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

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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 stability and maturation 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

Abbreviations: C, carbon; **DH**, degree of humification; **EC**, electrical conductivity; **EU**, European Union; **FA**, fulvic acid; **HA**, humic acid; **HI**, humification index; **HR**, humification rate; **N**, nitrogen; **NH**, non-humified carbon; **SMS**, spent mushroom substrate; **TEC**, total extractable carbon; **TOC**, total organic carbon; **WS**, wheat straw

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

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

	Spent mushroom substrate	Wheat straw
Moisture (%)	52.1	5.6
Ash (%)	51.0	9.5
Volatile solids (%)	49.0	90.4
pH	7.2	6.8
EC (dS m^{-1})	4.8	1.4
Total organic carbon (%)	27.4	52.6
Total nitrogen (%)	1.3	0.44
C/N ratio	21.0	119.5

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 subsamples 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 subsamples. 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 ($p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$).

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 stabilization 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) monitorised at 0, 1, 3, 9, 15, 30, 45, 60 and 90 days of the composting period.

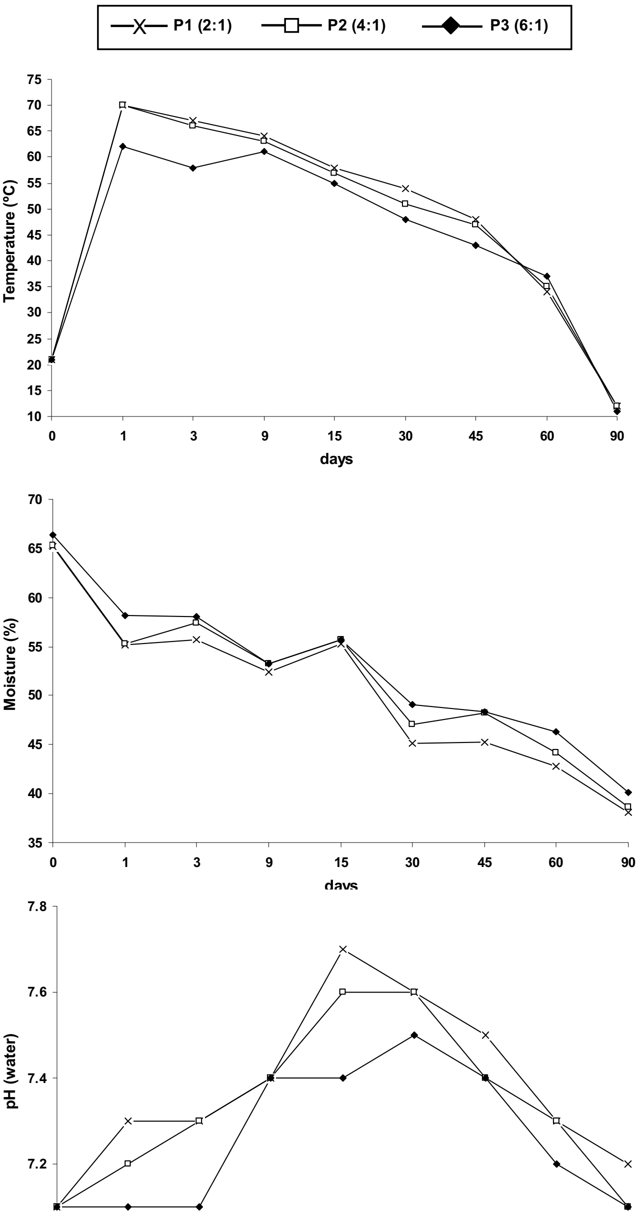

Fig. 1 Evolution of temperature, moisture and pH during the composting process in the three piles (P1, P2, P3) with different SMS:WS proportions.

After one day, the temperature rapidly increased in the 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 the 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 (Das 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 stabile 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, $p \leq 0.001$) between the evolution of pH and total N in the three piles, would confirm alkalinization due to organic N mineralisation to $N\text{-}NH_4^+$ 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.

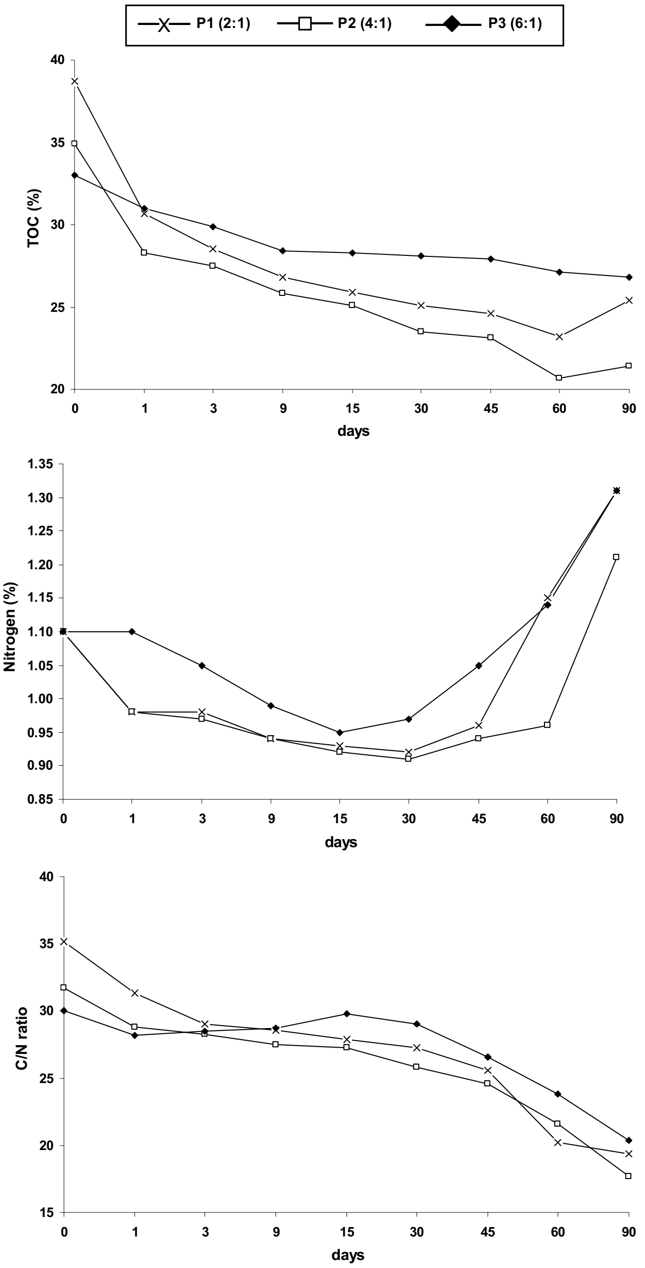

Fig. 2 Evolution of organic carbon (TOC), nitrogen and C/N ratio during the composting process in three piles (P1, P2, P3) with different SMS:WS proportions.

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

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)

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

[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)

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 (≈14%) 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 (≈1), 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.

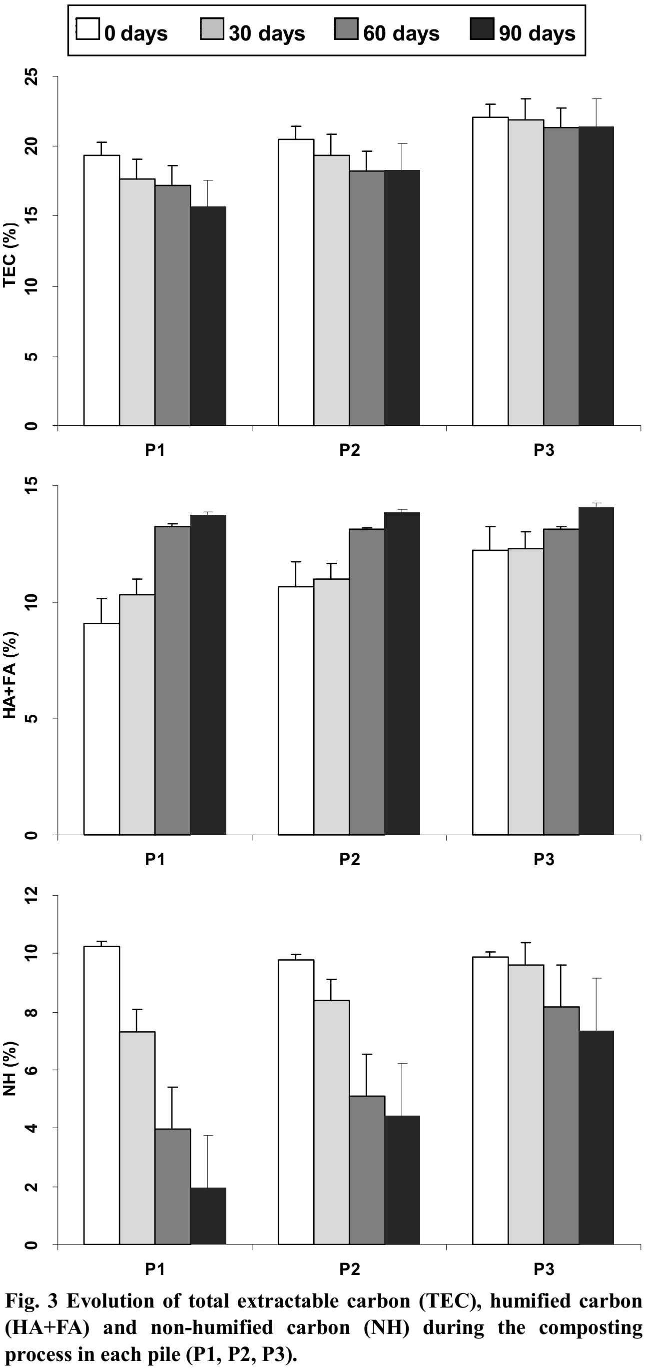

Fig. 3 Evolution of total extractable carbon (TEC), humified carbon (HA+FA) and non-humified carbon (NH) during the composting process in each pile (P1, P2, P3).

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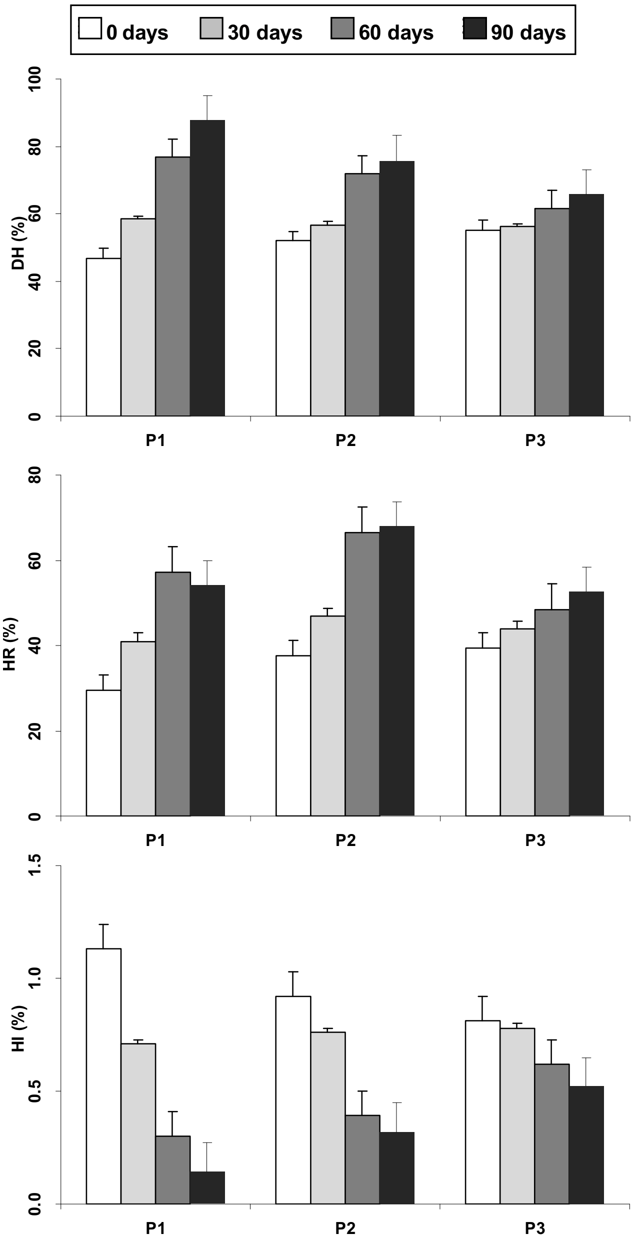

Fig. 4 Evolution of the degree of humification (DH), humification rate (HR) and humification index (HI) during the composting process in the piles (P1, P2, P3).

REFERENCES

Bernal MP, Navarro AF, Roig A, Cegarra J, Garcia D (1996) Carbon and nitrogen transformation during composting of sweet sorghum bagasse. *Biology and Fertility of Soils* **22**, 141-148

Bishop PL, Godfrey C (1983) Nitrogen variations during sludge composting. *BioCycle* **24**, 34-39

CEC (2005) Commission of the European Communities. Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste. COM(2005) 666 final, Brussels, 32 pp

CEC (2006) Commission of the European Communities. Thematic Strategy for Soil Protection. COM(2006) 231 final, Brussels, 12 pp

CEC (2008) Commission of the European Communities. Green Paper on the management of bio-waste in the European Union. COM(2008) 811 final, Brussels, 18 pp

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

Ciavatta C, Vittori Antisari L, Sequi P (1988) A first approach to the characterization of the presence of humified materials in organic fertilizers. *Agrochimica* **32**, 510-517

Ciavatta C, Govi M, Sequi P (1993) Characterization of organic mater in compost produced with municipal solid wastes: an Italian approach. *Compost Science and Utilization* **1**, 75-81

Das K, Keener HM (1996) Process control based on dynamic properties in composting: moisture and compaction considerations. In: De Bertoldi M (Ed) *The Science of Composting*, Part 2. Springer, pp 116-125

De Bertoldi M, Citernesi U, Griselli M (1982) Microbial population in compost process. In: The Staff of BioCycle (Ed) *Composting: Theory and Practice for City, Industry and Farm*, The J.G. Press, Pennsylvania, pp 26-32

FAO (2007) Food and Agriculture Organization of the United Nations. Available online: http://faostat.fao.org

Golueke CG (1972) *Composting: A Study of the Process and its Principles*, Rodale Press Inc., Emmaus, USA, 110 pp

Guo M, Chorover J, Rosario R, Fox RH (2001) Leachate chemistry of field-weathered spent mushroom substrate. *Journal of Environmental Quality* **30**, 1699-1709

Italy (1997) Decreto Legislativo 5 febbraio 1997 n. 22. Attuazione delle direttive 91/156/CEE sui rifiuti, 91/689/CEE sui rifiuti pericolosi e 94/62/CE sugli imballaggi e sui rifiuti di imballaggio. Gazzetta Ufficiale della Repubblica Italiana n. 38 del 15/02/1997

Italy (2006) Decreto Legislativo 29 aprile 2006 n. 217 - Revisione della disciplina in materia di fertilizzanti. Supplemento Ordinario alla Gazzetta Ufficiale. Serie Generale n. 141 del 20 giugno 2006

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

Paré T, Dinel H, Schnitzer M, Dumontet S (1998) Transformations of carbon and nitrogen during composting of animal manure and shredded paper. *Biology and Fertility of Soils* **26**, 173-178

Paredes C, Bernal MP, Cegarra J, Roig A (2002) Bio-degradation of olive mill wastewater sludge by its co-composting with agricultural wastes. *Bioresource Technology* **85**, 1-8

Plaza C, Senesi N, Brunetti G, Mondelli D (2005) Co-composting of sludge from olive oil mill wastewater mixed with tree cuttings. *Compost Science and Utilization* **13**, 217-226

Senesi N (1989) Composted materials as organic fertilizers. *The Science of the Total Environment* **81/82**, 521-542

Senesi N, Miano TM, Brunetti G (1996) Humic-like substances in organic amendments and effects on native soil humic substances. In: Piccolo A (Ed) *Humic Substances in Terrestrial Ecosystems*, Elsevier, New York, pp 531-593

Sequi P, De Nobili M, Leita L, Cercignani G (1986) A new index of humification. *Agrochimica* **30**, 175-179

Stevenson FJ (1994) *Humus Chemistry: Genesis, Composition, Reactions* (2nd Edn), Wiley-Interscience, New York, 496 pp

Tiquia SM, Tam NFY, Hodgkiss IJ (1998) Changes in chemical properties during composting of spent pig litter at different moisture contents. *Agriculture, Ecosystems and Environment* **67 (1)**, 79-89

Zucconi F, De Bertoldi M (1987) Compost specifications for the production and characterization of compost from municipal solid waste. In: De Bertoldi M, Ferranti P, L'Hermite P, Zucconi F (Eds) *Compost: Production, Quality and Use*, Elsevier, London, pp 20-29