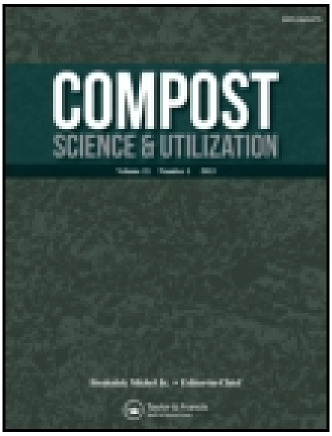

Compost Science & Utilization
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ucsu20

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Published online: 23 Jul 2013.

To cite this article: M.J. Díaz, E. Madejón, J. Ariza, R. López & F. Cabrera (2002) Cocomposting of Beet Vinasse and Grape Marc In Windrows and Static Pile Systems, Compost Science & Utilization, 10:3, 258-269, DOI: 10.1080/1065657X.2002.10702088

To link to this article: http://dx.doi.org/10.1080/1065657X.2002.10702088

Compost Science & Utilization, (2002), Vol. 10, No. 3, 258-269

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Two composts were obtained by cocomposting a concentrated depotassified beet vinasse and grape marc using an aerated static pile and a windrow system. The composting mixtures comprised grape marc (83%) and vinasse (17%) for the aerated static pile system and grape marc (77%), vinasse (20%) and phosphate rock (3%) for the windrow. Changes in temperature followed a similar path for both mixtures, however the thermophilic phase was longer in the aerated static pile (25 days) than in the windrow (10 days). This fact caused differences in both organic matter degradation, weight losses (21% for static pile and 10% for windrow) and gas losses during the process. Nevertheless, the composts obtained by the two systems had a high fertilizer nutrient value (18.2 g kg^{-1} N; 3.1 g kg^{-1} P; 13.6 g kg^{-1} K, C/N 16.1 for compost obtained in static pile and 20.6 g kg^{-1} N; 13.7 g kg^{-1} P; 13.1 g kg^{-1} K; C/N 18 for compost obtained in windrow). A high degree of stability was reached in both composting systems (124 $cmol_c$ kg^{-1} CEC for static pile and 153 cmolc kg^{-1} CEC for windrow at 80 days of composting). The chemical and physical properties of both vinasse composts suggest their possible use as soil conditioner.

Introduction

Concentrated beet vinasse is a high-density waste from the sugar industry. Vinasse is usually considered to be highly polluting as it is produced in very large amounts during a short season (10^6 million metric tons per year in Spain). Moreover, vinasse presents two main environmental problems: a high organic strength (BOD 61-70 g O_2 l^{-1}) and high salinity (EC 250-300 dS m^{-1}) (López *et al.* 1992).

Considering vinasse from the point of view of its organic matter (350 g kg^{-1} dw.) and nutrient content (30 g kg^{-1} -N; 30 g kg^{-1} -K dw.), it constitutes a valuable resource as a fertilizer and a source of nutrients and organic matter. However, the direct application of concentrated vinasse on agricultural lands may lead to economical and environmental problems due to its high salinity, low P content (0.12 g kg^{-1} - P_2O_5) and its density (1,3 g cm^{-1}) (López *et al.* 1992; Murillo *et al.* 1993).

Grape marc, a primary waste of wine production, can be recycled as fertilizer due to its organic matter and nutrient contents. The direct incorporation of grape marc into agricultural land, a common practice, has become a serious problem because the degradation products can inhibit root growth (Inbar, *et al.* 1991). However, grape marc is well balanced nutritionally, suitable for composting as produced and readily available in the region (Andalusia, Spain).

To overcome these disadvantages and to recycle both wastes, an alternative is the cocomposting of vinasse with grape marc. Composting is a low-cost natural way of recycling organic matter.

The aim of this research was to investigate the cocomposting of vinasse and grape marc using windrow and aerated static pile systems. The differences in control parameters, mass balance and final characteristics of the composts obtained are also discussed.

Materials and Methods

Design and Operation

Two composting piles were established with the following mixtures of grape marc (GM) and vinasse (V) (dry weight percentages):

Aerated static pile: GM (83%) + V (17%)
Windrow: GM (77%) + V (20%) + PR (3%)

These proportions were mainly based on the vinasse-sorption capacity of the solid waste, on the optimum moisture content and on the optimum free air space (FAS) of the mixture for an optimum composting process (Díaz 1998). The windrow mixture was complemented with phosphate rock (PR) to ensure a C/P ratio lower than 150 (Gray *et al.* 1971). Characteristics of the raw materials are reported in Table 1.

TABLE 1.
Some characteristics[a] of the raw materials used in the composting process

Parameter	Units	Vinasse Average	Vinasse [b]SD	Grape Marc Average	Grape Marc [b]SD	Phosphate Rock
Moisture	g kg^{-1}	600	40	310	23	20
OM[c] (dw[d])	g kg^{-1}	270	5.60	720	12.5	-
pH		4.7	0.22	7.15	0.16	-
EC[e]	dS m^{-1}	-	-	4.78	0.56	-
N (dw)	g kg^{-1}	25	5.20	14.2	3.20	-
P(dw)	g kg^{-1}	0.3	0.03	3.2	0.20	140
K (dw)	g kg^{-1}	29.9	10.9	10.0	4.31	1.0
C/N		6	-	30	-	-
Na (dw)	g kg^{-1}	28	10.0	4.1	0.52	3.4
Ca (dw)	g kg^{-1}	3.4	1.23	28.2	9.53	300
Mg (dw)	g kg^{-1}	5.0	1.15	4.3	0.29	2.0
Fe (dw)	mg kg^{-1}	203	26	2870	245	-
Cu (dw)	mg kg^{-1}	6	-	90	21	-
Mn (dw)	mg kg^{-1}	10	-	50	11	-
Zn (dw)	mg kg^{-1}	15	4.0	115	13	-

[a]Each value is the average of three samples; [b]SD, standard deviation; [c]OM, organic matter; [d]dw, dry weight; [e]EC Electrical conductivity

Both mixtures were formed into trapezoidal piles under cover to avoid rainfall that can cause a decrease of compost temperature and a reduction of compost activity (Hay and Kuchenrither 1990). Due to the small dimensions of the experimental composting plant, each experiment was carried out in a different year. Both composting systems were started in the same month (February) to avoid excessive differences in the ambient temperature behavior.

Both piles were set up with the same size 3 m (length) x 3 m (width) x 1,5 m (height). Physical and chemical characteristics of the initial mixtures are reported in Table 2. It is interesting to note that both initial mixtures had C/N values lower than the optimum value for composting (25-35; Gray 1971; Golueke 1972). This fact could lead to excessive nitrogen losses during the process.

The aerated static pile was centered over three aeration lines consisting of perforated pipes (5 cm of diameter) installed in a groove in the concrete floor. Aeration was provided by a blower which operated in the positive mode (forced aeration). The pipes were covered to a depth of approximately 150 mm with cured compost to im-

TABLE 2.
Physical and chemical characterization of the two initial mixtures[a]

		Aerated Static Pile	Windrow		
Parameter	Units	Average	[b]SD	Average	[b]SD
OM[c] (dw)[d]	$g\ kg^{-1}$	644	34	721	21
N (dw)	$g\ kg^{-1}$	19.2	5.26	21.0	4.26
C/N		18.6	–	19.0	–
P (dw)	$g\ kg^{-1}$	3.0	0.31	13.4	1.12
K (dw)	$g\ kg^{-1}$	12.6	1.04	11.9	1.26
Na (dw)	$g\ kg^{-1}$	11.3	1.15	8.2	2.15
Ca (dw)	$g\ kg^{-1}$	30.8	5.69	24.0	3.18
Mg (dw)	$g\ kg^{-1}$	6.3	1.36	4.3	0.95
Fe (dw)	$mg\ kg^{-1}$	2110	236	1510	142
Mn (dw)	$mg\ kg^{-1}$	39	4.20	43	2.36
Cu (dw)	$mg\ kg^{-1}$	65	6.12	90	3.26
Zn (dw)	$mg\ kg^{-1}$	125	12.2	136	10.8
Pb, Cd, Cr, Co, Ni (dw)	$mg\ kg^{-1}$	<5	–	<5	–
Density	$g\ cm^{-3}$	1.60	0.25	1.57	0.08
Porosity	%	70	4.10	69	3.36

[a]Each value is the average of three samples; [b]SD, standard deviation; [c]OM, organic matter; [d]dw, dry weight

prove air distribution and prevent blocking of the holes in the pipes. The outer part of the piles was not covered. The timer in the static pile was set in intervals of 15 minutes for three hours each day during the thermophilic phase and in intervals of 15 minutes for one hour each day during the mesophilic phase. Aeration design (0.15 m^3 per minute per dry metric ton) was based on Haug (1993). Aeration was stopped during the maturation phase.

The windrow was turned using a front end loader at 10 day intervals the first six weeks of the process (the more active biooxidative phase). Golueke (1972) recommended that the windrow needed to be turned for a total of seven turns maximum during thermophilic phase. No turning was performed during the mesophilic phase.

During the thermophilic phase both piles were watered regularly to maintain moisture contents of around 55% in accordance with a recommended range of 50-60% (McKinley *et al.* 1985). No additional water was added during the mesophilic and maturation phases.

Analyses

Temperatures and samples were taken at two depths (0-30 cm) and (40-100 cm) at three randomized points of each pile. Sampling and temperature measurements were made three to four times a week during the initial stage (more rapid degradation and transformation) and weekly during the final stages. The temperature profile was recorded by means of six replicates. Six subsamples of compost were taken from the pile at the same times.

Moisture content was measured by drying at 105°C to constant weight. pH and electrical conductivity (EC) were measured in a 1:5 (w/v) water-compost extract. Total organic matter (OM) was measured at 550°C**.** Kjeldahl nitrogen determination was performed according to Hesse (1971). Mineral elements (Na, K, Ca, Mg, Fe, Mn, Cu, Zn, Ni, Cr, and Pb) were determined after mineralization by atomic spectrophotometry (Hesse 1971) and total P was determined by colorimetric method using the phosphovanadomolibdic complex (Hesse 1971).

Elemental analysis (C, N, O, H) of the initial mixtures and final composts was performed in a Perkin-Elmer model 240 C Elemental Analyzer (Perkin-Elmer, Norwalk, Connecticut):

Cation exchange capacity (CEC) of compost samples was determined according to Harada *et al.* (1981). In vitro assay of germination and root growth for *Lepidium sativum* L. seed was performed using compost water extract (1:10 w/v) (Zucconi *et al*. 1981 modified by Díaz Burgos 1990). Germinated seeds and root length were recorded after 48 h, and a germination index (GI) was obtained for each species by multiplying the germination percentage (%G) by the root length percentage divided by 100.

Determination of porosity of the mixtures was carried out in tubes (0.07 m^3; 1 m long and 30 cm of diameter). The tubes were filled with compost, then water was slowly added until filling the tube completely, shaking slightly to avoid the formation of air bubbles inside the compost mass. The difference between the initial and the final weight is considered as the volume of pores (the volume occupied by the micropores where the water could not penetrate was assumed to be negligible) (Díaz, 1998).

Density of the mixtures was determined in dry samples by Helium gas pycnometry, using a Quantachrome model MVP-1 instrument (Quantachrome, Boynton Beach, Florida). Three measurements were carried out for each material in the same conditions. (Sacks *et al.* 1991).

Mass Balance

A schematic mass balance for batch compost systems is shown in Figure 1.
A total mass balance gave:

$$IS + IM + WI + OI = FS + FM + WO + CO_2 + NH_3 \quad (1)$$

The oxidation of the biodegradable solids in the mass occurs according to equation 2. It was assumed that in the mass balance initial non-biodegradable solids are equal to final non-biodegradable solids (Haug 1993).

$$C_aH_bO_cN_d + 0.5\,(ny + 2s + r - c)\,O_2 \rightarrow n\,C_wH_xO_yN_z + s\,CO_2 + r\,H_2O + (d - nz)\,NH_3 \quad (2)$$

where

$$r = 0.5\,[\,b - nx - 3\,(\,d - nz)] \quad (3)$$

and

$$s = a - nw \quad (4)$$

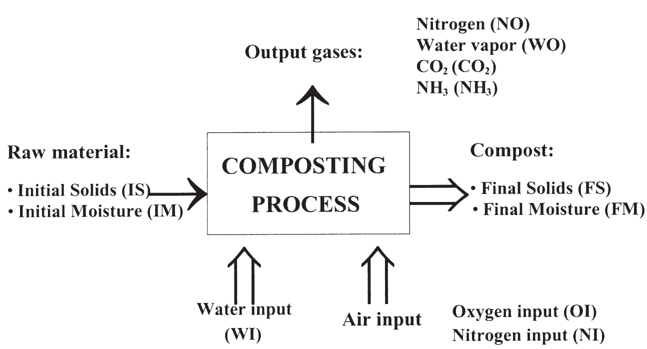

Figure 1. Mass balance for batch compost system.

Throughout these equations carbon dioxide (CO_2), ammonia (NH_3) and water (WO) produced for organic decomposition were determined. The stoichiometric oxygen required for decomposition was determined from the organic feed decomposition (Equations 2, 3, 4). It was assumed nitrogen input was equal to nitrogen output. A total water balance gave:

$$IM + WI + WR = WO + FM$$

Where: WR is the water produced in the stoichiometric reaction.

Results and Discussion

Temperature Changes

Three typical phases of composting were observed during the process (Figure 2). (i) a short initial mesophilic phase (T<40°C) lasting approximately two days for both piles. (ii) a thermophilic phase, during which the temperature increased (T>40°C) and reached a maximum temperature of 58°C at five days of composting for both piles. (iii) a maturation phase, when the temperature decreased slowly to mesophilic values above 40°C in both piles.

During the thermophilic phase, slight increases in temperature were observed in both piles. The thermophilic phase of the static pile was longer (25 days) than that recorded for in the turned windrow (ten days). The length of the thermophilic phase depends on the size and shape of piles and the system used (Haug 1993). Moreover, the compost exposed surface area can have a significant effect on the rate of heat lost (Haug 1993). It was considered that the higher heat loss in the windrow was due to the larger exposed surface area to air in this composting system during turnings.

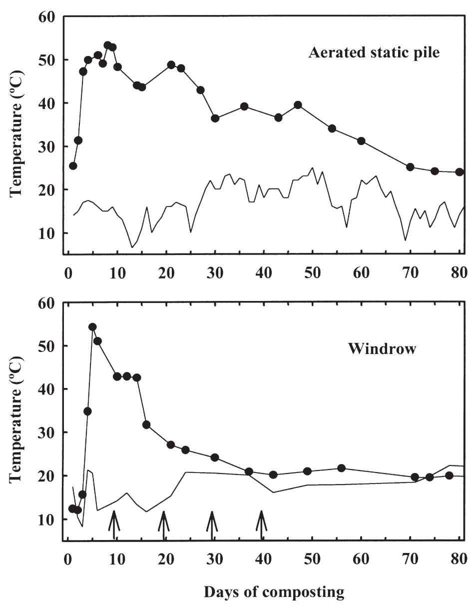

Figure 2. Temperature (°C) changes in the piles during composting. The temperatures are the average of the values recorded at the different depths in the pile (• pile temperature: - Air temperature). The arrows indicate the turning points in windrow pile.

After 80 days of composting, the temperature remained at 24ºC in aerated static pile and 20ºC in windrow. The different aeration systems can result in differences in the temperature trend of the piles (Hay and Kucherither 1990; Tiquia *et al.* 1996).

As the two experiments of composting were performed in different years, slight variations in ambient temperature profiles were found.

Ammonium and Nitrate Evolution

NO_3^--N and NH_4^+-N evolution in the compost mass during the composting process is shown in Figure 3. A similar trend was observed for both piles with respect to inorganic nitrogen evolution during the process. A high NO_3^--N content was observed of in both mixtures at the beginning of composting was observed (1066 mg kg^{-1} for the aerated static pile and 460 mg kg^{-1} for the windrow). This fact could be attributed to an initial nitrogen mineralization of the substrates during their storage. The NO_3^--N decreased during the thermophilic phase and then slightly increased during the maturation phase to 599 mg kg^{-1} for aerated static pile and 411 mg kg^{-1} for windrow. Bishop and Godfrey (1983) reported that maximum nitrification occurred at mesophilic temperatures. Other authors have reported similar NO_3^--N evolution during composting (Bishop and Godfrey 1983; De Bertoldi *et al.* 1982 Mahimairaja *et al.* 1994).

The NH_4^+-N content for both piles rapidly increased during the thermophilic phase. The maximum of NH_4^+-N content was higher and occurred earlier in the windrow (1580 mg kg^{-1} at 7 days) than in the aerated static pile (960 mg kg^{-1} at 10 days). Studies on composting have shown that ammonification depends on parameters such as C/N ratio, pH and temperature (Bishop and Godfrey 1983; Bonazzi *et al.* 1990, Thambirajah *et al.* 1995). In this study, the C/N ratio of the composts, and the maxi-

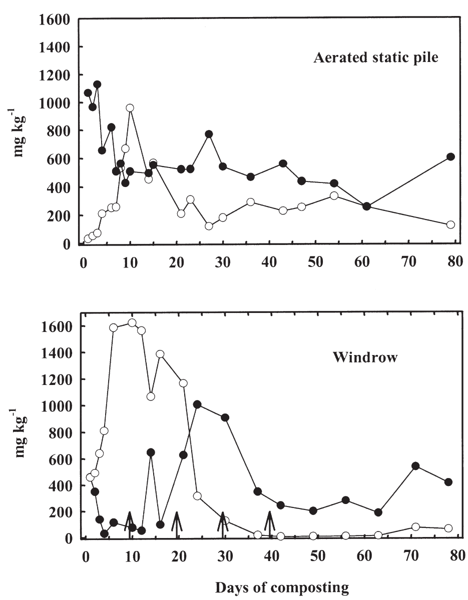

Figure 3. Inorganic nitrogen content (mg kg^{-1}) in the piles during composting (● NO_3-N; ○ NH_4-N). The arrows indicate the turning points in windrow pile.

mum of temperature and pH (8.5 and 8.2 at 10 days for aerated static pile and windrow respectively) were similar in both systems. However, Nakasaky *et al.* (1992) showed that turning frequency and the rate of air flow may affect NH_4^+-N evolution. The turnings performed in the windrow system may have caused higher ammonification than occurred in aerated static pile. After 25 days, the NH_4^+-N content decreased in both piles reaching the initial values at the end of the processes. A similar tendency was observed by Díaz Burgos *et al.* (1987);), Nakasaky *et al.* (1992) and Bhanawase *et al.* (1994). This decreasing trend guaranteed that ammonification was ending and can be used as a criteria of compost maturity (Mathur *et al.* 1993).

Structural Changes

Some structural changes were observed during composting.

Initial porosity was 70% and 57.7% for the aerated static pile and the windrow respectively. At 80 days, values of 69% for aerated static pile and 65.2% for windrow were recorded. The porosity of the compost mass did not change during composting using the static pile system whereas a noticeable increase in porosity was observed using the windrow system. Fulford (1987) did not find changes of porosity in the compost mass using the static pile system. However, important increases of porosity of the compost mass were obtained using the windrow system (Haug 1993).

The density of the compost mass was 1.60 g cm^{-3} and 1.57 g cm^{-3} for the aerated static pile and the windrow respectively at the beginning of the process. At 80 days, values of 1.83 g cm^{-3} for aerated static pile and 1.70 g cm^{-3} for windrow were recorded. The increase of density in both piles could be due to the organic matter losses and, therefore, an increase of the inorganic fraction in the compost mass. Density of the inorganic fraction (2 - 4 g cm^{-3}) is higher than the organic fraction density (0.4 - 1 g cm^{-3}) (Haug 1993). In aerated static pile, a higher consumption of the organic matter and, consequently, a greater increase of the inorganic fraction was observed. This fact explains the differences in the final density, which were higher in the static pile than in the windrow pile.

CEC Evolution

TABLE 3.
Evolution of CEC in compost during the process

Time Days	Aerated Static Pile CEC[a] c mol_c kg^{-1}	Windrow CEC[a] c mol_c kg^{-1}
1	66	75
6	68	87
12	70	103
24	74	nd
37	nd	116
49	83	nd
63	103	119
71	120	125
80	142	131

[a]Volatile solid basis

The values of CEC during the process for both piles are given in **Table** 3. CEC values depend on the starting material. Its evolution and stabilization have been proposed as an index of maturity (Estrada *et al.* 1987; Saharinen 1996). CEC evolution was similar in both piles and CEC values increased steadily to reach constant values in the maturation phase (142 and 153 $cmol_c$ kg^{-1} respectively for aerated static pile and windrow), in dicating compost stabilization.

Phytotoxicity Assay

Table 4 shows the evolution of %G (germination percentage) and GI (germination index) during composting in both piles. Phytotoxicity decreased during composting because toxic substances are metabolized. As composting continued, phytotoxicity decreased and finally disappeared completely at the end of composting process. Phytotoxicity disappeared at 60 days in the windrow, whereas for the aerated static pile 80 days of composting were needed to consider the compost free of phytotoxic substances. The windrow system seemed to be more efficient in suppressing toxicity. Nevertheless the values of GI and %G obtained for both composts at the end of the process indicated the absence of phytotoxicity as indicated by a (GI>60; (Zucconi *et al.* 1981).

TABLE 4.
Evolution of germination percentages (G%)[a] and germination index (GI)[a] in compost during the process.

Time(days)	Aerated Static Pile		Windrow	
	%G	GI	%G	GI
1	9	6	12	10
40	26	32	40	38
60	42	37	67	50
80	56	67	86	78

[a]Values referred to the control

Stoichiometric Data

As composting is considered to be a typical aerobic process, the final products of the respiration are H_2O and CO_2. In an elemental analysis of waste for aerobic degradation, only the four basic elements in the process (hydrogen, oxygen, nitrogen and carbon) are taken into account. Analyses of mixtures are shown in Table 5. The percentages of the different elements were very similar for both mixtures. These stoichiometric relationships formulae were comparable to those found for other agricultural residues (Haug 1993).

TABLE 5.
Elemental composition of the initial and final compost mixtures

	Aerated Static Pile		Windrow	
	% Dry Weight			
	Initial	Final	Initial	Final
Carbon	40.87	33.61	44.52	39.92
Hydrogen	4.95	3.46	4.96	4.25
Oxygen	52.01	60.63	48.06	53.24
Nitrogen	2.17	2.30	2.47	2.59
Stoichiometric formula	$C_{22}H_{32}O_{21}N_1$	$C_{17}H_{21}O_{23}N_1$	$C_{21}H_{28}O_{17}N_1$	$C_{18}H_{23}O_{18}N_1$

Mass Balance

After the maturation phase, the piles were weighed. From an initial mass of 9034 kg of dry solid, 7139 kg of dry compost was recovered in the aerated static pile. The losses were 21% of the initial dry weight. In the windrow, from an initial mass of 9151 kg of dry solid, 8198 kg of dry compost were recovered. The losses were 10% of the initial dry weight.

The mass balance for both piles is shown in Table 6. The total estimated losses of gases and leachates during the process were 8579 kg for aerated static pile and 4182 kg for windrow. The estimated main gas losses consisted of carbon dioxide and water that was evaporated from the compost (54.2% and 39.57% with respect to water input for aerated static pile and windrow respectively). Ammonium losses were 43 kg for aer-

TABLE 6.
Mass balance for aerated static pile and windrow

Aerated Static Pile			
Inputs (kg)		Outputs (kg)	
• Raw material		• Compost	
Initial solids	9034	Final solids	7139
Initial moisture	4788	Final moisture	4247
• Air		• Gases	
Stoichiometric O_2 (calculated)	3336	Stoichiometric CO_2 (calculated)	3884
• Water added	987	Stoichiometric NH_3 (calculated)	43
		Evaporated water and leachates (estimated)	4652
Total	18145	Total	18145
Windrow			
Inputs (kg)		Outputs (kg)	
• Raw material		• Compost	
Initial solids	9151	Final solids	8198
Initial moisture	3752	Final moisture	4345
• Air		• Gases	
Stoichiometric O_2 (calculated)	2318	Stoichiometric CO_2	2506
		Stoichiometric NH_3 (calculated)	21
• Water added	1504		
		Evaporated water and leachate (estimated)	1655
Total	16725	Total	16725

ated static pile (0.47% of the initial dry solids) and 21 kg for windrow (0.23% of the initial dry solids). Despite of the relative low values of C/N of the initial mixtures, low N losses were observed in both systems.

In general, the total losses were higher in the aerated static pile system than in the windrow system. This fact can be explained by the longer thermophilic phase recorded for the static pile, which thus caused a higher decomposition rate.

Quality of Compost

The main chemical characteristics of the final products are shown in Table 7.

Results revealed high amounts of macronutrients, particularly N, K and P. A higher P content was obtained in compost from windrow, due to the phosphate rock added to this pile. Adequate C/N and C/P values for final compost were found in both systems. The low concentration of heavy metals confirms the safety of the original materials. These heavy metal contents were below the limits established by Spanish legislation (BOE 1998).

The quality of the composts obtained in this study can be considered comparable to the quality of other composts reported in the literature (Vallini *et al.* 1984; Zucconi and De Bertoldi 1987; Tomati *et al.* 1995). The relative high EC value of the composts could be a problem for their agricultural use. However, due to the quality of the composts, moderate doses of the compost (15-20 Mg ha^{-1}) should be sufficient to assure the nutritional requirements of the crops without seriously increasing soil salinity (Madejón *et al.* 2001).

TABLE 7.
Physical and chemical characterization of the two composts [a]

		Aerated Static Pile		Windrow	
Parameter	Units	Average	[b]SD	Average	[b]SD
Moisture	g kg^{-1}				
OM[c] (dw)[d]	g kg^{-1}	532	15.0	680	21.0
EC[e] (1:5)	mS cm^{-1}	11.8	1.52	17.5	2.51
N (dw)	g kg^{-1}	18.2	1.40	20.6	2.32
C/N		16.1	-	18.0	-
P (dw)	g kg^{-1}	3.1	0.48	13.7	1.72
C/P		95.3	-	27.6	-
K(dw)	g kg^{-1}	13.6	1.54	13.1	1.70
Na (dw)	g kg^{-1}	15.1	1.70	9.8	1.76
Ca (dw)	g kg^{-1}	31.1	3.25	27.8	4.84
Mg (dw)	g kg^{-1}	6.3	0.61	4.7	0.12
Fe (dw)	mg kg^{-1}	2580	210	1900	320
Mn (dw)	mg kg^{-1}	44	8.58	46	11.0
Cu (dw)	mg kg^{-1}	53	5.16	96	5.22
Zn (dw)	mg kg^{-1}	113	13.2	138	21.0
Pb,Cd,Cr,Co,Ni. (dw)	mg kg^{-1}	<5	-	<5	-
Density	g cm^{-3}	1.83	0.09	1.70	0.04
Porosity	%	69.0	1.20	65.2	1.42

[a] Each value is the average of three samples; [b]SD, standard deviation; [c]OM, organic matter; [d]dw, dry weight; [e]EC, electrical conductivity.

Conclusions

Composting mixtures of vinasse (17-20%) and grape marc is technically feasible using either windrow or aerated static pile composting systems.

Temperature profiles indicated that the process was successful in both systems. A longer thermophilic phase was observed in the aerated static pile and thus, higher weight (21% and 10% for aerated static pile and windrow respectively) and gas losses were obtained using this composting system.

Changes in ammonium, nitrate and CEC were similar in both systems.

The increase of porosity of the compost was greater during composting in the aerated static pile than that observed in the windrow. However, the evolution of the compost density was similar in both systems.

Each of the composts obtained had a high nutrient value, a high level of stability and an absence of phytotoxicity and could be used to increase soil organic matter content and thus soil fertility.

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