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Composting winery waste: sludges and grape stalks ☆

E. Bertran [a,b,*], X. Sort [a], M. Soliva [c], I. Trillas [b]

[a] Miguel Torres S.A., C/Comerç, no. 22, 08720 Vilafranca del Penedès, Barcelona, Spain
[b] Unitat de Fisiologia Vegetal, Departament de Biologia Vegetal, Facultat de Biologia, Universitat de Barcelona, Avda. Diagonal, no. 645, 08028 Barcelona, Spain
[c] Escola Universitària d'Enginyeria Tècnica Agrícola, C/Urgell, no. 187, 08036 Barcelona, Spain

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Abstract

The composting of winery waste is an alternative to the traditional disposal of residues, and also involves a commitment to reducing the production of waste products. We studied two residues (sludge and grape stalks), mixed in two proportions (1:1 and 1:2 sludge and grape stalks (v/v)), and we also examined the effects of grinding the grape stalks. Our results showed that composting the assayed materials was possible. Best results were obtained in the compost heap in which the residues were mixed in the proportion 1:2, and where the grape stalks had been previously ground. Optimum results required a moisture around 55% and a maximum temperature around 65 °C and an oxygen concentration not lower than 5–10%. The resulting compost had a high agronomic value and is particularly suitable for the soils of the vineyards which have a very low organic matter content. The compost can be reintroduced into the production system, thereby closing the residual material cycle.

Keywords: Composting; Grape stalk; Organic wastes; Sludge; Vineyard

1. Introduction

Composting is defined as the aerobic biological decomposition and stabilization of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to obtain a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land (Golueke, 1982; Haug, 1993). The turned pile system requires periodic turning of these organic materials to increases the oxygen supply to microorganisms and to homogenizes the materials and reduces particle size, at the same time as it redistributes microorganisms, moisture and nutrients. Since microbial activity generates heat and evaporates water, optimal moisture levels need to be established for different composting materials. Optimal moisture levels are usually between 40% and 60% (Poincelot, 1975; Tiquia et al., 1996). Temperature should also be regulated to ensure both the proper oxidation of organic matter into CO_2 and H_2O, and hygienization (Grundy et al., 1998; Hoitink and Keener, 1993). Once the more easily degradable materials have decomposed, the compost temperature falls to that of the environment temperature and the process is stabilized (Nogueira et al., 1999). The pH has a marked effect on the microbial population. In the early stages of composting pH is slightly acidic because of the production of organic acids, but later the pH increases because of protein decomposition that liberates ammonium. The end product has a neutral-alkaline pH (Soliva, 2001). An optimum carbon-to-nitrogen (C:N) ratio should be maintained as microorganisms require C for growth and N for protein synthesis. Low ratios cause the loss of N as ammonia and give rise to odor problems, whereas higher ratios lengthen the composting process (Fraser and Lau, 2000).

Wineries produce a number of biological wastes including: grape stalks and sludge from organic wastewater treatment plants (Diaz et al., 2002; Ranalli et al., 2001; Trillas et al., 2002). The composting of these residues allows them to be reapplied to the soil (Ferrer et al., 2001). The use of compost in vineyards is of

☆ This research was conducted within the Facultat de Biologia, Universitat de Barcelona, and Miguel Torres S.A.

* Corresponding author. Tel.: +34-93-402-1463; fax: +34-93-411-2842.
E-mail address: ebertran@bio.ub.es (E. Bertran).

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growing interest due to the general poverty of soils, typified by low levels of humus and their exposure to erosion (Balanyà et al., 1994; De Bertoldi et al., 1986). The application of compost increases the percentages of organic matter, nutrient levels (providing a slow fertilization action over a long period of time), microbial biomass and improves the soils' physical properties (aeration, water holding capacity, etc.) (Ribereau-Gayon and Peybaud, 1982). The low extractions of nitrogen on the vineyard (30–50 kg N/Ha) and the great sensitivity of the young vineyard to excess nitrogen determine the characteristics of the organic matter that is needed (Delas, 2000; Vez, 1993), that is it should be mature, correctly stabilized and with an available N fraction in the medium and long term. With these characteristics it is possible to apply relatively high doses of compost (30–50 t/Ha) as a physical amendment to aid soil structuring before planting. Later, according to soil and leaf analysis results, low or moderate applications of compost can be made. Greater applications however can be made to poor soils located on slopes, or soils exposed to high risks of erosion. Vineyards occupying such sites should consider a superficial compost application as a mulch protector of the soil surface.

The objective of this study was to develop the simplest and least expensive composting program using winery sludge and grape stalks so as to obtain a high quality compost for application in the vineyard.

2. Methods

2.1. Vineyard waste products

Grape stalks, that is the grape skeleton, were obtained from grape stripping operations. This waste product has a high degree of fibers (lignin and cellulose) and a high percentage of nutritive mineral elements, especially nitrogen and potassium. In the Mediterranean areas, stalks are obtained from the end of August to mid-October. The stalks were separated from the fruit by being fed into a de-stemmer and they were then used in the composting process (Diaz et al., 2002; Mustin, 1987). A part of this waste was ground using a Gandini Chipper 05TPS. The sludge was supplied from the wastewater treatment plant, the semi-solid material consisting of the residue from the biological reactor, obtained when troughs, filters and pipes in wineries are cleaned. The sludge used for composting was digested aerobically and centrifuged. Sludge is produced all year round, albeit in greater quantities during the vintage. The characteristics of the materials used in the composting process are shown in detail in Table 1 and the metal composition of the sludge is shown in Table 2. All values were below the limits established by European Guidelines (Working document on sludge, 2000). The sludge used in the first experiment described below had lower levels of volatile solids and nitrogen, but higher levels of Ca and Cu than that used in the second experiment as it had been allowed to accumulate over a longer period of time and was hence, more stable.

2.2. Composting design

The project was carried out on an uncovered plot exposed to the elements. The compost piles were built following the same protocol and comprised a layer of stalks followed by a layer of sludge, and according to the design of the experiment. The piles were: 2.5 m diameter × 1.5 m height (De Bertoldi et al., 1986; Haug, 1993; Hoitink and Keener, 1993). The piles were prepared by mixing the two components with mechanical mixing equipment. Turning was also performed using the same equipment in order to promote aeration. Prior studies suggested that the most appropriate piles proportion was 1:1 and 1:2 for the best integration of materials and C:N ratio.

Table 1
Chemical characteristics of waste materials

Materials	% Moisture	pH 1:5	EC μS/cm 1:5	% N Kjeldahl	% VS	C:N	% P	% K
Sludge—experiment 1	81.6	8.3	2060	3.4	45.4	5.4	1.0	0.6
Sludge—experiment 2	86.7	8.3	1031	5.8	68.0	5.2	1.0	0.7
Grape stalk	20–70[a]	9.58	1365	1.1	87.3	38.6	0.1	4.2

All results except moisture, pH and EC are expressed as % DW (dry weight).
[a] Around 20% for plant material used in experiment 1 and 70% for material used in experiment 2.

Table 2
Metal composition of sludge

Material	Ca	Mg	Fe	Cr	Ni	Pb	Cu	Zn	Hg	Cd
Experiment 1	9.7	0.4	0.9	41	24	48	1342	321	0.0	<1.5
Experiment 2	2.5	0.4	0.5	60	41	39	783	724	1.1	<1.5

Ca, Mg and Fe % DW (dry weight).
Cr, Ni, Pb, Cu, Zn, Hg, Cd mg/kg DW (dry weight).

The initial experiment was performed for 115 days during spring–summer, with waste taken from the last vintage. Grape stalk moisture was 20% (Table 1). Pile one was built in the proportion 1:1 (sludge:stalk, v/v), where the high doses of sludge were used to integrate the materials that had not been previously ground. The second pile was built using ground grape stalks in the proportion 1:2 (sludge:stalk, v/v), thereby eliminating greater quantities of stalk wastes.

To optimize water and oxygen levels and to evaluate the effects of using fresh, dry plant wastes, a second set of experiments was conducted over an 80-day period during fall–winter. Grape stalk moisture was increased to 70% (Table 1). Thus, the third pile was built in the proportion 1:1 (sludge:stalk, v/v), as was the fourth but the grape stalks were previously ground (to evaluate the grinding effect), while the fifth pile was built in the proportion 1:2, again using ground stalk.

2.3. Analytical tests

A number of analytical tests were run on the materials both during the composting process and at the end. Temperature and oxygen were measured at two different depths: 30 and 70 cm and moisture at 50 cm. Also measured was: pH, electrical conductivity (EC), volatile solids (VS, %), nitrogen (N, %), ratio carbon/nitrogen (C:N) and germination and self-heating tests were conducted (Brinton et al., 2001; Jorba and Trillas, 1983; Ministerio de Agricultura, Pesca y Alimentación, 1993; Soliva, 2001). The temperature was measured using a portable thermometer with a probe 8×1000 mm. The oxygen was measured with a portable oximeter connected to a 1.5 m probe. The moisture was calculated by sample weight loss at 105 °C for a period of 24 h. The pH and the EC were measured from an aqueous extract (1/5 w/v). VS was calculated by sample weight loss at 560 °C for 3–4 h. The organic nitrogen was evaluated using the Kjeldahl method from 0.3 to 0.5 g from a ground dry sample. The C:N ratio was calculated from VS values and Kjeldahl nitrogen values (Soliva, 2001). The germination test was performed using the germination index (48 h at 25 °C in the dark) of 25 seeds of *Lepidium sativum*, in a 9 mm Petri dish with 4 ml of compost extract (1/5 wt) (De Bertoldi et al., 1986; Jorba and Trillas, 1983). The self-heating test was conducted using a Dewar vessel and 500 g of wet sample. The difference between the maximum temperature attained and environment temperature was correlated with the level of maturity (Brinton et al., 2001).

3. Results and discussion

In pile 1 (Fig. 1) a slow increase in temperature was recorded. The first maximum was measured after 21 days, while the maximum value (74 °C) was recorded on day 54, following turning and watering. Moisture was recorded initially at 80% and remained at around 55% with watering. After 80 days, the temperature fell to that of the environment. In pile 2 (Fig. 2) a rapid increase in temperature was recorded so that on day 6 a figure of 60 °C was reached. The temperature fluctuated at and around 60 °C until day 80, at which point the temperature stabilized gets lower values. Moisture was initially around 50% and remained between 50% and 60% with watering throughout composting. On day 26 marked drops in temperature (17 °C) and moisture (40%) were recorded. Turning on its own was insufficient to raise the temperature, which only increased following watering. This indicates that for the assayed materials and in these composting conditions, moisture levels must not fall

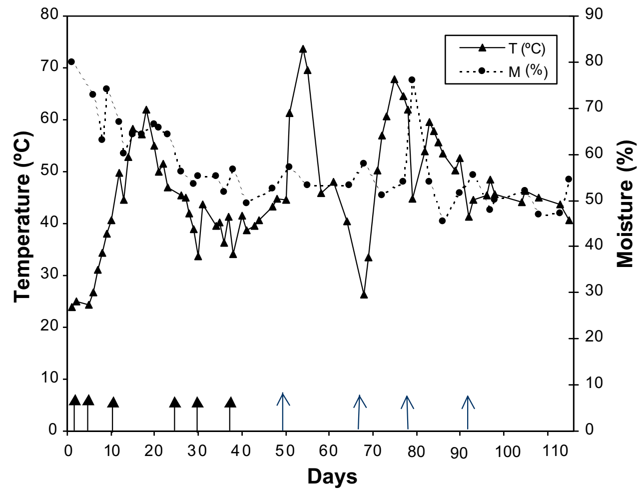

Fig. 1. Pile 1—changes in temperature (average of readings taken at depths of 30 and 70 cm) and moisture (measured at a depth of 50 cm). Full arrows indicate turnings and empty arrows indicate watering.

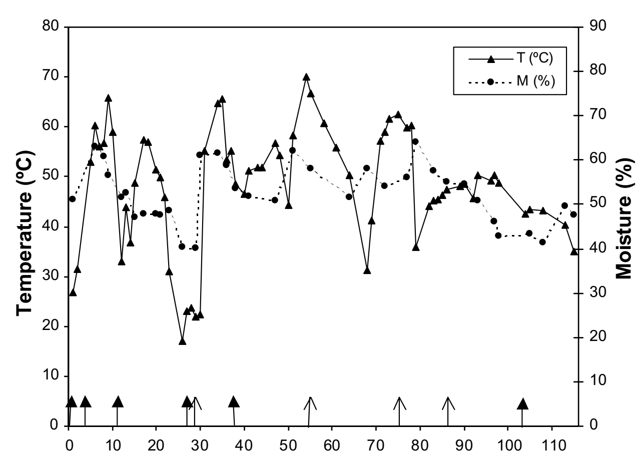

Fig. 2. Pile 2—changes in temperature (average of readings taken at depths of 30 and 70 cm) and moisture (measured at a depth of 50 cm). Full arrows indicate turnings and empty arrows indicate watering.

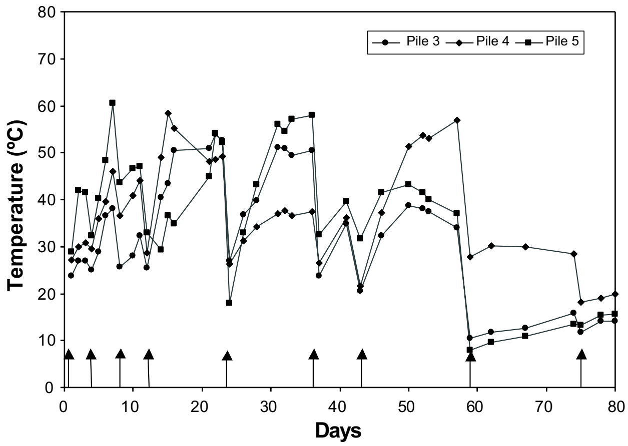

Fig. 3. Experiment 2—changes in temperature (average of readings taken at depths of 30 and 70 cm). Full arrows indicate turnings.

below 55% otherwise adequate microbial activity and the consequent high rate of degradation cannot be maintained.

In the second set of experiments (Fig. 3), the temperature of pile 3 recorded three maxima: 54 °C on day 22, 51 °C on day 31 through to day 36 and 39 °C on day 50. Following turning on day 58, the temperature fell and stabilized at the environment temperature. Pile 4 reached 46 °C in seven days, the maximum (59 °C) was recorded on day 15, while between days 24 and 38 the temperature fluctuated around 35 °C because of low values of moisture and oxygen concentration. From day 50 to day 57, the temperature increased and fluctuated around 55 °C and after day 58, following the turning of the pile, the temperature stabilized. In pile 5 the temperature rose rapidly in just seven days to values above 60 °C and two more maxima were recorded around 60 °C later on in the process. Between days 46 and 57 the temperature fluctuated around 40 °C, and then temperature stabilized. Watering was unnecessary throughout the experiment as the stalks were still wet. Moreover, the winter weather conditions ensured that the moisture of the three piles was kept above 55% (data not shown). This rainfall, together with the lack of turning, meant that the oxygen levels fell (until day 31) reaching a minimum value of 5%. This condition was particularly significant in the cases of piles 3 and 4, but after turning on day 37, the oxygen levels rose to around 18% in all three piles (data not shown). The decrease in oxygen concentration caused the micro-organisms to reduce their activity as reflected in a stabilization temperature between 30 and 40 °C (Fig. 3) (Hoitink and Keener, 1993; Poincelot, 1975).

The slower increases in temperature in piles 1 and 3 compared to those in piles 2, 4 and 5 could be attributed to the fact that the grape stalks had not been ground meaning that the materials were only integrated after several turnings. The piles with the higher ratio of grape stalk (2 and 5) recorded the highest temperatures and provided the best hygienization of materials (Golueke, 1982). A seasonal effect was noted on the composting process, so that higher temperatures were obtained in the thermophilic and stabilization stages of composting in piles 1 and 2 that were built during spring–summer and whose grape stalks at the beginning of the process were drier (20% moisture) (Tiquia et al., 2000).

In both experiments, the pH values tended to diminish to a neutral pH during composting. The initial pH value was higher for piles mixed in the proportion 1:2 due to the higher stalk ratio (Table 1), while after composting these piles recorded higher EC values due to the mineralisation of the materials. The generally lower EC values recorded in composts obtained in experiment 2 can be attributed to the washing effect of rainfall and also to the lower initial EC value of the sludge (Table 1). The importance of grinding was also evident in the conservation of organic nitrogen. Thus, piles with ground stalks tended to minimize any losses of N (Table 3). The percentage of volatile solids fell during composting because of mineralisation. The C:N ratio tended to fall during the process, though in pile 1 the C:N ratio increased because of the greater N losses (Table 3). The high percentage of germination (Table 3) in all piles showed that the composts were not phytotoxic (Jorba and Trillas, 1983; Ranalli et al., 2001). These values (above 70%) were also confirmed by the V degree obtained on the self-heating test (I = raw material, II = not mature active compost, IV = moderately stable, and V = stable compost) (Brinton et al., 2001). In the second experiment, by controlling the levels of moisture and temperature, and by turning more frequently in the first few days, it was possible to accelerate the composting process with respect to the first experiment. Thus in three months it was possible to obtain an adequate compost for application to the soil (Table 3) that adhered to European Guidelines (Working document: Biological treatment of biowaste, 2001).

A comparison of the best compost obtained (pile 5) with those from other organic wastes showed that its chemical values fell within the same range in most instances, with the exception of a high calcium value owing to the nature of the wine making process (Table 4) (Soliva and Felipó, 2002). The compost obtained just from grape stalks would be similar to that of vegetal wastes (VW), however the incorporation of sludge allows the elimination of two waste materials and ensures that a better product is obtained.

The compost obtained is particularly recommended for application to the vineyard because: (i) the humidified nature of the organic matter would facilitate its incorporation and improve the water holding capacity of the soil, an important factor for the quality and specificity of wine production, (ii) nitrogen is released only gradually which is particularly appropriate for the

Table 3
Physico-chemical and chemical characteristics of mixed materials (onset) and compost obtained (end)

Piles	% Moisture	pH 1:5	EC µS/cm 1:5	% N Kjeldahl DW	% VS	C:N	% Germination
Experiment 1							
Pile 1 (1:1NG) onset	80	8.5	1500	3.3	55	8.3	–
Pile 1 (1:1NG) end	54	7.5	3260	2.2	51	11.4	91
Pile 2 (1:2G) onset	50	9.0	1500	2.7	76	14.2	–
Pile 2 (1:2G) end	47	7.9	4155	2.2	51	11.9	87
Experiment 2							
Pile 3 (1:1NG) onset	73	8.3	951	2.73	55.3	10.1	–
Pile 3 (1:1NG) end	60	7.0	2160	2.14	41.5	9.7	84
Pile 4 (1:1G) onset	74	8.5	1005	2.57	59.8	11.6	–
Pile 4 (1:1G) end	62	7.9	1699	1.95	40.5	10.4	71
Pile 5 (1:2G) onset	74	9.1	1194	2.23	67.5	15.1	–
Pile 5 (1:2G) end	66	8.3	1585	2.29	54.5	11.9	78

NG (not ground), G (ground), % DW (dry weight).

Table 4
Average chemical composition and characteristics of S + GS: sludge + grape stalks (pile 5) and several organic wastes: VW: vegetable wastes, SC (MW): separate collection of municipal wastes, SS + VW: sewage sludge + vegetable wastes, CM: cow manure (Soliva and Felipó, 2002)

	VW	SC (MW)	SS + VW	CM	S + GS (1:2)
pH	7.85	7.40	7.53	8.65	8.3
EC	0.61	3.64	4.10	5.10	1.58
C:N	25.65	9.8	12.27	12	11.9
%					
M	62.47	55.95	16.96	65.28	66
VS	53.35	46.29	62.14	56.66	54.5
N_{Kj}	1.04	2.37	2.53	2.42	2.29
P	0.15	0.37	2.33	0.86	0.4
K	0.42	1.58	0.42	2.05	1.3
Ca	3.97	7.61	5.96	4.11	14.3
Mg	0.85	1.62	0.96	0.58	0.3
Fe	0.94	1.03	1.12	0.57	0.5
mg/kg					
Zn	76	173	1087	204	187
Mn	185	243	143	ND	ND
Cu	42	64	338	60	156.9
Ni	47	52	54	47	17.6
Cr	16	25	95	56	23.4
Pb	38	107	110	12	8
Cd	0.17	0.33	1.5	0.36	0.2

vineyard that suffers from high nitrogen levels and (iii) it contains high to moderate values of potassium which is considered a quality factor in wines (acidity control). In short, the compost obtained from the two waste products matches the requirements of a fertilizer to ensure the production of quality wines (Delas, 2000; Ribereau-Gayon and Peybaud, 1982; Vez, 1993).

4. Conclusions

It was possible to carry out the co-composting of winery wastes (sludge mixed with grape stalks) satisfactorily, while recovering organic matter and potassium from the system. The evolution of the process, the temperatures attained and the analytic values obtained would ensure a proper hygienization, and the transformation of all the materials for their further application in the vineyard. The optimum ratio for mixing the wastes was 1:2 as this ensured that piles reached higher temperatures more quickly. When mixing in these proportions the VS percentage was more readily stabilized with low mineralisation, more nitrogen was retained, and the C:N ratio was similar to that found in soils. Furthermore, it was possible to eliminate more grape stalks. Ground grape stalks gave better results as they integrated more easily with sludge and were also found to improved the C:N ratio and attain higher temperatures. These piles using ground stalks did not need to be turned so frequently. Our results, however, demonstrate the importance of turning the pile every other day for the first 10 days so as to homogenize the materials, while during the composting process turning is needed after a decrease in temperature or when oxygen levels fall below 5% to ensure the continuation of the composting process. The moisture levels for the assayed materials should not be lower than 55% so as to promote microbial activity. The degree of moisture of the grape stalks at the onset of the second experiment (fresh material) and the season (winter) meant watering was not required in this uncovered composting process.

References

Balanyà, T., Saña, J., González, M.L., De la Peña, M., 1994. Utilización de compost de residuos sólidos urbanos en un viñedo del Penedés. Viticultura/Enología Profesional 31, 20–25.

Brinton, W.F., Evans, E., Droffner, M.L., Brinton, R.B., 2001. A standardised Dewar test for evaluation of compost self-heating. Biocycle Report. Woods End Research Laboratory, p. 16. Available from <www.solvita.com>.

De Bertoldi, M., Ferranti, M.P., L'Hermite, P., Zucconi, F., 1986. In: Compost: Production, Quality and Use. Elsevier Applied Science, London, p. 852.

Delas, J., 2000. La fertilisation de la vigne. Collection des Usuels Féret de la Vigne et du Vin. Éditions Féret, Bordeaux. p. 159.

Diaz, M.J., Madejon, E., Lopez, F., Lopez, R., Cabrera, F., 2002. Optimization of the rate vinasse/grape marc for co-composting process. Process Biochemistry 37, 1143–1150.

European Commission, 2001. Working document: Biological treatment of biowaste, 2nd Draft, p. 22.

European Commission EEC, 2000. Working document on sludge, 3rd Draft, p. 20.

Ferrer, J., Paez, G., Marmol, Z., Ramones, E., Chandler, C., Marin, M., Ferrer, A., 2001. Agronomic use of biotechnologically processed grape wastes. Bioresource Technology 76 (1), 39–44.

Fraser, B.S., Lau, A.K., 2000. The effects of process control strategies on composting rate and odor emission. Compost Science and Utilization 8 (4), 274–292.

Golueke, C.G., 1982. When is compost ''safe''? A review of criteria for assessing the destruction of pathogens in composting. BioCycle 28, 28–38.

Grundy, A.C., Green, J.M., Lennartsson, M., 1998. The effect of temperature on the viability of weed seeds in compost. Compost Science and Utilization 6 (3), 43–51.

Haug, R.T., 1993. The Practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton. p. 717.

Hoitink, H.A.J., Keener, H.M., 1993. Science and Engineering of Composting: Design, Environmental, Microbiological and Utilisation Aspects, first ed. Renaissance Publications, The Ohio State University, Ohio. p. 728.

Jorba, J., Trillas, M.I., 1983. Rapid bioassay to control maturity in pine bark compost. In: Caballero, A. (Ed.), International Symposium on Substrates in Horticulture Other than Soils In Situ. In: Acta Horticulturae, vol. 150. ISHS, Barcelona, pp. 67–74.

Ministerio de Agricultura, Pesca y Alimentación, 1993. Métodos oficiales de análisis. Secretaria general de alimentación. Dirección general de política alimentaria, España, p. 149.

Mustin, M., 1987. Le compost: gestion de la matière organique. Éditions François Dubusc, Paris. p. 954.

Nogueira, W.A., Nogueira, F.N., Devens, D.C., 1999. Temperature and pH control in composting of coffee and agricultural wastes. Water Science and Technology 40 (1), 113–119.

Poincelot, R.P., 1975. The biochemistry and methodology of composting. Bulletin 754. The Connecticut Agricultural Experiment Station, New Heaven, pp. 1–13.

Ranalli, G., Bottura, G., Taddei, P., Garavani, M., Marchetti, R., Sorlini, C., 2001. Composting of solid and sludge residues from agricultural and food industries. Bioindicators of monitoring and compost maturity. Journal of Environmental Science and Health A 36 (4), 415–436.

Ribereau-Gayon, J., Peybaud, E., 1982. Ciencias y técnicas de la viña: Tratados de ampeología. Tomo I: Biología de la viña. Suelos de Viñedo. Editorial Hemisferio Sud S.A., Argentina. p. 671.

Soliva, M., 2001. Compostatge i gestió de residus orgànics. Estudis i monografies no. 21. Àrea de Medi Ambient, Diputació de Barcelona, p. 111.

Soliva, M., Felipó, M.T., 2002. Organic wastes as a resource for Mediterranean soils. Workshop ''Biological Treatment of Biodegradable Wastes—Technical Aspects''. DG Environment and the JRC, Brussels, p. 19.

Tiquia, S.M., Tam, N.F.Y., Hodgkiss, I.J., 1996. Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. Bioresource Technology 55, 201–206.

Tiquia, S.M., Richard, T.L., Honeyman, M.S., 2000. Effect of windrow turning and seasonal temperatures on composting of hog manure from hoop structures. Environmental Technology 21, 1037–1046.

Trillas, I., Aviles, M., Ordovas, J., Bello, A., Tello, J.C., 2002. Using compost as a Methyl Bromide alternative. BioCycle 43 (9), 64–68.

Vez, A., 1993. La fumure de la vigne. Station fédérale de recherches agronomiques de Changins. Revue Suisse Vitic. Arboric. Hortic 25 (1), 57–64.