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 air input temperature set point. The steam supply was regulated by a motorized valve and stepless controller. Platinum resistance temperature sensors were mounted in the air space above and below the compost, and in four positions in the compost, in a 1.5 m sided square arrangement. Oxygen was monitored in the air above the compost using an 'Oxystor' sensor and 'Oxymac' microprocessor (AEM bv, Maasbree, Netherlands). Ammonia levels in the air above the compost were monitored with a Draeger gas detector and CH20501 sample tubes. Air pressure in the plenum was monitored with tube manometers (Type M-D Dwyer Instruments Inc.).

Tunnel temperature and aeration regimes

i) *Single tunnel system*

A temperature regime based on a conventional bulk Phase II was used.

(a) 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).

(b) air temperature set at 57°C, with compost temperature maintained at 58-61°C for 6 h (pasteurization).

(c) air temperature reduced to 43-45°C, with compost temperature maintained at 47-49°C allowing ammonia to clear (conditioning).

ii) *Two tunnel system*

Compost (4 t) was filled into a tunnel to a depth of 1.7 m and the end doors were left open. The airflow was set at 9 $m^3$/hour. After six days, the compost was emptied from the tunnel, mixed and re-wetted and then filled back into the tunnel to a height of 1.5 m. The same conventional Phase II bulk tunnel composting regime used for the single tunnel system was then applied.

In both the single and two tunnel systems, 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 common ingredients of the substrates were new season chopped wheat straw, broiler poultry manure and gypsum. An analysis of the organic ingredients is shown in the Appendix.

Bales of straw were chopped in a round-bale chopper (model 6-10, Kidd Farm Machinery Ltd, Devizes, Wilts), wetted and formed into stacks using a compost turning machine. Water was added in four applications to stacks which were turned five times in a four-day period on the compost yard.

Compost ingredient treatments

i. control, chopped straw + poultry manure.
ii. chopped straw, poultry manure + recycled processed compost (15% on a dry matter basis).
iii. control + cellulase enzymes (supplied by Courtaulds Chemicals, Derby), added to the stack ingredients at 10 litres of 10% w/v solution per tonne of compost ingredients.

Water and poultry manure additions to the stacks were adjusted to achieve a compost mixture at the time of filling of the bulk tunnels with target moisture and nitrogen contents of 77-79% and 2.5-2.8% of dry matter respectively. The quantities of materials and water used and maximum stack temperatures are shown in Table 1.

Four replicate runs of the experiment were conducted, with the six treatments (2 tunnel regimes x 3 compost ingredients) allocated to different tunnels for each replicate run. The tunnel and compost ingredient treatments are shown in Figure 1.

Cropping procedure

Following pasteurization and conditioning, the compost was cooled to 26°C and equal quantities were inoculated with mushroom spawn ('spawned') using the Hauser A12 and Le Lion X25 strains at a rate of 0.5% of compost fresh weight. Half of the compost spawned with each strain was supplemented with the soya meal-based 'Betamyl 1000' containing formaldehyde denatured protein, at a rate of 1% of compost fresh weight. Spawned compost (45 kg) was filled into wooden trays (internal dimensions 0.91 x 0.61 x 0.18(deep) m) and hydraulically pressed with a pressure of $1.03 \times 10^7$ Pa. Trays with spawned compost were then stacked in a spawn running room where the compost temperature was maintained at 26°C

± 1°C. About 14 days after spawning, the trays were covered (cased) with a moist mixture of sphagnum peat and sugar beet lime (4:1 v/v) to a depth of 45 mm. Casing spawn of the appropriate strain (Hauser A12 or Le Lion X25) was mixed into the casing at a rate of 4 $kg/m^3$ casing. Cased trays were stacked four high in cropping sheds, with six replicate trays of each spawn strain and supplement subtreatment from each compost treatment arranged in a randomized block design. For each replicate run of the experiment there were 144 trays per shed, with 24 trays from each of the six compost treatments. The compost temperature was maintained at 26°C for a further 6-7 days; fresh air was then introduced into the shed to obtain a $CO_2$ concentration of 0.1% v/v; air temperature and relative humidity were maintained at 17.5°C and 88% respectively. Mushrooms were picked as large buttons (diameter 30-40 mm) over a 30 day period (four flushes), with the first flush of mushrooms being picked *c.* 17 days after casing.

Compost analysis

Composts were analysed for pH and dry matter, total nitrogen, ammonium ($NH^+_4$) and ash contents at the time of filling the bulk tunnels and at the end of the composting period.

A measurement of compressed bulk density was made by determining the weight of compost which filled the 0.91 x 0.61 x 0.18 m cropping trays after a pressure of $1.03 \times 10^7$ Pa had been applied for 5s. A subjective assessment of gaseous pollution resulting from compost odour was made when the stacks were filled into the tunnels, and at the time of emptying and refilling for the two tunnel system composts.

## Results

Composting process

None of the treatments resulted in strong odours associated with conventionally prepared, Phase I composts. The single tunnel system required a higher fan capacity (exceeding 200 $m^3$ air/tonne compost/hour) than the 2-tunnel system, where a fan capacity of 200 $m^3$ air/tonne compost/hour was adequate. For the initial, high temperature stage, a fan capacity of 10 $m^3$ air/tonne compost/hour was used.

Control of the single system was more difficult due to the greater activity of the compost, resulting in the need for frequent changes in the air temperature and air flow set points to maintain the desired compost temperatures. The single tunnel process took an average of 8-9 days for the ammonia to clear from the substrate. In the second phase of the 2-stage process, an average of 5-6 days were required to clear ammonia from the compost (total period of the two stages was 12 days).

Compost analysis

There was some variation in the compost total N content at filling of the tunnels (Table 2). Composts in the first replicate of the experiment generally had a lower total N content than composts in replicates 2, 3 and 4. However, compost ammonium ($NH^+_4$) was lowest in the third replicate. Compost moisture content was lowest in the first replicate and highest in the second.

The addition of recycled compost resulted in a 39% reduction in the water added to the ingredients to achieve a moisture content at filling of 77-80%. The ash and N contents of the compost with recycled material were slightly higher than those of the control and enzyme treatments. The pH values of the different treatments at filling were not significantly different.

At spawning, the total N, ash and moisture contents of the 2-tunnel treatments were generally

higher than those of the single tunnel treatments (Table 3). Ammonium ($NH^+_4$) content and pH were not significantly different. ($NH^+_4$) content was 0.1% or higher in some of the composts although compost pH was generally below 7.3. Total N and ash contents at spawning were slightly higher in the compost with recycled substrate than in the control and enzyme treatments.

The bulk density of the 2-tunnel process compost was significantly greater than that from the single tunnel process and was similar to that obtained from conventional Phase I/II composts. The addition of recycled compost to the ingredients resulted in a slightly higher bulk density than the control or enzyme treatments (Table 3).

Mushroom yield

Mushroom yields from the different treatments are shown in Table 4. In the first replicate of the experiment, compost from the single tunnel control treatment was discarded due to a tunnel fault and subsequent desiccation of the substrate. In replicate 2, the 2-tunnel control treatment resulted in a yield of less than 100 kg mushrooms/tonne compost due to over-wet compost. This result has therefore been disregarded.

In replicates 1, 3 and 4, the 2-tunnel process generally resulted in a higher yield than the single tunnel process. In replicate 2, there was no difference between the two processes. Average yields in 3 flushes from the 2-tunnel process (260 kg/t) were similar to those obtained from Phase I/II composts (Appendix, Table 2). There were no differences in mushroom quality. Overall, there was no difference in yield between the control compost and composts with added enzyme or recycled substrate.

There were no relationships between mushroom yield and any of the compost analysis factors at filling or spawning (N, $NH^+_4$, ash and moisture contents, pH and bulk density).

In replicates 3 and 4, the strain Le Lion X25 yielded higher than the strain Hauser A12. In replicates 1 and 2 there was no significant difference between strains. The supplement Betamyl 1000 resulted in an overall yield increase of 6.7%.

## Conclusion

1. There were no significant odour emissions from either the single tunnel or 2-tunnel composting systems.

2. The 2-tunnel process resulted in a compost with a higher bulk density and mushroom yield potential than the single tunnel process.

3. In 3 out of 4 replicate runs of the experiment, the 2-tunnel process resulted in an average yield of 306 kg/tonne substrate in four flushes, compared with 283 kg/tonne from the single tunnel treatment. In the remaining replicate, an over-wet compost resulted in a reduced mushroom yield.

4. Total processing times for the single tunnel and 2-tunnel systems were 9 and 12 days respectively.

5. The single tunnel process needed a higher fan capacity in the tunnel and required more frequent adjustment of the temperature and air flow set points than the 2-tunnel system.

6. The addition of recycled compost in the initial ingredients reduced the water applications by improving the water absorption of the blended materials. The final bulk density of the compost was slightly improved but the mushroom yield was not significantly different from the control.

7. The addition of a low rate of cellulase enzyme to the compost ingredients did not significantly affect mushroom yield or compost density.

8. Supplementation with Betamyl 1000 increased mushroom yields by an average of 6.7%.

9. Mushroom yield and quality and compost density from the 2-tunnel process were similar to those obtained from conventional Phase I/Phase II composts.

**Figure 1**

**Experimental Treatments**

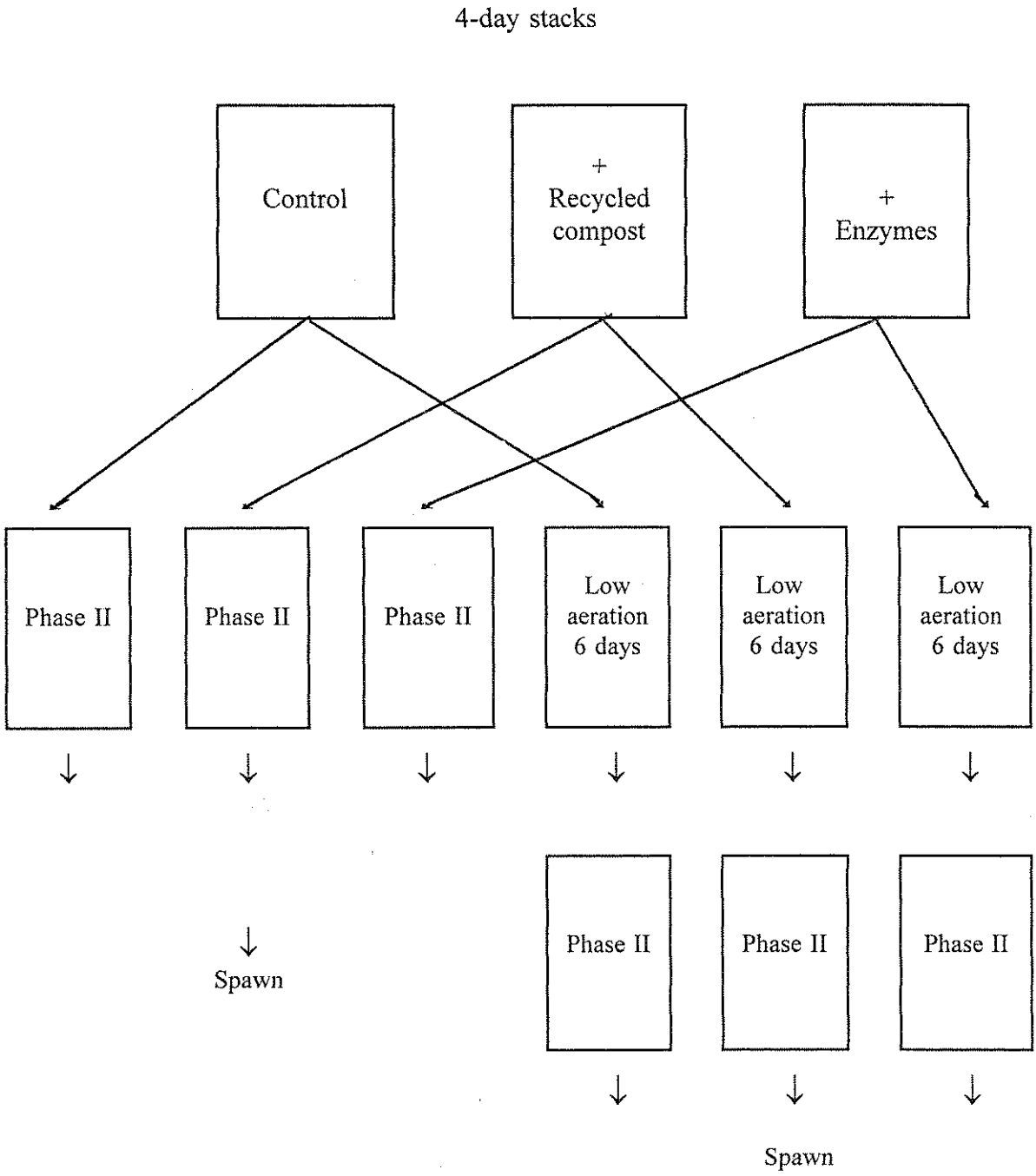

**Table 1 Materials used in preparing composts (kg/tonne fresh compost, excluding water added) and maximum stack temperatures**

| Replicate | Treatment | Straw | Poultry manure | Recycled compost | Water litres/tonne | Max. stack temp. C |
|---|---|---|---|---|---|---|
| 1 | Control | 485 | 485 | 0 | 3372 | 31.5 |
| | +Recycled | 316 | 316 | 348 | 1930 | 34.3 |
| | +Enzyme | 485 | 485 | 0 | 3054 | 38.2 |
| 2 | Control | 510 | 459 | 0 | 5063 | 32.2 |
| | +Recycled | 333 | 296 | 351 | 3056 | 32.9 |
| | +Enzyme | 510 | 459 | 0 | 4980 | 46.0 |
| 3 | Control | 510 | 459 | 0 | 4015 | 34.8 |
| | +Recycled | 333 | 296 | 351 | 2363 | 28.9 |
| | +Enzyme | 510 | 459 | 0 | 3786 | 21.6 |
| 4 | Control | 510 | 459 | 0 | 3400 | 39.9 |
| | +Recycled | 333 | 296 | 351 | 2271 | 36.3 |
| | +Enzyme | 510 | 459 | 0 | 2897 | 37.8 |

* Gypsum was added to all the composts at 30 kg/tonne fresh ingredients

**Table 2 Compost analysis at filling of bulk tunnels**

| Replicate | Treatment | Percentage of dry weight | | | | |
|---|---|---|---|---|---|---|
| | | N | NH4+ | Ash | Moisture, % | pH |
| 1 | Control | 2.01 | 0.57 | 13.2 | 77.2 | 7.8 |
| | +Recycled | 2.55 | 0.80 | 13.5 | 76.1 | 7.7 |
| | +Enzyme | 2.00 | 0.56 | 13.2 | 76.4 | 8.0 |
| 2 | Control | 2.89 | 1.17 | 11.6 | 82.1 | 8.2 |
| | +Recycled | 2.59 | 1.29 | 13.7 | 80.3 | 8.4 |
| | +Enzyme | 2.30 | 0.96 | 10.4 | 81.5 | 7.9 |
| 3 | Control | 2.28 | 0.30 | 11.7 | 79.2 | 7.4 |
| | +Recycled | 2.87 | 0.48 | 16.4 | 79.7 | 7.8 |
| | +Enzyme | 2.40 | 0.31 | 13.0 | 79.4 | 7.6 |
| 4 | Control | 2.77 | 0.81 | 12.2 | 77.5 | 8.1 |
| | +Recycled | 2.84 | 0.83 | 13.5 | 78.7 | 7.9 |
| | +Enzyme | 2.46 | 0.76 | 12.7 | 78.0 | 8.0 |
| Mean | Control | 2.49 | 0.71 | 12.2 | 79.0 | 7.9 |
| | +Recycled | 2.71 | 0.85 | 14.3 | 78.7 | 8.0 |
| | +Enzyme | 2.29 | 0.65 | 12.3 | 78.8 | 7.9 |

**Table 3 Compost analysis at spawning**

| Replicate | Treatment | Percentage of dry weight N | NH4+ | Ash | Moisture, % | pH | Blk density kg/m3 |
|---|---|---|---|---|---|---|---|
| 1 | **1 Tunnel** | | | | | | |
| | Control | 2.58 | 0.15 | 18.9 | 61.1 | 7.1 | 400* |
| | +Recycled | 2.86 | 0.17 | 19.4 | 61.2 | 7.1 | 400 |
| | +Enzyme | 2.29 | 0.13 | 18.9 | 60.9 | 7.1 | 400 |
| | **2 Tunnel** | | | | | | |
| | Control | 2.80 | 0.22 | 19.3 | 67.2 | 7.6 | 500* |
| | +Recycled | 3.55 | 0.14 | 22.4 | 69.3 | 7.4 | 500 |
| | +Enzyme | 3.32 | 0.24 | 24.1 | 74.9 | 7.7 | 500 |
| 2 | **1 Tunnel** | | | | | | |
| | Control | 3.09 | 0.04 | 17.4 | 70.4 | 7.1 | 450 |
| | +Recycled | 2.91 | 0.05 | 17.6 | 74.6 | 7.1 | 550 |
| | +Enzyme | 2.60 | 0.06 | 16.3 | 70.8 | 7.2 | 500 |
| | **2 Tunnel** | | | | | | |
| | Control | 2.74 | 0.05 | 16.1 | 79.8 | 7.1 | 600 |
| | +Recycled | 3.12 | 0.04 | 18.7 | 73.3 | 7.0 | 575 |
| | +Enzyme | 2.70 | 0.04 | 16.5 | 75.3 | 6.8 | 575 |
| 3 | **1 Tunnel** | | | | | | |
| | Control | 2.58 | 0.03 | 17.8 | 70.6 | 7.1 | 400 |
| | +Recycled | 3.21 | 0.10 | 19.8 | 68.9 | 6.9 | 475 |
| | +Enzyme | 2.71 | 0.02 | 17.5 | 68.4 | 6.8 | 425 |
| | **2 Tunnel** | | | | | | |
| | Control | 3.04 | 0.03 | 17.5 | 74.1 | 7.1 | 450 |
| | +Recycled | 3.02 | 0.02 | 18.4 | 74.1 | 7.3 | 550 |
| | +Enzyme | 3.23 | 0.05 | 19.4 | 73.0 | 7.4 | 475 |
| 4 | **1 Tunnel** | | | | | | |
| | Control | 3.15 | 0.04 | 18.8 | 70.2 | 6.9 | 400 |
| | +Recycled | 2.76 | 0.06 | 19.2 | 73.0 | 7.1 | 450 |
| | +Enzyme | 2.36 | 0.17 | 17.2 | 68.5 | 6.8 | 400 |
| | **2 Tunnel** | | | | | | |
| | Control | 3.05 | 0.07 | 17.9 | 74.1 | 6.7 | 575 |
| | +Recycled | 3.18 | 0.09 | 21.9 | 73.1 | 6.8 | 600 |
| | +Enzyme | 3.17 | 0.05 | 20.9 | 70.6 | 6.7 | 575 |
| Mean | **1 Tunnel** | | | | | | |
| | Control | 2.85 | 0.07 | 18.2 | 68.1 | 7.1 | 413 |
| | +Recycled | 2.94 | 0.10 | 19.0 | 69.4 | 7.1 | 469 |
| | +Enzyme | 2.49 | 0.10 | 17.5 | 67.2 | 7.0 | 431 |
| | **2 Tunnel** | | | | | | |
| | Control | 2.91 | 0.09 | 17.7 | 73.8 | 7.1 | 531 |
| | +Recycled | 3.22 | 0.07 | 20.4 | 72.5 | 7.1 | 556 |
| | +Enzyme | 3.11 | 0.10 | 20.2 | 73.5 | 7.2 | 531 |

* Bulk densities in replicate 1 were measured to within 50 kg/m3; in other replicates to within 25 kg/m3. The bulk density of commercial compost ranges between 450 and 550 kg/m3.

**Table 4** **Mushroom yield from 4 flushes, kg/tonne compost at spawning**

| Replicate | Treatment | Control | | +Betamyl | | Mean |
|---|---|---|---|---|---|---|
| | | A12 | X25 | A12 | X25 | |
| 1 | **1 Tunnel** | | | | | |
| | Control | * | * | * | * | * |
| | +Recycled | 272 | 265 | 298 | 263 | **275** |
| | +Enzyme | 300 | 298 | 301 | 316 | **304** |
| | **2 Tunnel** | | | | | |
| | Control | 293 | 303 | 320 | 350 | **317** |
| | +Recycled | 370 | 335 | 382 | 359 | **362** |
| | +Enzyme | 329 | 331 | 346 | 330 | **334** |
| 2 | **1 Tunnel** | | | | | |
| | Control | 188 | 198 | 263 | 231 | **220** |
| | +Recycled | 165 | 165 | 184 | 193 | **177** |
| | +Enzyme | 209 | 199 | 220 | 212 | **210** |
| | **2 Tunnel** | | | | | |
| | Control | * | * | * | * | * |
| | +Recycled | 178 | 175 | 191 | 168 | **179** |
| | +Enzyme | 166 | 184 | 205 | 205 | **190** |
| 3 | **1 Tunnel** | | | | | |
| | Control | 305 | 332 | 301 | 300 | **310** |
| | +Recycled | 258 | 281 | 266 | 295 | **276** |
| | +Enzyme | 288 | 312 | 279 | 302 | **296** |
| | **2 Tunnel** | | | | | |
| | Control | 324 | 357 | 334 | 360 | **344** |
| | +Recycled | 276 | 282 | 302 | 322 | **296** |
| | +Enzyme | 281 | 292 | 285 | 310 | **293** |
| 4 | **1 Tunnel** | | | | | |
| | Control | 253 | 276 | 269 | 296 | **274** |
| | +Recycled | 237 | 240 | 302 | 313 | **273** |
| | +Enzyme | 231 | 245 | 266 | 282 | **256** |
| | **2 Tunnel** | | | | | |
| | Control | 288 | 312 | 290 | 303 | **298** |
| | +Recycled | 245 | 223 | 287 | 296 | **263** |
| | +Enzyme | 310 | 322 | 259 | 326 | **304** |

## APPENDIX

Table A1. Analysis of organic ingredients used in the experimental composts.

| Ingredient | % dry matter | % of dry matter | |
|---|---|---|---|
| | | N | Ash |
| Wheat straw | 86.7 - 91.4 | 0.6 - 0.8 | 5.4 - 6.5 |
| Poultry manure | 68.4 - 86.7 | 4.9 - 5.6 | 13.8 - 15.8 |

Table A2. Mushroom yields (kg/t) from commercial and 'formula 3' composts in three flushes (unsupplemented compost).

| Compost | Strain | Yield (kg/t) |
|---|---|---|
| Commercial Phase II | A12 | 249 |
| Commercial Phase I | A12 | 237 |
| Commercial Phase II | X25 | 260 |
| Formula 3 | A12 | 235 |
| Formula 3 | A12 | 237 |
| Formula 3 | A12 | 202 |
| Formula 3 | A12 | 333 |
| Formula | A12 | 313 |
| Mean | | 258 |