Assessment of a composting process for the treatment of beef cattle manure

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Abstract

The intensive breeding of beef cattle in Juncosa de les Garrigues (Catalonia, Spain) leads to the production of large volumes of manure that need appropriate management. Land application in the area at agronomic rates is not enough to ensure good management practices, making necessary extended on-farm storage and the export of part of the production to long distances. In this context, the implementation of a collective treatment based on composting could help in enhancing the handling of manure. We assessed a full-scale composting process based on turned windrows (W), and involving treatment of beef cattle manure (CM) alone (two typologies were considered according to C/N ratios of ~ 25 (CM1, W1) and ~ 14 (CM2, W2)), or mixed with bulking agent (CM2/BA, W3) and dewatered digested sewage sludge (CM2/BA/DDSS, W4). Composting significantly improved the transportability of nutrients (final volumes were 40-54% of initial). Temperatures > 55ºC were reached in all the treatments but following different time patterns. Under the applied conditions of turning and rewetting, 14 weeks of processing did not ensure the production of stable, and mature, compost. Thus, only compost from W1 attained the maximum degree of stability, as well as concentration of ammonium-N < 0.01% (with ammonium-N/nitrate-N ratio of 0.2), and low phytotoxicity. However, the high pH, salinity, and heavy metal contents (Cu and Zn) may limit still its final use. Addition of BA was advised to be kept to a minimum, whereas, use of DDSS as co-substrate was not recommended in agreement to the higher losses of N, and levels of heavy metals in the final compost.

Keywords: Organic waste management; beef cattle manure; composting process; compost; nutrients recycling; agricultural value.

Introduction

Cattle manure (CM) is produced in large amounts in the breeding facilities of Juncosa de les Garrigues (Catalonia, Spain). [1] In this municipality are fattened more than 9.000 beef calves per year, which leads to an annual manure production of more than 20.000 Mg. In this context, appropriate land application of manure at agronomic rates must be assured to preserve the environmental quality of agricultural ecosystems, atmosphere, and water resources. The low requirements in fertilization of the local rainfed agriculture (mainly consisting on the cropping of almond trees and olive trees), coupled to the difficulty in accessing part of the existing fields due to the topography of the terrain (slopes, terraces, etc.), make necessary extended storage on the farms and the export of part of the production to long distances. Thus, it would be interesting to consider the implementation of a collective low-technology treatment that could help in reducing the volume of manure to be managed while enhancing its properties, resulting in the production of a material easier to handle and transport. In this regard, among the available technologies to treat manure, [2] composting is attractive because allows producing a value-added product (compost) for the recycling of organic matter (OM) and nutrients.

Indeed, composting is a widely applied process when dealing with organic solid waste management. [3] It consists on the biological decomposition and stabilization of organic by-products, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plants seeds, and can be beneficially applied to land. [4] Aeration and moisture need to be supplied in order to attain good process performance. Aeration can be provided either by mechanical turning or by means of forced aeration. Use of bulking agent (BA) will increase convective airflow through windrows. On the other hand, rewetting can be required to compensate the large quantity of water that can evaporate during composting and maintain the optimum moisture content (MC) for microbial activity. In this regard, too high MCs result in undesired anaerobic conditions while very low contents cause early dehydration, which will stop the process.

The quality of the compost is dependent on many factors such as feedstock sources and proportions used, composting procedure, and length of maturation. It can be evaluated according to physical, chemical, and biological criteria. [5-7] Physical parameters include temperature, MC, bulk density, particles size, porosity, and airflow resistance, as well as thermal, electrical, mechanical, and optical properties. Chemical criteria focus on the composition and particularly on the content of nutrients, water-soluble extract, presence of heavy metals and organic pollutants, OM quality, cation exchange capacity, etc. Finally, biological criteria include microbial activity indicators based on the monitoring of the respiration or enzyme activity, as well as phytotoxicity tests. The quality of the compost defines the marketing potential of the product. Compost can be employed as soil amendment and fertilizer in agriculture [8] and landscaping, [9] but also as growing media in horticulture [10] and gardening. [11] Features of good quality are stability (and maturity) and sufficiently low salinity and heavy metal contents. Immature or poorly stabilized composts may have adverse effects on seed germination and/or plant growth due to the presence of phytotoxic compounds. [12-13]

Composting has been reported as alternative for manure management in beef cattle farms [14-15] in contrast to fresh handling or stockpiling. [16] On-farm factors such as operational practices, bedding, and climate will significantly affect the characteristics of CM (i.e., MC, carbon-to-nitrogen ratio (C/N), etc.) and, thus, the composting process itself. [17] Manure sources suitable for composting include solid dung, separated solid fractions, and settled sludges. [18] Mixture with a vegetable-based substrate may be appropriate to give the product structure, as well as an increased C/N ratio. Liquid manures should be previously processed through a solid-liquid separation treatment [10,13,19-20] unless only small amounts are added to the composting blend. Ammonia (NH_3) volatilization from mixtures with a high initial ammonium-N content can be difficult to avoid during composting. [15,18] Although a variety of materials can be employed as bedding material, in farms, use of cereal straw is rather common and many composting experiences have been described using such farmyard manure/bedding mixture. [21-24] Otherwise, straw can be also supplied as composting co-substrate. [25-26] Yet, straw may result expensive, which can limit its use. Blend of farmyard manure with other by-products prior to composting is also feasible [27-29] but appropriateness, availability of materials in the geographical area, and reasonable costs should be guaranteed. In this regard, co-composting may even imply an economic income for manure processing facilities.

The objective of this work was to assess a composting process based on turned windrows and involving treatment of beef CM. Effect of farmyard manure typology, addition of BA, and use of dewatered digested sewage sludge (DDSS) as co-substrate were considered. The quality of the produced compost was evaluated in terms of stability, chemical composition, and agricultural value. The assessment here described was carried out in the framework of a study for the farmers of Juncosa de les Garrigues.

Materials and methods

Feedstocks used for composting

Table 1 shows the composition of the feedstocks used in the composting experiment. Manure was collected from different beef cattle farms, where straw was used as bedding material, in Juncosa de les Garrigues. Two typologies of CM were considered according to their initial C/N ratio; typical value [1] (CM2, source: fattening calves, C/N ~ 14) and high value [1] (CM1, source: highly bedded young calves, C/N ~ 25) (Table 1). DDSS was obtained from the Waste Water Treatment Plant (WWTP) of Lleida (Catalonia). Sewage sludge from primary and secondary clarifiers is treated in mesophilic anaerobic digesters for biogas production and subsequently dewatered by means of centrifuge decanters. DDSS was tested as co-substrate because there is availability of such by-product in the area, and potentially, it might imply an economic income (coming from the WWTP) while supplying water and nutrients to the composting mixture. The BA consisted of hammer-milled municipal tree pruning waste from the city of Lleida. Use of BA was evaluated because it influences the aeration of the windrows during the composting process.

Composting procedure

Four composting windrows were prepared using CM alone (windrows 1 (W1, CM1) and 2 (W2, CM2)), CM mixed with BA (windrow 3 (W3, CM2/BA)), and CM mixed with DDSS and BA (windrow 4 (W4, CM2/DDSS/BA)) (Table 2). Experiments were carried out at the Catalan Municipal Waste Treatment Centres (MWTCs) of the Baix Camp County (Botarell) (W1) and the Segrià County (Montoliu de Lleida) (W2, W3, and W4). Feedstocks were transported to the MWTCs by truck. Windrows were prepared into paved and covered open buildings using a front-end loader. In W3 and W4, the materials to be composted were piled together targeting the volumetric ratios shown in Table 2, and subsequently mixed using a windrow turner. Raw materials were weighed before being piled. The resulting windrows were 1.3 ±0.2 m high and 2.9 ±0.2 m wide at the base, and varied in length from 9 to 13 m. Windrows were turned occasionally for aeration (roughly once per week; except for W1 first 3 weeks, when turning was 4 days per week) (Fig.1) by means of a windrow turner. Besides, the windrows were rewetted with water in order to provide moisture and to maintain its content between 40% and 65% (w/w) [17] throughout the experimental period (14 weeks).

Process monitoring

Temperature of the windrows was measured manually. It was averaged considering 4 measuring points per windrow (80 cm depth). Temperature was measured using a 638 Pt digital thermometer and a Pt100 penetration probe -1 m long- (Crison Instruments S.A., Alella, Spain). Mean daily air temperatures during the experimental period were obtained from weather stations located less than 10 km from the study sites. These temperatures averaged 21.9ºC (ranging from 14.2ºC to 26.0ºC) in the case of W1, and 16.3ºC (ranging from 7.3ºC to 27.8ºC) in the rest of the cases. Weekly, the MC in the windrows was measured gravimetrically after drying a fresh sample at 105ºC up to constant weight (3 replicates). Volume of the windrows was estimated once per month according to length, width, and height measurements, and expressed in relative terms (% of initial). Samples of feedstocks used for physicochemical characterization were obtained after receiving the feedstocks in the corresponding treatment centre. Samples of compost used for physicochemical characterization, stability, and biological tests were obtained after screening the compost and discarding particles larger than 15 mm.

Compost quality

Stability

Compost stability was evaluated qualitatively according to the Dewar self-heating test [30-31] (2 replicates). The principle of this method is to record the highest temperature achieved after placement of compost into a standardized vessel for several days. Interpretation of the results is based on division into five levels of 10ºC increments of the compost heating over ambient, ranging from Class I (40-50ºC or more) to Class V (0-10ºC).

Physicochemical analyses

The pH and electrical conductivity (EC) at 25ºC were measured using a pH-meter and a conductimeter, respectively, in a 1/5 (w/w) extract made with distilled water. OM was determined gravimetrically after ignition of a dry sample in a muffle furnace at 550ºC. Organic nitrogen (Org-N) was determined using the Kjeldahl method based on the digestion of a dry sample, distillation, and final titration. [31-32] Total ammonium (NH_4^+) was determined by distillation of a fresh sample diluted in water, and subsequent titration. [33] Nitrates (NO_3^-) were determined by ionic chromatography [34] in a 1/5 (w/w) water extract from a fresh sample. The C/N ratio was estimated considering C as organic-C (0.58*OM) [13] and N as Org-N plus NH_4^+-N. Phosphorus (P) and potassium (K), as well as cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) were determined by emission spectroscopy using the inductively coupled plasma (ICP) method after microwave-assisted acid digestion of a dry sample. [33-34] Analogously, mercury (Hg) was determined using the cold-vapor atomic fluorescence spectrometric (CVAFS) method. [35]

Biological tests

A modified germination test was carried out in order to evaluate phytotoxicity problems linked to the use of compost. [36] A filter paper was placed inside Petri dishes and wetted with 5 mL of compost/water extract at a ratio 1/5 (w/w). Then, 10 seeds of lettuce (*Lactuca sativa* L.) were placed on the paper. Deionized water was used as a control and all experiments were run in quadruplicate. The Petri dishes were covered with a bell to minimize water loss and then were incubated at 20ºC under a daily cycle of 8 h light / 16 h dark. The filter paper was kept moist throughout the test. At the end of 7 days, the percentage of seed germination in compost extract was compared with that of the water control and expressed in relative terms as germination percentage.

A modified growing test was carried out in order to evaluate the vegetal response to the use of compost. [31] The test was conducted in 500 mL plastic pots using certified barley seeds (*Hordeum vulgare* L.). Pots were filled with compost mixed with a reference substrate (peat) at ratios of 0, 25, and 50% (in volume) and watered with 18/20/20 (N/P/K) nutrient solution in order to obtain 150 mg N L^{-1} substrate. After a short period of time to allow the surplus of water to drain, 10 seeds were sown in each pot. All experiments were run in quadruplicate. The planted pots were kept in a greenhouse located at the Campus of the University of Lleida, where they were regularly watered. At the end of 21 days, the plants were harvested by cutting them off between the root and stalk, and the dry weight (at 65ºC) was recorded. The vegetal yield in the tested substrates (25-50% compost mixtures) was expressed as a percentage of the yield in the peat control.

Statistical analyses

Data concerning biological tests was subjected to an analysis of variance. The separation of means was done by the Duncan's multiple range test ($\alpha = 0.05$). The statistical analysis was made using the SAS statistical package. [37]

Results and discussion

Process monitoring

Temperatures into the thermophilic range (above 55ºC) were reached in all the experimental windrows (Fig.1), which is indicative of an intense microbial activity linked to the degradation of organic compounds. The achievement of high temperatures during composting increases the likelihood of better destruction of pathogens, parasites, and weed seeds. [15] In this regard, the US EPA [38] stated as guideline for pathogen elimination during biosolids windrow composting temperatures of 55ºC or higher for 15 days or longer (during this period, the windrow must be turned a minimum of 5 times). Maximum temperatures attained in this work were 71.0ºC for W1, 73.6ºC for W2, 66.6ºC for W3, and 68.9ºC for W4. However, time-dependent temperature profiles varied according to the treatment applied. It was not always possible to identify the usual pattern [10,19,24] of a thermophilic phase followed by a mesophilic phase. In addition, temperatures might fluctuate greatly throughout the experiment as previously reported in similar studies. [26] On the other hand, the MC in the windrows was significantly lower at the end of the process than it was initially even though the multiple rewetting events applied (Fig.1).

The slowest initial temperature increase was in W1 (it took 6 days to attain temperatures above 55ºC), probably because of the more frequent windrow turning during the first days of experiment. The averaged temperature of the windrow exceeded 55ºC in 45% of the days with data, and lower temperatures were obtained at the end of the experiment (the temperature upturns observed at this point may be explained by the rewetting events applied). Within W2, the temperature rose up faster than in W1 up to attaining the maximum value and then initiated a progressive decrease throughout the experimental period but not below 49ºC (temperature exceeded 55ºC in 74% of the days with data). A lower initial turning frequency may have reduced the composting rate [39] and resulted in a longer thermophilic phase (despite of the lower C/N ratio of CM2). A systematic turning schedule according to temperature registers, as used for example by Cáceres et al., [10] would help in enhancing the control over the process operation. In the case of W3, temperature increased similarly to W2 but then fell down below 49ºC for several weeks. Afterwards, temperatures into the thermophilic range were recovered and maintained until the end of the experiment (temperature exceeded 55ºC in 46% of the days with data). Hence, blending of CM with BA (at a volumetric ratio of 1/1), targeting an increase in the porosity of the windrow for a better aeration by natural convection, limited the attainment of temperatures above 55ºC. This behavior could be explained because of a lower capability of the windrow for heat retention and the non-reduction of the turning frequency with respect to W2. Use of BA may also help in conditioning high MC materials (such as sewage sludge), [40] but this is not necessarily applicable here, where manures to be processed had MCs below 70%. Thus, it is advisable to keep the use of BA to a minimum in order to save in running costs and space within the composting facility. Finally, temperature in W4 did not follow a clear trend, exceeding 55ºC in 69% of the days with data.

The high temperatures at the end of the experimental period of 14 weeks (particularly in W2, W3, and W4) would make advisable a longer time frame before stopping the process. Similar composting experiences (involving the formation of turned windrows for CM treatment) considered variable processing times depending on the case study, with active decomposition periods lasting from 8 to 21 weeks that could be followed by maturation periods comprising several months. [16,21-27] Inappropriate duration of the global process will have negative effects on the quality of the produced compost, resulting in a poorly stabilized and immature material with a limited potential use. [7] Thus, temperature drop to ambient level (while assuring appropriate MC) should be prioritized as indicator of completion of the active decomposition period [17] in relation to other operational criteria such as processing time length (e.g., linked to space availability in the treatment facility).

The volume of the windrows decreased sharply throughout the experiment. Final volume of the windrows accounted for only 40-54% of the initial volume (Table 3). This reduction is consistent with the values reported by other authors, [13,21] being mainly attributable to the conversion of organic compounds into carbon dioxide (CO_2), loss of moisture, and reduction of the particles size during composting. Such volume reduction (and consequent mass loss) results in the concentration of the mineral fraction, which helps to increase the transportability of the final product (compared to fresh manure) for the export of nutrients to long distances. [41]

Compost quality

Stability

Once the process was finalized, only compost from W1 reached the maximum degree of stability in the self-heating test (Table 4). Poorly stabilized composts can pose problems during storage or shipping, and use. The material may become anaerobic, odorous, and develop toxic compounds. Active decomposition of the material after application to soil or addition to growing media can impair plant growth by reducing root-available oxygen, plant-available nitrogen, or through release of phytotoxic compounds into the root zone. [42]

Chemical composition

Table 5 shows the main physicochemical characteristics of the final composts obtained from the four treatments applied. The pH values were neutral to alkaline depending on the particular case. Final pH in compost from W1 was especially high (above 9.0), which could have important implications on the fertility and productivity of soils subjected to compost amendment, as well as on the development of pH-sensitive plants. [43] High occurrence of nitrification (conversion of NH_4^+ into NO_3^-) after the thermophilic phase may help in reducing the pH (and alkalinity) of the compost since it is an acidifying process. [10,13,23] The measure of EC is meaningful because it reflects the salinity of the compost, i.e., overly salty compost is likely harmful to plants. In this regard, higher sensibility to EC exists when compost is used as growing media. [11] Owing to the increase in the concentration of mineral matter throughout the process, the EC of the final compost rose up to 8.4-15.4 dS m^{-1} (values measured after 1/5 (w/w) water extraction). Those composts obtained exclusively using CM presented the higher values. Generally, the EC of animal manure composts are higher than those of other organic waste composts. [44] Blending of these composts with other non-saline materials may help in balancing the EC.

The OM content of the composts was lower than that of the processed feedstocks due to the degradation of organic compounds and the consequent release of C as CO_2. Final C/N ratios in the compost were 14.7 for W1, 9.6 for W2, 10.4 for W3, and 8.5 for W4. The concentration of Org-N increased for composts from W1, W2, and W3 with respect to the corresponding raw feedstocks, but not for compost from W4 (prepared using DDSS). Initially, this last windrow presented the highest concentration of NH_4^+-N but the lowest C/N ratio, which resulted in significant losses of N due probably to NH_3 volatilization. [45] Literature usually describes negative correlation between the C/N ratio and N loss during composting, [24,26] with recommendable initial values for the C/N ratio above 20. [17] However, some works dealing with CM composting report lower initial values for the C/N ratio, [16,46] and that NH_3 volatilization is also favored by other factors such as high concentrations of easily decomposable N and C compounds in the raw material, high number of turnings, good porosity, high temperature and pH, and warm environmental conditions. [47] Whatever the reason, N losses by volatilization should be minimized in order to (i) retain N in the compost so as to maximize its fertilizing value for crop production and (ii) reduce their environmental impact, e.g., release of NH_3 (offensive odorant and acidifying agent). On the other hand, high losses of soluble forms by runoff were not expected since composting was performed on covered surfaces that preserved the windrows from rain. Concentrations of NH_4^+-N declined throughout processing but ranged from < 0.01% (W1) to ~ 0.3% (W2, W3, and W4) on a dry weight basis. Thus, only in W1 the final NH_4^+-N content was below the maximum of 0.04% recommended in finished composts. [48] In addition, the NH_4^+-N/NO_3^--N ratio in this compost was as low as 0.20 (NO_3^--N = 0.03%), practically equaling the threshold of 0.16 established as indicator of maturity by Bernal et al. [49]

Presence of heavy metals in compost must be controlled in order to protect soil quality and prevent contamination [50]. In this regard, the Spanish legislation establishes limitations in the heavy metal contents of the fertilizing products made from waste and other organic components [51] (threshold concentrations of Cd, Cr, Cu, Hg, Ni, Pb, and Zn are 0.7, 70, 70, 0.4, 25, 45, and 200 mg kg^{-1} dry weight for the higher quality products (class A); 2, 250, 300, 1.5, 90, 150, and 500 mg kg^{-1} for the medium quality products (class B); and 3, 300, 400, 2.5, 100, 200, and 1000 mg kg^{-1} for the lower quality products (class C), respectively), as well as growing media [52] (same threshold concentrations for classes A and B, but not applicable for class C). In our study, compost from W4 (prepared using DDSS) presented the highest heavy metal contents. Concentrations of Cd, Cr, Cu, Hg, Ni, and Zn above those previously referred for class A products were measured in this compost, but still below thresholds proposed for class C products. However, concentrations of Cu and Zn were also high when composting CM alone. These relatively high concentrations in compost are largely derived from additives used as animal feeds that can contain high levels of these metals since most of the dietary Cu and Zn are not assimilated by livestock, but excreted in manure. [44]

Biological tests

Germination test

The best results of the germination test were obtained for the compost extract from W1, although germination was lower than for the water control (Table 6). Conversely, strong phytotoxicity was evidenced for the compost extract from W2 since no seed germination took place in this case. Phytotoxicity linked to the use of immature compost, or fresh manure, can be caused by several parameters including salinity, NH_4^+, organic compounds such as fatty acids and phenolic substances, and heavy metals. [12,53-54]

Growth test

According to FCQAO [31] recommendations, compost is considered to be tolerated by plants, and suitable as soil improver and fertilizer, if no visible chlorosis or necrosis appear on the leaves, and the vegetal yield when using 25% compost mixture reaches at least 90% of the yield obtained using the reference substrate alone. In this study, the yield achieved using mixture of compost from W1 (25% compost + 75% peat) was even higher than the yield achieved using reference substrate (100% peat) (Table 7), and no visible damage was detected in the barley plants. These satisfactory results were not obtained for composts from W2, W3, and W4. On the other hand, and according to the aforementioned source, [31] compost can be used as blending component for growing media if the vegetal yield when using 50% compost mixture reaches at least 90% of the yield obtained using the reference substrate alone. Again, results for compost from W1 were satisfactory (but not for the others), although there was a little delay in germination which had no effects in the final growth.

Conclusions

I. A full-scale composting process in turned windrows was monitored during 14 weeks. CM alone (two typologies of manure, i.e., with C/N ratios of ~ 25 (CM1, W1) and ~ 14 (CM2, W2)), or mixed with BA (CM2/BA blended at volumetric ratios of 1/1, W3) and DDSS/BA (CM2/DDSS/BA blended at volumetric ratios of 1/1/1, W4) was used in this experiment.

II. Temperatures > 55ºC were reached in all the treatments (which has positive implications concerning sanitation), but following different time patterns. Under the applied conditions of turning (frequency of ~ 1 time per week; except for W1 first 3 weeks, when turning was 4 days per week) and rewetting (40% < MC < 65%), the length of processing was not enough to obtain stable composts. Thus, only compost from W1 attained the maximum degree of stability. Use of BA (while maintaining turning frequency) reduced temperatures into the thermophilic range. A systematic program for the turning of the windrows according to the temperatures achieved during processing, as well as the assurance of the temperature drop to ambient levels at the end of the active decomposition period, would enhance the control over the process.

III. The volume of the windrows decreased sharply throughout the process, with final volumes accounting for 40-54% of initial.

IV. Chemical composition of the final composts evidenced high fertilizing values in terms of N/P/K. However, only compost from W1 satisfied the recommendations for the concentration of NH_4^+-N in mature composts (< 0.04%), with NH_4^+-N/NO_3^--N = 0.20. Addition of DDSS in W4 resulted in high contents of metals in the compost although Cu and Zn were also high when composting CM alone. The high pH (in case of W1), EC, or heavy metal contents may limit the use of the composts.

V. Maturation must be assured to reduce phytotoxicity issues. Biological tests (germination and growth) were conducted to evaluate the agronomic value of the final composts. Positive results were obtained only for compost from W1, satisfying the required criteria to be used as soil improver, fertilizer, or in the preparation of growing media.

VI. Use of BA is advised to be kept to a minimum when composting CM (although it may enhance convective aeration of windrows or help in the conditioning of feedstocks with MCs > 70%) to save in running costs and space within the treatment facility. Addition of DDSS is not advisable (even if it might represent an economic income) because it favors the loss of N, and increases the heavy metal contents in the final compost. Nutrient retention during composting must be guaranteed by minimizing NH_3 emissions.

VII. Overall, composting enhances the transportability of nutrients to long distances. This will reduce the risk of environmental affectations (soil, air, and water quality degradation) in areas with high farm densities such as Juncosa de les Garrigues while enhancing soil quality and crop productivity in other nutrient-deficient areas.

Acknowledgements

This research was funded by the Farmers Association of Juncosa de les Garrigues. Authors thank the collaboration of FCC Medio Ambiente exploiting the MWTC of the Segrià County, SECOMSA exploiting the MWTC of the Baix Camp County, and the experimental work carried out by the students Patrícia Martín and Vanessa Salvador (University of Lleida) as part of their degree thesis.

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Table 1. Physicochemical characteristics of the feedstocks used for composting (results except the MC, pH, and EC are expressed on a dry matter basis).

Parameter	CM1	CM2	DDSS
MC (%)	68.7	65.6	76.6
pH	8.8	8.6	8.3
EC (dS m^{-1})	8.2	6.5	3.8
OM (%)	79.8	72.8	45.6
Org-N (%)	1.64	2.36	3.73
NH_4^+-N (%)	0.20	0.70	2.18
NO_3^--N (%)	0.01	< 0.01	< 0.01
C/N ratio	25.2	13.8	4.5
P (%)	0.78	0.72	2.63
K (%)	3.44	2.76	0.46
Cu (mg kg^{-1})	11.4	60.5	267
Zn (mg kg^{-1})	157	520	693
Cd (mg kg^{-1})	nm	0.1	0.9
Cr (mg kg^{-1})	nm	< 11	153
Hg (mg kg^{-1})	nm	nd	1.93
Ni (mg kg^{-1})	nm	nd	27
Pb (mg kg^{-1})	nm	nd	60

CM: cattle manure; DDSS: dewatered digested sewage sludge; EC: electrical conductivity; MC: moisture content; nd: not detected; nm: not measured; OM: organic matter; Org-N: organic nitrogen.

Table 2. Mixtures of materials to be composted.

Windrow	Materials	Targeted volumetric ratio	Weight (Mg)
W1	CM1	-	20
W2	CM2	-	9.3
W3	CM2/BA	1/1	10.3/1.8
W4	CM2/DDSS/BA	1/1/1	7.4/11.0/1.4

BA: bulking agent; CM: cattle manure; DDSS: dewatered digested sewage sludge; W: windrow.

Table 3. Evolution of the relative volume (% of initial) for the composting windrows (W).

Time (weeks)	W1	W2	W3	W4
1	100	100	100	100
4	83	77	66	86
9	68	59	60	54
14	54	47	40	41

Table 4. Results of the self-heating test at the end of the composting process.

Compost	Class
W1	V
W2	III
W3	III
W4	IV

W: windrow.

Table 5. Physicochemical characteristics of the final composts (results except the MC, pH, and EC are expressed on a dry matter basis).

Parameter	Compost			
	W1	W2	W3	W4
MC (%)	34.8	24.2	18.2	24.5
pH	9.3	8.0	8.0	7.2
EC (dS m^{-1})	14.7	15.4	12.4	8.4
OM (%)	66.6	52.4	55.7	35.9
Org-N (%)	2.63	2.85	2.82	2.15
NH_4^+-N (%)	< 0.01	0.30	0.28	0.30
NO_3^--N (%)	0.03	< 0.01	< 0.01	0.10
C/N ratio	14.7	9.6	10.4	8.5
P (%)	1.58	1.12	1.07	2.07
K (%)	2.42	4.23	3.34	2.22
Cu (mg kg^{-1})	21	97	103	181
Zn (mg kg^{-1})	242	873	801	629
Cd (mg kg^{-1})	nm	< 0.7	< 0.7	0.8
Cr (mg kg^{-1})	nm	< 10	13	81
Hg (mg kg^{-1})	nm	0.13	0.12	1.32
Ni (mg kg^{-1})	nm	25	44	38
Pb (mg kg^{-1})	nm	< 20	< 20	42

EC: electrical conductivity; MC: moisture content; nm: not measured; OM: organic matter; Org-N: organic nitrogen; W: windrow.

Table 6. Results of the germination test. Relative germination percentage for lettuce seeds after 7 days of incubation. Values followed by the same letter are not significantly different ($\alpha = 0.05$).

Extract	Germination (%)
Control (water)	100 e
Compost from W1	89 d
Compost from W2	0 a
Compost from W3	19 b
Compost from W4	77 c

W: windrow.

Table 7. Results of the growth test. Relative vegetal yield of barley after 21 days in the 25-50% compost mixtures with respect to the reference substrate. Values in the same column followed by the same letter are not significantly different ($\alpha = 0.05$).

Substrate	25% compost + 75% peat	50% compost + 50% peat
Reference (100% peat)	100% b	100% b
Compost from W1	197% c	124% b
Compost from W2	56% a	12% a
Compost from W3	36% a	28% a
Compost from W4	30% a	33% a

W: windrow.

Figure 1. Evolution of the temperature and moisture content (MC) in the composting windrows (W).

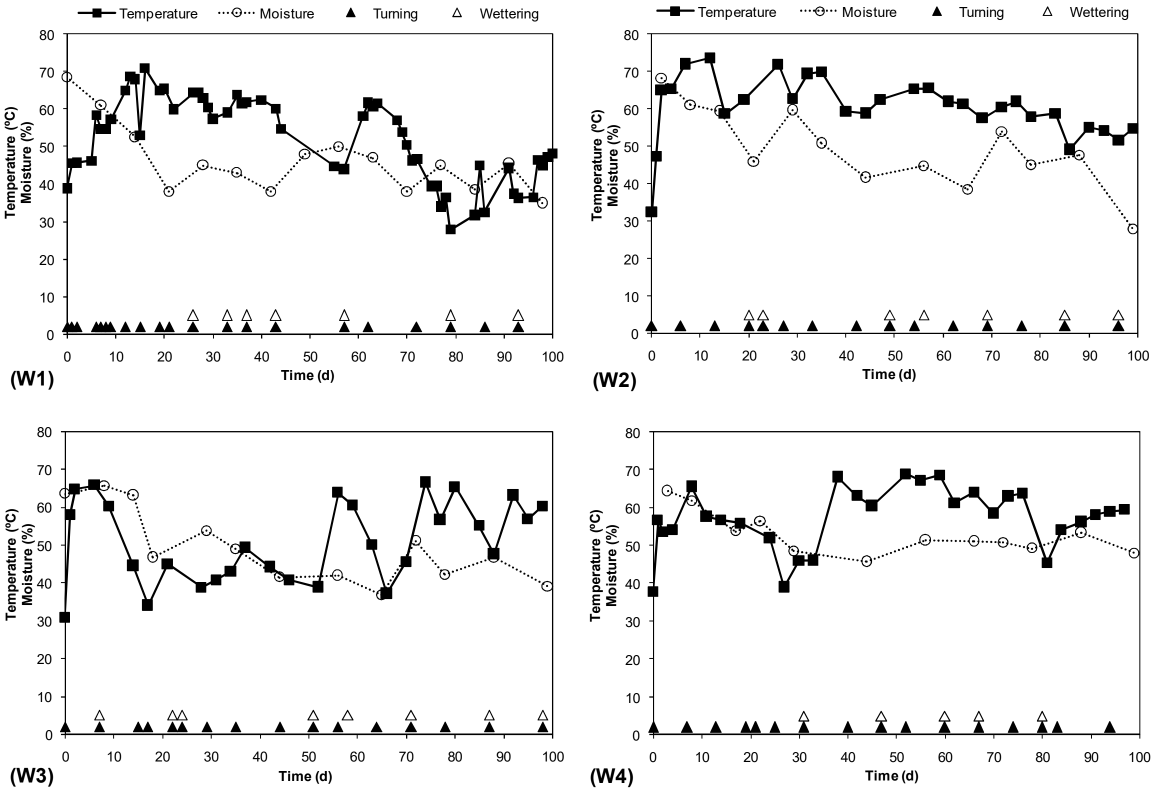
Temperature
Moisture
Turning
Wettering
Temperature (ºC)
Moisture (%)
Time (d)
0
10
20
30
40
50
60
70
80
90
100
(W1)
(W2)
(W3)
(W4)

Fig. 1