Composting Exhausted Wastes of Mushroom Cultivation: Maturity Parameters and Organic Matter Stabilization

Gennaro Brunetti¹ • Pedro Soler-Rovira²* • Nicola Senesi¹

¹ Dipartimento di Biologia e Chimica Agroforestale ed Ambientale, Università di Bari, via G. Amendola 164/A, Bari, Italy
² Instituto de Ciencias Agrarias, Centro de Ciencias Medioambientales. Consejo Superior de Investigaciones Científicas (CSIC). Serrano 115 depe., 28006 Madrid, Spain

Corresponding author: * pedro.soler@ccma.csic.es

ABSTRACT

The aim of this work was to study the parameters of the composting process of organic wastes originated from mushroom production industry. To accomplish these objectives three piles (P1, P2 and P3) obtained with a spent mushroom substrate (SMS) with different proportions of wheat straw (WS) and urea were composted for 90 days in a static-pile system with continuous monitoring of the process. Samples from each pile were periodically taken to assess physico-chemical properties (pH, E.C., TOC, N, C/N ratio), organic matter and humification parameters. The comparative examination of results obtained for original substrates and final composts showed an increased stabilization and maturity degree of the organic matter, especially for the piles with a higher proportion of straw. All the piles achieved the stabilization and maturity levels required for a safe application of compost as a soil organic amendment.

Keywords: composting process, humification indexes, maturity parameters, spent mushroom substrate, waste management

INTRODUCTION

Spent mushroom substrate (SMS) is a decomposed growing medium that results from mushroom growth in a blend of natural materials, generally represented by agricultural and animal wastes, such as wheat-straw bedded horse manure, broiler chicken manure, cottonseed meal, gypsum and other materials. In the last decade mushroom production increased up to around 60% in the world, and 70% in Italy (FAO 2007). Consequently, an adequate disposal method is needed for the high quantities of SMS generated in this agro-food industrial activity.

Recent proposals for waste policies in the EU (CEC 2005) include the long-term goal to become a recycling society that use wastes as a resources. In this sense, SMS represents a bio-waste that may be recycled as an agronomically efficient organic amendment to restore, maintain, and/or improve the content of organic matter (OM) in soils. Further, the European Thematic Strategy for Soil Protection (CEC 2006) calls for the use of compost as one of the best sources of stable organic matter from which humus can be formed in soils.

However, fresh/immature organic wastes contain some components, such as inorganic solutes, which may inhibit plant growth (Ciavatta et al. 1993), and unstable organic substances that would adversely affect the dynamics of soil organic matter (Senesi 1989). In addition, surface/ground water resources may be threatened by runoff and/or leaching of soluble waste constituents of fresh SMS (Guo et al. 2001). Thus, the composting treatment has become an attractive solution to reduce the possible negative environmental impact and to prevent the threat of “eco-dumping” of bio-wastes (CEC 2005). However, fresh SMS cannot be composted alone due to its inappropriate chemical and physical properties, thus composting mixtures of SMS with a ligno-cellulosic material, such as wheat straw (WS), is expected to be a promising approach.

The EU guidelines will result in the introduction of different kinds of new wastes in the recycling market, thus the companies will face the need of studying the composting treatment of specific substrates and/or mixtures and the agricultural value of the final products (CEC 2005). In order to avoid public awareness and ensure the proper functioning of the recycling market, it will be necessary to introduce common standards on bio-waste treatment and compost quality (CEC 2008).

During composting mineralization and humification processes transform the raw organic matter in the waste into a more stabilized material that contains the so-called “humic-like” substances (HS) that are suggested to represent reliable indicators of stability and maturity during and after the composting process (Senesi et al. 1996; Paré et al. 1998). HS are the most important fraction of soil organic matter that promotes soil fertility and soil protection from degradation (Stevenson 1994). Thus, the quantity of HS-like components and the degree of humification are believed to be of primary importance for the evaluation of the agronomic efficacy, environmental safety and economic value of compost (Senesi et al. 1989).

The objectives of this study were to: a) identify appropriate proportions of SMS and WS for mixture composting; b) to compare changes in temperature, physico-chemical and chemical parameters, occurring during decomposition of organic matter; c) to determine organic matter evolution and humic fraction enrichment in various composts, and d) to evaluate the maturity of the final compost and their quality for their use as soil organic amendment.

MATERIALS AND METHODS

Composting process

The experiment was developed in Rutigliano, Bari province, Italy, in the facilities of Fungo Puglia S.r.l. (Ltd), a company that mainly
produces mushrooms (Agaricus bisporus) grown on various kinds of substrates. The SMS residue obtained at the end of the production had a low C/N ratio (Table 1), thus, before starting the composting process WS was added in an appropriate proportion to increase the C/N ratio up to 25-35. The main physico-chemical properties of the SMS and WS sample used in this study are shown in Table 1.

A static pile composting procedure was used at three different ratios of SMS:WS (w:w) on a dry weight basis: P1 (2:1), P2 (4:1) and P3 (6:1). In the P1 and P2 experiment an adequate amount of urea was added in order to obtain the same initial content of N in the three piles.

After mixing the components in the mentioned proportions, trapezoidal piles (4.5-m long and 2.5-m high) were constructed and water was added to provide the appropriate moisture content (about 65%). The temperature was checked daily in 10 different points of the composting mass, and the piles periodically turned to avoid losses of organic C and maintain an active microbial population. The procedure was considered completed after 3 months (90 days) according to the criteria established by the Italian law (Italy 1997).

At the beginning of the composting process (0 days) and after 1, 3, 9, 15, 30, 45, 60 and 90 days (end of the process), five sub-samples were randomly collected from five sites of each pile along the whole substrate from the top to the bottom avoiding to collect the first 5-8 cm of the surface. Composite samples were then prepared by mixing equal amounts of the five corresponding sub-samples. Analytical results obtained allowed to evaluate the evolution of the composting process and correct any possible deviation observed during the process.

Chemical analyses

The samples were crushed and air-dried, and then ground to 0.5-mm for analysis. Each sample was analysed in triplicate by conventional methods: (a) ash content was measured after heating the samples for 1 night at 550°C; (b) the pH was measured at a sample: water ratio of 1:10; (c) electrical conductivity (EC) was measured on water extracts obtained at a sample: water ratio of 1:10; (d) total organic carbon (TOC) was determined by dichromate oxidation and subsequent titration with ferrous ammonium sulphate; (e) total N content was obtained by the Kjeldahl method; (f) total extractable carbon (TEC), humified carbon (HA + FA) and non-humified carbon (NH) were determined by a procedure based on the extraction of the sample with 0.1 M NaOH and 0.1 M Na_4P_2O_7, acidic precipitation to pH <2; fractionation on solid polyvinylpyrrolidone, dichromate oxidation and subsequent titration with ferrous ammonium sulphate (Ciavatta et al. 1988). The degree of humification (DH) was calculated as DH% = 100 × (HA + FA)/TEC; the humification rate (HR) as HR% = 100 × (HA + FA)/TOC; and the humification index (HI) as HI = NH/(HA + FA) (Sequi et al. 1986; Ciavatta et al. 1988).

Statistics

The statistical analyses were performed using the Statgraphics Plus 5.1. software (Statistical Graphics Corp.). Correlation coefficients (r) were assessed by considering three confidence levels (p ≤ 0.05, p ≤ 0.01, p ≤ 0.001).

RESULTS AND DISCUSSION

Composting can be defined as “the biological oxidative decomposition of organic constituents in wastes of almost any nature under controlled conditions” (Golueke 1972). Composting is, therefore, a form of organic waste stabilisation that requires special conditions, particularly of temperature, moisture, aeration, pH and C/N ratio, related to optimum biological activity in the various stages of the process (Senesi 1989). The recycling guidelines in the EU will result in the introduction of new kind of wastes (i.e. SMS) to the composting industries (CEC 2008), so the study of composting conditions and the evaluation of the composition and quality of the final products obtained are required.

Chemical parameters

Fig. 1 shows the evolution of the process parameters in the three SMS-WS piles (P1, P2 and P3) monitored at 0, 1, 3, 9, 15, 30, 45, 60 and 90 days of the composting period.

After one day, the temperature rapidly increased in the

### Table 1 Chemical parameters (dry matter basis) of spent mushroom substrate and wheat straw

<table>
<thead>
<tr>
<th></th>
<th>Spent mushroom substrate</th>
<th>Wheat straw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>52.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>51.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Volatile solids (%)</td>
<td>49.0</td>
<td>90.4</td>
</tr>
<tr>
<td>pH</td>
<td>7.2</td>
<td>6.8</td>
</tr>
<tr>
<td>EC (dS m⁻¹)</td>
<td>4.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Total organic carbon (%)</td>
<td>27.4</td>
<td>52.6</td>
</tr>
<tr>
<td>Total nitrogen (%)</td>
<td>1.3</td>
<td>0.44</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>21.0</td>
<td>119.5</td>
</tr>
</tbody>
</table>
three piles, with values of 70°C in P1 and P2, and 62°C in the P3 (Fig. 1). The higher temperature observed in P1 and P2 piles may be attributable to a great quantity of readily degradable compounds (Senesi 1989) originated from the ligno-cellulosic composition of the WS. This thermophilic phase, characterised by high temperatures, lasted for more than 20 days. Fig. 1 shows that in the interval between 1-30 days the temperature values oscillated from 70 to over 50°C in P1 and P2 piles, and from 62 to 48°C in the P3 pile. After the thermophilic phase, the temperature was maintained around 35-45°C for 30 days and then started to diminish during the cooling and maturation period. At the end of the composting process the temperature was stabilised at values similar to the surrounding ambient.

At the beginning of the process the moisture in the three piles was around 65% (Fig. 1), which is considered as an optimal value to start the composting process (Dechane and Keener 1996; Tiquia et al. 1998) since under 40% the microbial activity decrease and can be stopped when moisture content is below of 20%. On the other hand, above 65% of moisture content the water occupies the majority of the interstitial space, displacing the molecular oxygen diffusion and thus creating possible episodes of anaerobic or putrefactive fermentations. During composting no differences were found between the moisture values in three piles; from the second week until the end of the process the moisture was around the 40% (Fig. 1). The lowest value corresponded to the P1 pile, where the moisture content was 38.1% after the 90 days.

In agreement with the general trend ascertained, also in the present study, from initial values around neutrality (7.1), the pH rapidly reached slightly alkaline values during the first 15 days. At this phase the pH was higher in P1 (7.7) and P2 (7.6) (Fig. 1). Between the 15-30 days of composting the pH was quite stable and then tended to decrease to reach a value close to neutrality. Thus the pH was always over 7 and in range from 6.0 to 8.5 throughout the process as established by the Italian law for composting materials.

At the beginning of the experiment, the differences of TOC between the P1 and P2 mixtures (38.7 and 34.9%, respectively) and the P3 (33.0%), can be attributable to a lower proportion of WS in the latter (Fig. 2). During the first days of composting, the rapid decrease of the TOC in the P1 and P2 piles (Fig. 2) suggest the occurrence of extended mineralization processes due to the presence of WS as easily decomposable carbon source. After this initial period, the TOC content tended to diminish more gradually and to increase slightly at the end of the process in the P1 and P2 mixtures.

Fig. 2 shows that until 30 days of composting the content of total N decreased in the three piles, especially in P1 and P2. This behaviour may be explained by: (a) the occurrence of less-decomposable N due to a higher proportion of exhausted SMS in the P3 pile; and (b) the presence of higher quantity of easily degradable N in P1 and P2 mixtures due to urea addition. At the end of the process, the content of total N increased in the three piles, probably due to the concentration effect due to the volume reduction of the composting mass.

The evolution of the N content was the opposite of pH value, thus the increase of pH with composting time may be feasibly ascribed to mineralisation of N compounds to alkaline ammonia (Bishop and Godfrey 1983; Plaza et al. 2005). In fact, the significant negative correlation (r = -0.721, p ≤ 0.001) between the evolution of pH and total N in the three piles, would confirm alkalization due to organic N mineralisation to N-NH4+ followed by N losses through ammonia volatilisation.

The materials and proportions to prepare the mixtures were selected to have an initial C/N ratio of around 30 in the composting piles. This parameter diminished gradually during the composting time but with different intensity in the three mixtures (Fig. 2); in the case of the P3 pile, its different behaviour may be attributable to the lower decrease of TOC during the process. The rapidly decrease of the C/N ratio in P1 and P2 piles was followed by a gradual decrease until the 45th day to 19.4, 17.7 and 20.4 in the P1, P2 and P3, respectively.

Although the decrease of C/N ratio may be mainly attributable to mineralization processes of organic C compounds (Bernal et al. 1996; Paredes et al. 2002), the increase of N content from the N-fixing bacteria could also contribute to this effect during the mesophilic phase of composting (De Bertoldi et al. 1982; Charest and Beauchamp 2002). The C/N ratios after 90 days of composting pointed out a high stabilization and maturity degree in the organic matter in the end-products (Zucconi and De Bertoldi 1987; Senesi 1989), especially in mixture P2.

The contents of heavy metals in the initial mixtures and in the end-products are shown in Table 2. The increase with the composting time may be attributable to a concentration effect possibly due to the loss of weight in all the composting piles. This effect can be more easily observed in the P1 and P2 piles where higher bio-oxidative activity and a more intense mineralization were found, as explained previously. However, as Table 2 shows, the final contents of all the studied metals were below the maximum values for compost in
Europe (ORBIT/ECN 2008) and the limits allowed by the national law (Italy 2006) for the use of compost as soil amendment.

**Humification parameters**

The evolution of the humification parameters in the three mixtures was studied in samples collected after 1, 20, 60 and 90 days of composting (Figs. 3, 4). After 90 days of composting, the total extractable carbon (TEC) contents were 21.5% (P3), 18.3% (P2) and 15.7% (P3) (Fig. 3). The TEC content decreased slightly with the time of composting in all the mixtures, about 10-20% in the P1 and P2, and only by 3% in the P3, with respect to the initial contents. On the contrary, a higher (HA + FA) C content was observed in the three mixtures at the end of the composting time (Fig. 3). Although the content was similar (1671%) in the three mixtures, the increase of the (HA + FA) C with respect to the initial contents was different: 51, 30 and 15% in the P1, P2 and P3 piles, respectively. Meanwhile, the non-humified C fraction (NH) decreased markedly during the process (Fig. 3) and, with respect to the initial contents, it was reduced by the 81, 55 and 26% in the P1, P2 and P3 piles, respectively. These results suggested that co-composting of SMS with WS increased the relative contents of HS in the final products (Senesi 1989), especially in the P1 mixture.

According to the differences in the TEC and (HA + FA) C fractions contents, a different evolution of the DH and HR values can be observed (Fig. 4). In the three mixtures both values increased with the time of composting. In particular, after 90 days the DH values are in the order P1 > P2 > P3, while the HR values are P2 > P1 > P3. These differences are ascribed to the different proportion of (HA + FA) C with respect to the TEC and TOC contents in the mixtures. At the beginning of the process, the three mixtures showed a similar HI (1671), with a lower value in the P3 because of a higher content of SMS in the mixture. The decrease of the HI values with the time of composting (Fig. 4), more noticeably in the P1 and P2 piles, can be attributed to a more marked decrease of the non-humified (NH) fraction and greater increase of the humified fractions, i.e. the (HA + FA) C. These results show that the DH and HR values increased with the time of composting, while the HI values decreased. These results suggested that this type of treatment led to a stabilization of fresh organic matter in the waste and resulted in final products with a high agronomic quality (Sequi et al. 1986).

The results obtained in this work indicated that co-composting of SMS and WS under the conditions used can be an attractive solution for the disposal of these agro-industrial wastes according to the EU recycling guidelines. The maturity and degree of stabilization achieved by organic matter and the levels of heavy metals in the final product are the best indicators for a safe recycling of these composts as organic amendments of soils.

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**Table 2** Heavy metal contents in the three piles (P1, P2, P3) at the initial (i) and final (f) stages of the composting process, and limit values for compost (mg kg⁻¹, dry matter basis)

<table>
<thead>
<tr>
<th></th>
<th>Cd</th>
<th>CrVI a</th>
<th>Hg</th>
<th>Ni</th>
<th>Pb</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 i</td>
<td>0.28</td>
<td>&lt; 0.5</td>
<td>0.01</td>
<td>8.42</td>
<td>9.71</td>
<td>22</td>
<td>58</td>
</tr>
<tr>
<td>P1 f</td>
<td>0.36</td>
<td>&lt; 0.5</td>
<td>0.07</td>
<td>23.80</td>
<td>20.40</td>
<td>44</td>
<td>102</td>
</tr>
<tr>
<td>P2 i</td>
<td>0.37</td>
<td>&lt; 0.5</td>
<td>0.02</td>
<td>10.47</td>
<td>11.52</td>
<td>28</td>
<td>72</td>
</tr>
<tr>
<td>P2 f</td>
<td>0.45</td>
<td>&lt; 0.5</td>
<td>0.09</td>
<td>31.15</td>
<td>23.41</td>
<td>52</td>
<td>121</td>
</tr>
<tr>
<td>P3 i</td>
<td>0.40</td>
<td>&lt; 0.5</td>
<td>0.04</td>
<td>11.73</td>
<td>13.95</td>
<td>31</td>
<td>88</td>
</tr>
<tr>
<td>P3 f</td>
<td>0.47</td>
<td>&lt; 0.5</td>
<td>0.12</td>
<td>24.27</td>
<td>24.50</td>
<td>51</td>
<td>122</td>
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<tr>
<td>Europe</td>
<td>1.4</td>
<td>0.9</td>
<td>1.0</td>
<td>47</td>
<td>121</td>
<td>143</td>
<td>416</td>
</tr>
<tr>
<td>Italy</td>
<td>1.5</td>
<td>0.5</td>
<td>1.5</td>
<td>100</td>
<td>140</td>
<td>230</td>
<td>500</td>
</tr>
</tbody>
</table>

a Hexavalent chromium
b Mean limit values for compost from source separation (ORBIT/ECN 2008)
c Maximum values for trade and use of compost in agriculture (Italy 2006)
Fig. 4 Evolution of the degree of humification (DH), humification rate (HR) and humification index (HI) during the composting process in the piles (P1, P2, P3).

REFERENCES


Charest MH, Beauchamp CJ (2002) Composting of de-inking paper sludge with poultry manure at three nitrogen levels using mechanical turning: behaviour of physico-chemical parameters. *Bioresource Technology* 81, 7-17


ORBIT/ECN (2008) Compost production and use in the EU, Final report of ORBIT e V. European Compost Network ECN to European Commission, Joint Research Centre


