



Quality assessment of composts officially registered as organic fertilisers in Spain

Belén Puyuelo¹, Joseba S. Arizmendiarieta^{1,2,3}, Ignacio Irigoyen^{1,3} and Ramón Plana^{1,4}

¹Fertile Auro Association, 36211 Vigo, Spain. ²Luar Environmental Consultancy, Euskadi, Spain. ³Public University of Navarre, Dept. Agronomy, Biotechnology and Food, 31006 Pamplona-Iruña (Navarre), Spain. ⁴Organic Wastes Management Consultancy, 08027 Barcelona, Spain.

Abstract

Composting of organic wastes is a management strategy linked to circular economy models through the transformation of these wastes into an organic product, compost, which can be used as fertiliser, soil amendment or growing media. However, the concept of 'compost quality' is not enough defined to take a technical decision about which is its best use or application. In the last decade, different guidelines and regulations about organic fertilisers have been developed. For instance, in Spain the Fertilisers Regulation categorises compost under five kinds according to the raw materials used – organic amendment compost (OaC), manure compost (MaC), green compost (GrC), vermicompost (VC), 'alperujo' compost (AIC) –, and under three quality levels (A, B or C) depending exclusively on the heavy metals content. This work analyses the national database of all composts (307) marketed in Spain, considering the analytical parameters declared, with the objective of proposing a methodology to define a global quality index. For this assessment, two indicators are employed: a fertility indicator, related to the nutrients content, and a clean indicator, related to the heavy metals content. Results show an average compost formulation 2.5:2.5:2.5 (N:P₂O₅:K₂O). MaC and OaC present the highest fertility indicator, whereas VC the lowest. Regarding the clean indicator, GrC, MaC and VC are cleaner than OaC. In the future, this new quality assessment should be completed by including other indicators related to physical and biological characteristic (*e.g.* porosity, stability/maturity, phytotoxicity) that could determine the most proper use of compost.

Additional keywords: compost quality; heavy metals; macronutrients; maturity; fertility indicator; clean indicator.

Abbreviations used: AIC (Alperujo Compost); CI (Clean Indicator); EWC (European Waste Code); FI (Fertility Indicator); GrC (Green Compost); MaC (Manure Compost); MITECO (Ministerio Transición Ecológica); OaC (Organic amendment Compost); RD (Real Decreto/Royal Decree); TOC (Total Organic Carbon); Wi (Weighing factor).

Authors' contributions: Conceived, designed and performed the experiments: BP, JSA and RP. Analyzed the data: BP and JSA. Contributed reagents/materials/analysis tools: II and BP. Wrote the paper: RP, BP and II. All authors read and approved the final manuscript.

Citation: Puyuelo, B.; Arizmendiarieta, J. S.; Irigoyen, I.; Plana, R. (2019). Quality assessment of composts officially registered as organic fertilisers in Spain. Spanish Journal of Agricultural Research, Volume 17, Issue 1, e1101. <https://doi.org/10.5424/sjar/2019171-13853>

Received: 26 Aug 2018. **Accepted:** 14 Mar 2019.

Copyright © 2019 INIA. This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC-by 4.0) License.

Funding: European Agricultural fund for Rural Development and Rural Development Program of Gobierno de Navarra 2014-2020 (project "Pilot Project of circular bio-economy of organic wastes at local scale with social and training dimension").

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to Ramón Plana: plana.compost@gmail.com

Introduction

One of the main widespread critics to the inclusion of composting in the organic waste management strategies, which limits its implementation, is the statement that there is neither demand nor market for the resulting product: compost. However, according to the needs of organic matter in soils, it is highly required to provide them with amendments and organic fertilisers, given the serious progressive global loss of fertile soil, which is estimated at 75 billion tonnes a year (Pimentel & Burgess, 2013).

Focusing on the Mediterranean basin, the organic carbon content of more than 75% of soils is lower than 2% (Zdruli *et al.*, 2004). In the specific case of Spain, according to official figures by the Spanish Ministry for the Ecological Transition (MITECO in its Spanish acronym), more than 50% of croplands have an organic matter content of less than 1.7% (López & Grau, 2005), the minimum concentration to consider a soil at risk of desertification.

Such scenario presents a growing demand for the supply of inputs to the soils to keep their fertility and productivity, but high quantities of those inputs are

imported from other territories. That is the case, for example, of phosphorus; a non-renewable resource mainly found in mines in Morocco and other countries in the North of Africa, Middle East and China, and whose demand is expected to increase by 2% per year from 2020 (Jasinski, 2017). Regarding Spain, a heavy reliance on these inputs is noticeable, as in the last five years the imports of mineral and organic fertilisers and peat moss have grown by around 25-30%. During 2016, imports of such materials reached 1.3 million tonnes (AEAT, 2017).

In this context, it is clear the need and demand of a local product – or at least national – able to act as organic amend for the improvement and/or conservation of soils, and that has macro and micronutrients nourishing the crops. Such product is compost. Nevertheless, even if composting facilities have been processing urban wastes since 1931 (Larsen, 1993), the evolution in the composition of such wastes has varied significantly since the middle of the last century (Walsh, 2002) from being mainly composed by organic remains, to be more and more polluted by nonorganic materials (plastic, glass, metals...). This new situation diffculted the operation of waste management facilities as well as increased their operation cost. Furthermore, the final product –the so-called compost – had lower quality due to (i) the presence of inert materials, (ii) higher concentration of heavy metals, and (iii) its elaboration was less cared because of the increased treatment costs. Given this gradual reduction of its visual and agronomic quality, the word compost has become, along the second half of the 20th century, a concept with negative connotations, which impacts on its demand in the agricultural and professional market.

In order to protect soils, as well as to avoid contamination in the food chain and to guarantee the quality of the materials used in agriculture, official guidelines have been set on fertilisers likely to be applied in croplands; which include those of organic nature, and those produced through the composting process. These national and international regulations describing the standards on the quality of compost are limited to legal definitions, lists of organic materials accepted in its production, and to the establishment of legal categories of product's quality according to its content of heavy metals (Brinton, 2000). For example, the European Waste Framework Directive (EC, 2008) established the source-separate collection of biowaste as mandatory to produce compost. On the contrary, it will be considered a biostabilised product, not allowed for agricultural use. Once compost fulfils such legal requirements of the Framework Directive, no further distinctions are demanded, that may allow assessing the higher or lower quality of the product

during its final application, like the fertility potential. At European level, the most recent normative on the quality of compost, referenced below, introduces benchmarks boosting the distinction between kinds and quality grades of the product, such as the minimum maturity and stability levels that compost must have. In the case of Spain, the most recent guidelines on fertilisers RD 506/2013 and its update RD 999/2017 (BOE, 2017); from now on Spanish Fertiliser RD, which is the transposition of the European Regulation no. 2003/2003 (EC, 2003); categorise compost in five kinds – according to the raw materials used – and in three quality levels (Class A, B or C) depending only on the heavy metals content of compost. In this regard, Class A of the Spanish legislation resembles the EC Ecolabel (EC, 2015) and the Austrian Compost Ordinance (2001), considered as the most demanding guidelines on compost quality (Table 1). Anyway, such European guidelines (Saveyn & Eder, 2014) and others like Portuguese (DRE, 2015), introduce additional benchmarks for the determination of the legal quality (apart from the concentration of heavy metals), which does not happen in the Spanish legislation.

Thus, even if this legal framework has clarified legally what compost is, some confusion exists still among consumers about the different quality levels that this product may have depending on what it will be used or applied for. Such confusion has negative impact on its demand and consumption. Additionally, it is important to consider that some composting facilities are more focused on keeping at all costs the possibility of receiving enough organic waste to guarantee their economic viability. In these cases, compost sales are not an important factor in the facilities' management. They just seek to reach the minimum legal requirements for the final product to be considered as compost. On the contrary, there are facilities, mainly privately managed, that do try to obtain specific characteristics for their compost in order to increase their economic value: maturity, minimum concentration of macro and micronutrients, particle size, concentration of heavy metals, etc. In these cases, the type and quantity of the wastes treated, the chosen composting system, and the process duration are decisive.

Moreover, in the case of Spain and other countries, there is not verified public information about the total quantities of compost produced per year in all the existing composting facilities. In Spain, only some autonomous communities, like Catalonia, offer estimated quantities of compost produced in public composting sites. That means that this information is limited to the product obtained from urban biowaste selectively collected, but no details are published regarding compost from sewage sludge, green wastes,

Table 1. Different legislations on the maximum heavy metals content permitted in compost, which determines its legal quality.

Legal basis or Standard	Quality / Standard	Maximum concentration values (mg kg ⁻¹ dm)								
		As	Cd	Cr (Tot)	Cr (VI)	Cu	Hg	Ni	Pb	Zn
EU - Council Regulation No 2092/91 (EEC, 1991)		-	0.7	70	0	70	0.4	25	45	200
EU - End-of-waste criteria on biodegradable waste subject to biological treatment (Saveyn <i>et al.</i> , 2014)		-	1.5	100	-	200	1.0	50	120	600
EU - COM Decision 2015/2099 eco-label to growing media (EC, 2015)		-	1.0	100	-	100	1.0	50	100	300
Spain - RD 506/2013 on Fertiliser Products (BOE, 2017)	Class A	-	0.7	70	nd	70	0.4	25	45	200
	Class B	-	2.0	250	nd	300	1.5	90	150	500
	Class C	-	3.0	300	nd	400	2.5	100	200	1000
Austria - Compost Ordinance BGB1.I I 292/2001 (Austrian Compost Ordinance, 2001)	Class A+	-	0.7	70	-	70	0.4	25	45	200
	Class A	-	1.0	70	-	150	0.7	60	120	500
	Class B	-	3.0	250	-	500	3.0	100	200	1800
Canada – Guidelines for Compost Quality	Category A	13	3.0	210	-	400	0.8	62	150	700
Canadian Council of Ministers of the Environment (CCME, 2005)	Category B	75	4.0	-	-	-	5.0	180	500	1850
Portugal – Law Decree (No 103/2015) on Fertiliser Products (DRE, 2015)	Class I	-	0.7	100	-	100	0.7	50	100	200
	Class II	-	1.5	150	-	200	1.5	100	150	500
	Class II A	-	3.0	300	-	400	3.0	200	300	1000
	Class III	-	5.0	400	-	600	5.0	200	500	1500

(-) not considered. nd: below the detection limit.

livestock manures, or other organic wastes legally authorized as raw material for compost production. Even though, every compost producer in Spain that markets its product must register it in the Ministry for the Ecological Transition (MITECO in its Spanish acronym). All products registered in the fertilisers list must also provide information about the producer, raw materials and the details of their final physico-chemical and biological analysis (main and secondary elements, micronutrients, heavy metals and pathogens, among others) performed by a certified laboratory and in accordance with UNE methodology, where it is proven that the parameters fulfil the requirements included in the national legislation in force (Spanish Fertiliser RD). Taken into account the organic wastes used in the formulation of each compost and to the elaboration process, the Spanish register establishes five different categories of compost.

Nevertheless, Spanish compost market is at a disadvantage for not having real information about the quantity produced, and because it does not exist a common and compulsory classification allowing distinguishing the different produced composts according to their quality, beyond their content of heavy metals. Such classification would help to determine which is the most appropriate use, as well as dose and form of application for each compost.

The quality indicators or indexes of compost included in the bibliography are of two kinds (Wang *et al.*, 2004; Huerta *et al.*, 2008; Saha *et al.*, 2010; Martínez *et al.*, 2016):

- Legal: ruled primarily by the heavy metals content and addressed to guarantee that minimum levels on the following aspects are reached: organic matter content, C/N ratio, sanitation, absence of extraneous elements and, occasionally, compost stability.
- Agronomic or fertility-related: for which the evaluated aspects are the macronutrients content (N, P, K), the total organic carbon (TOC) and the C/N ratio. In the case of growing media manufacturers and depending on the use of compost, other parameters may be included; such as conductivity, particle size and phytotoxicity (germination rate).

The quality indicators developed in India by Saha *et al.* (2010) deserve to be highlighted. They assess both indexes for rating the fertility and cleanness of a compost by defining different factors for various parameters and by applying weighing factors. The criteria that Saha *et al.* (2010) developed were applied specifically to the local context of their geographical area (*e.g.*, low nitrogen content of wastes) and are set according to the physical and chemical parameters established in their legislation – The Fertiliser (Control) Order 1985 (Official Gazzete,

1985) – to which has been also added the measuring of the stability of compost. In this sense, the main goal of this work is to present the main characteristics of the Spanish compost and to define a quality assessment system adapted to them.

Material and methods

Analysis of the information registered in the Spanish fertilisers list (Group VI)

To develop this study, the Spanish registry of fertilisers regulated by the Spanish Fertilisers RD and available at the Agriculture section of the website of the Ministry for the Ecological Transition (MITECO) has been consulted on March 30th of 2018. The register contains 44 product categories. However, when carrying out this study, the only categories analysed were those classified under the heading about organic, which are the following ones: (i) ‘6002-Organic amendment compost’ (OaC), (ii) ‘6003-Green compost’ (GrC), (iii) ‘6004-Organic amendment manure compost’ (MaC), (iv) ‘6005-Organic amendment vermicompost’ (VeC), and (v) ‘6009-Alperujo compost’ (AIC). A database has been elaborated with all the available information in the registry for each different compost of each category (OaC, GrC, MaC, VeC and AIC). For each compost the following aspects are considered: (i) European Waste Code (EWC) of raw materials composition; (ii) content in main elements (total N, nitric N, ammoniacal N, organic N, ureic N, P₂O₅, K₂O), secondary elements (SO₃, Na₂O, CaO, MgO), micronutrients (B, Co, Cu, Fe, Mn, Mb, Zn), other characteristics (organic matter, organic carbon, humic extract, humic acids, fulvic acids, Cl⁻, maximum humidity, conductivity, density, pH, C/N), heavy metals (Cd, Cu, Ni, Pb, Zn, Hg, Cr, Cr(VI)) and pathogens content (*Salmonella* and *E. coli*).

Before initiating the analysis of the databases, the information provided by the different registries has been unified and standardised, by performing a previous consideration of some aspects in order to filter the collected samples. Once all data were explored and validated, a descriptive statistical analysis (means, standard deviations) of the physico-chemical parameters of the compost of each category was performed. In addition, frequency with which each residual raw material intervenes as an ingredient in the compost of each category was calculated and plotted.

Besides this, correlations between different physical and chemical parameters and the different waste raw

materials used in the formulation of each compost were computed using SPSS Statistics 23.

Quality assessment definition

In order to define a quality assessment system for Spanish’s compost, the study of Saha *et al.* (2010) was used as reference. A methodology has been developed to calculate new fertility and clean indicators adapted to the Spanish context. To do this, it has been taking into account the parameters of the quality check of compost established in the Spanish legislation (Spanish Fertiliser RD) as well as the most demanded characteristics of fertilisers in the European market.

Fertility indicator

The fertility indicator (FI) of produced composts has been set according to the formula proposed by Saha *et al.* (2010):

$$FI = \frac{\sum_{i=1}^n S_i W_i}{\sum_{i=1}^n W_i}$$

where S_i is a factor associated to the content of each parameter considered in the assessment of fertility and W_i is their weighing factor.

In order to establish the FI, the stability degree of the organic matter has not been considered, contrary to what Saha *et al.* (2010) did, since it is not a parameter required by the Spanish legislation and, therefore, it is not available in the analysis of the MITECO’s fertilisers registry. While trying to estimate the measure of stability, which is moreover an indirect measure of the maturity (Oviedo *et al.*, 2015), attempts were made to estimate such parameter through other connections such as humic/fulvic acids or ammonium/nitrate (Jiménez & Pérez, 1992; Ko *et al.*, 2008). However, a very low percentage of samples state publicly those parameters, so the obtained results are only partial, in order to be able to consider maturity for the determination of the FI. The rest of the parameters considered in the study of Saha *et al.* (2010) to determine the FI (TOC, N, P, K and C/N) have been included in the present study by adapting to a greater or lesser extent the score values and the weighing factor to the European characteristics. Nitrogen is the parameter that suffers the highest variations in the score values. The low N content of the typical composts of the original study is more limited because of the low availability of wastes rich in proteins or livestock manures. Additionally, so as to achieve a higher distinction within the analysed samples, it has been considered relevant to use 6 scoring categories (from 0 to 5, where 0 is the minimum content of

macronutrients) instead of the 5 established by Saha *et al.* (2010) (Table 2). The weighing factors (W_i) considered are the same used by the authors.

Clean indicator

The clean indicator (CI) assesses the quality of compost according to its heavy metals content and has been established by the following equation (Saha *et al.*, 2010):

$$CI = \frac{\sum_{j=1}^n S_j W_j}{\sum_{j=1}^n W_j}$$

where S_j is a factor associated to the analytical result of the heavy metal and W_j is the weighing factor assigned to that specific heavy metal.

The score values proposed by Saha *et al.* (2010) have been adapted to the heavy metals content defined in the Spanish Fertilisers RD for the three quality categories (Class A, B or C). Moreover, an additional heavy metal (Hg) has been considered. The suggested values for the six scoring categories (from 0 to 5, where 0 represents the highest content of heavy metals) are equidistant. A maximum value of 5.5 is allowed for those products with a concentration in heavy metals lower than that required for the cleanest category (see Table 2). The weighing factor coincides with that used by Saha *et al.* (2010), adding the maximum factor to Hg due to its negative effects in the nervous system and foetal development in mammals (Govind & Madhuri, 2014).

Results and discussion

Four registered typologies of compost (281 entries) have been analysed: OaC (66.9%), MaC (10.0%), GrC (6.0%) and VeC (17.1%). When this work was performed there were only two composts registered as ALC, so this category has not been taken into consideration in this manuscript. Based on the information registered in the MITECO's database about physico-chemical characteristics, average values have been calculated in order to define a product-type for each compost typology (Table 3). The average values obtained show important differences among the four analysed typologies (OaC, MaC, GrC and VeC) in the type and amount of raw materials used in the production of compost (Fig. 1), in their composition (heavy metal contents, macronutrients and micronutrients), as well as in other physico-chemical parameters.

Raw materials used in the production of compost

The different compost typologies analysed in this paper have been produced from organic wastes or from by-products of different origin identified by their EWC. Figure 1 shows the main raw materials and the proportion in which they are used as ingredients for each of the analysed compost kinds. The EWC codes that most frequently appear in the composition are 020103 and 020106, which refer, respectively, to green waste and livestock manures. Those classified as green waste (020103) appear in 28.6% of OaC, in 14.8% of

Table 2. Impact factors (S_i) and weighed parameters (W_i) used to determine the fertility indicator (FI) (total organic carbon (TOC) content, macronutrients and C/N ratio) and the clean indicator (CI) (Cd, Cu, Ni, Pb, Zn, Hg, Cr) of studied composts. All analytical units are expressed on the dry matter (dm).

	S_i						W_i
	5	4	3	2	1	0	
FI							
TOC (% dm)	34.0	29.2	24.4	19.6	14.8	10	5
N (% dm)	5.0	4.0	3.0	2.0	1.0	0	3
P (% dm)	3.0	2.4	1.8	1.2	0.6	0	3
K (% dm)	3.0	2.4	1.8	1.2	0.6	0	2
C/N ratio	4.0	7.2	10.4	13.6	16.8	20	4
CI							
Cd (mg kg ⁻¹)	0.3	0.84	1.38	1.92	2.46	3.0	5
Cu (mg kg ⁻¹)	35	108	181	254	327	400	2
Ni (mg kg ⁻¹)	12	29.6	47.2	64.8	82.4	100	1
Pb (mg kg ⁻¹)	22	57.6	93.2	128.8	164.4	200	3
Zn (mg kg ⁻¹)	100	280	460	640	820	1,000	1
Hg (mg kg ⁻¹)	0.2	0.6	1.1	1.58	2.0	2.5	5
Cr (mg kg ⁻¹)	36	88.8	141.6	194.4	247.2	300	3

Table 3. Physico-chemical characteristics of the different compost categories analysed.

	OaC	MaC	GrC	VeC
Density, kg·L ⁻¹	0.8 ± 1.1	0.6 ± 0.2	0.8	0.6 ± 0.1
pH	7.5 ± 0.6	7.9 ± 0.7	7.7 ± 0.7	7.6 ± 0.5
Total OM, % (dm)	45.3 ± 9.2	48.9 ± 12.4	49.6 ± 12.8	37.4 ± 6.6
Organic carbon, % (dm)	23.7 ± 6.5	28.1 ± 8.4	25.5 ± 9.5	18.4 ± 3.9
Total humic extract, % (dm)	12.8 ± 6.6	12.2 ± 6.3	13.0 ± 14.1	11.5 ± 7.0
Humic acids, % (dm)	6.8 ± 4.6	5.8 ± 3.8	6.4 ± 4.8	7.5 ± 9.3
Fulvic acids, % (dm)	6.4 ± 4.5	6.3 ± 4.3	8.3 ± 11.7	6.2 ± 7.1
C/N ratio (C org./N org.)	13.7 ± 3.3	14.1 ± 3	12.5 ± 3.6	12.7 ± 3.3
Total N, % (dm)	2.16 ± 1.24	2.44 ± 0.98	2.03 ± 0.92	1.61 ± 0.57
N-NH ₄ ⁺ , % (dm)	0.32 ± 0.38	0.54 ± 0.6	0.06 ± 0.18	0.01 ± 0.03
N org, % (dm)	1.84 ± 0.83	2.16 ± 0.98	1.93 ± 0.91	1.49 ± 0.45
P ₂ O ₅ , % (dm)	1.72 ± 1.23	2.32 ± 1.54	0.76 ± 0.65	1.71 ± 0.94
K ₂ O, % (dm)	1.47 ± 0.84	2.46 ± 1.28	1.47 ± 1.03	1.10 ± 0.89
SO ₃ , % (dm)	1.8 ± 1.16	1.7 ± 0.99	0.06 ± 0.23	1.5 ± 1.52
CaO, % (dm)	7.9 ± 5.52	5.3 ± 3.17	0.5 ± 1.42	10.6 ± 9.05
MgO, % (dm)	1.0 ± 0.85	1.2 ± 0.93	0.1 ± 0.39	1.9 ± 1.74
Fe, % (dm)	1.1 ± 0.6	0.5 ± 0.46	0.03 ± 0.13	1.4 ± 1.87
Electrical conductivity, dS m ⁻¹	6.9 ± 5.3	7.8 ± 5.3	5.1 ± 3.0	4.8 ± 6.5
Chlorides content, % (dm)	2.4 ± 5.5	1.2 ± 1.2	0.1 ± 0.4	0.2 ± 0.2
Cadmium (Cd), mg kg ⁻¹ dm	0.9 ± 0.78	0.5 ± 0.38	0.3 ± 0.31	0.6 ± 0.74
Copper (Cu), mg kg ⁻¹ dm	155 ± 115.1	98 ± 113.0	44 ± 48.7	54 ± 36.0
Nickel (Ni), mg kg ⁻¹ dm	31.7 ± 26.20	15.9 ± 13.69	5.8 ± 6.77	19.9 ± 21.14
Lead (Pb), mg kg ⁻¹ dm	62.9 ± 58.09	36.0 ± 52.22	22.6 ± 35.43	13.8 ± 11.98
Zinc (Zn), mg kg ⁻¹ dm	378 ± 268.9	282 ± 233.6	121 ± 105.9	191 ± 161.5
Mercury (Hg), mg kg ⁻¹ dm	0.5 ± 0.60	0.2 ± 0.25	0.1 ± 0.14	0.2 ± 0.42
Chromium (Cr), mg kg ⁻¹ dm	64.6 ± 77.77	30.3 ± 31.05	16.1 ± 26.58	33.5 ± 51.31

MaC, in 25.0% of GrC and in 28.9% of VeC reported in the MITECO's fertilisers database. For its part, waste from livestock farming (020106) is present in 30% of OaC, 100% of MaC and 85% of VeC.

With regard to organic waste mainly used in the formulation of initial mixtures for composting, OaC offers the widest variety of EWC. In this type of compost there are five kinds of waste that appear, as raw material, in more than 20% of the checked samples: waste from vegetable tissue (020103), livestock manures (020106), sludge from urban wastewater treatment plants (190805), biodegradable waste from gardens and parks (200201), and the organic fraction of municipal waste not collected separately (200301). However, the organic fraction of municipal waste not collected separately (200301) is not legally accepted anymore for the production of compost (BOE 2011, BOE 2017). Current registries containing such waste correspond to authorizations granted before and that will expire between years 2018 and 2021. It has to be highlighted that

organic fraction of municipal solid waste separately collected (020108) is only employed in the 6.9% of the AoC and therefore it has not been included in Figure 1.

In the cases of MaC and GrC, the main organic wastes used in the initial mixtures are, obviously, those matching their designation: livestock manures (020106) in the first one, and waste from vegetable tissue (020103) and biodegradable waste from gardens and parks (200201) in the second one. It is remarkable that some products obtained only from manure or vegetal wastes are registered in type OaC, instead of in their specific category (MaC or GrC). Likewise, the registered VeC were produced mainly from green wastes (020103) and manures (020106). Vermicomposting is a biological transformation process that includes the action of earthworms, so it is logical to consider VeC as a product of a specific category, independently of the organic waste used in its initial formulation.

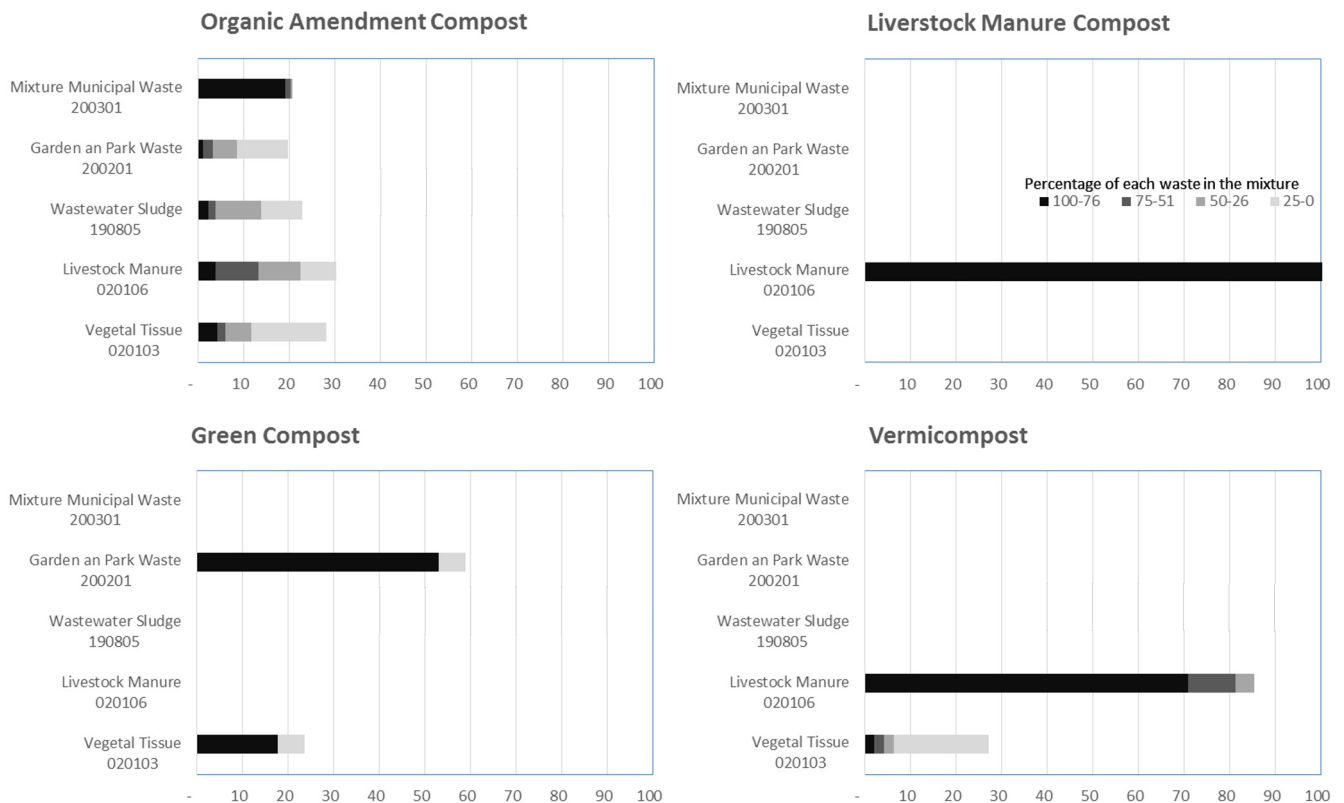


Figure 1. Most usual wastes employed in the elaboration of four typologies of compost marketed in Spain (organic amendment compost, manure compost, green compost and vermicompost). For each typology is shown the proportion of compost containing each main waste named according to the European Waste Code (X axis) and the percentage of each waste in the initial mixture (color of the bars).

Heavy metals in Spanish compost

In Spain the legal use of a compost is determined by its heavy metals content, as it is described in the Spanish Fertiliser RD. Compost class A has the lowest heavy metal content and it can be even employed in organic farming, whereas Class C has the highest content in heavy metals and therefore it can only be applied at a maximum rate of 5 Mg ha⁻¹. Table 4 summarises the percentage of samples classified as Class A, B or C, for each compost type. The standard deviation of all heavy metals concentration for each product-type reflects a wide variety. OaC, with the highest variety of raw materials, presents the lower percentage of samples classified as Class A, only 24.1% of the available samples (Table 4). The compost produced from green wastes (GrC) presented the maximum percentage of samples considered as Class A (76.5%). MaC and VeC (85% of the included products are mainly elaborated from livestock manures) have almost the same percentage of samples classified as Class A and Class B, and the remaining (7.1% and 15.2% respectively) as Class C (Table 4).

It is then remarkable the lack of analytical data in the registry for some metals that have a significant

influence in the legal classification of compost, such as Cd, Cr and Hg. In particular, 76 samples lack concentration data of Hg, 11 of Cr and 35 of Cd. Despite that, those products are registered in the MITECO's database and have been given a legal quality classification according to their heavy metals content, even some of them as Class A.

Raw materials employed in producing each compost determine its heavy metal content. The specific heavy metals that have a higher impact in the determination of the legal classification of compost (Spanish Fertilisers RD) for each typology have been studied:

- OaC: Data about the heavy metals content for this compost type evidence that Cu, Zn and Pb are the metals with the highest limitation impact in its legal quality. However Genevini *et al.* (1997), when analysing thirty composts from municipal solid waste, found Cd as the main metal limiting legal compost quality. These different results could be due to the change in municipal solid waste collection system during the last 20 years. In Spain, Catalonia started the source-separated collection of biowaste and its treatment through composting, almost 20 years ago. Puig *et al.* (2016) studied the heavy metals content

Table 4. Compost percentages, according to their typology, classified in the different categories of legal quality, depending on their heavy metals content (Spanish Fertilisers RD).

Typology of fertiliser	% of samples			N° of samples	% with incomplete data
	Class A	Class B	Class C		
OaC	24.1	51.3	24.6	188	26.6
MaC	46.4	46.4	7.1	28	32.1
GrC	76.5	23.5	0.0	17	76.5
VeC	41.3	43.5	15.2	48	35.6

of the compost produced in the composting plants located in Catalonia to treat biowaste (EWC 200108). They reported low concentration of heavy metals, especially for Ni (17.7 mg kg⁻¹), Pb (47.0 mg kg⁻¹), Cu (121.8 mg kg⁻¹) and Zn (281.5 mg kg⁻¹). This lower concentration of heavy metals in the compost-type (OaC) produced in Catalonia was also indicated by Huerta *et al.* (2011) and Cerda *et al.* (2017). These authors signalled that the main reason is the source-separated collection of biowaste in Catalonia.

- MaC: The heavy metals that limit the most in determining legal qualities are: Cu, Pb and Zn. Specially Cu and Zn are heavy metals related to the livestock manures and to the compost produced from them (Hsu & Lo, 2000, 2001).

- GrC: It has instead the highest percentage of products classified, as Class A. Cu and Pb are the limiting metals to determine the legal quality of the studied GrC. Nevertheless, most of the registries in this typology do not include information of Hg concentration, nor of other metals such as Cd, Ni and Cr. For this typology 76.5% of the samples are incomplete for at least one heavy metal (Table 4).

- VeC: Cd and Zn are the metals that limit the most in determining qualities. Specifically in the case of all registered VeC, the Pb concentration is lower than the limit legally established for the highest quality category (Class A).

Correlation between the content of different metals

A correlation has been found between the concentrations of Ni and Pb in all samples of typology OaC ($r^2=0.566$), MaC ($r^2=0.384$) and GrC ($r^2=0.810$), but not in category VeC ($r^2=0.007$). Such connection had already been announced by other authors (Saha *et al.*, 2010), but related to composts which predominantly contained vegetal remains from agriculture, that is, green waste. Among the samples in this study, this connection applies mainly to category GrC, which on

the other hand has the lowest average Ni concentration of the four studied typologies. In order to analyse if this bigger connection is influenced by the typologies of the wastes mainly used in the production of GrC (Fig. 1; EWC 020103 and 200201), an analysis tried to find out if the connection is better between the heavy metals (Ni and Pb) of composts using such wastes: type GrC and OaC. For GrC, results showed a strong connection between Ni and Pb concentrations ($r^2=0.97$) for EWC 200201 (vegetable waste from gardens and parks), and a lower one ($r^2=0.628$) for EWC 020103 (waste from vegetable tissue). For type OaC, which also includes a big amount of products elaborated from those wastes, the only connection between Ni and Pb exists for samples using wastes classified under EWC 200201 ($r^2=0.668$), while such connection does not happen for samples with wastes under EWC 020103 ($r^2=0.065$).

EWC 200201 mainly corresponds to woody materials that must be shredded so that they can be composted with an adequate particle size. The shredding machines normally used in composting facilities are industrial equipment with high-powered engines and stainless steel hammers or blades for crushing and/or cutting the wood. Both heavy metals (Ni and Pb) are related to different components of this kind of equipment. Ni is one of the heavy metals used to make iron into hard steels and can be found in stainless steels, so due to the use of blades and hammers, particles of this metal can contaminated the outflow of shredded wood material. Moreover, Pb is a normal additive for lubricant oils and even for soldering metals, so its presence in this kind of equipment is common. Since these products are related to leaking and wearing, the contamination by Pb of the shredded material should not be also unusual either. Specific tests should be done to confirm these sources of contamination for this kind of woody green wastes among other vegetal wastes.

In the specific case of VeC, there is no connection between heavy metals. That trend may be related to the bioaccumulation of heavy metals in the organism of the earthworms responsible for the degradation process of the organic waste (Wang *et al.*, 2017). Many studies have proved this process of bioaccumulation of heavy metals in earthworms. Pb is the heavy metal that shows the highest trend to be accumulated in their organisms (Liu *et al.*, 2012; Swati & Hait, 2017) and, therefore, vermicompost presents a low Pb content. Moreover, this study evidenced that the lack of connection is not related to the raw materials used. Most of the VeC (93%) included in the Spanish fertilisers registry are elaborated mainly with wastes from livestock manures (EWC 020106).

Compliance with national and international legal requirements of Spanish Compost

By considering average concentration values for the four typologies (Table 4), the compliance with national and international legal requirements of these products-types can be studied. Table 5 presents a comparative study of how the compost typologies would be classified by their legal quality according to different national and international guidelines.

When analysing the heavy metals concentration values resulting from the products-type (Table 3) with different legal requirements of limit concentration values (listed in Table 1), it follows that (Table 5):

- Typologies GrC and VeC keep the strictest requirements in all compared European regulations.
- In the case of MaC, the concentration values of Cu and Zn exceed the legal limits required to be considered as an ecological product and to be included in the Spanish legal quality Class B.
- According to the Spanish legislation, types OaC and MaC are mostly classified as compost Class B. GrC and VeC are instead mostly considered as compost Class A.
- According only to the heavy metal concentration, the application of Portuguese legislation gives similar classification of the product-type quality to the Spanish one. However, the Portuguese compost quality classification considers other parameters like inert materials content. Moreover, compost maturity also defines its possible uses and applications of the final product.
- The application of the Austrian Compost Ordinance (2001) allows to generally distinguishing different degrees of legal quality between type OaC (corresponding to Class B) and MaC (corresponding to Class A).

- If the Canadian guidelines (CCME, 2005) for compost quality were applied, all the studied compost typologies would reach the maximum category (A) and no differences among them would be visible.

- Overall, the product-type presenting the lowest legal quality would be type OaC, which would only fulfil the End-of-Waste standards and would be considered as Class B by the Spanish Fertilisers RD.

Contents of macro and micronutrients

The main macronutrients content (N, P, K) of the different compost categories analysed (Table 3) shows that MaC presents the highest potential as fertiliser, given its highest and practically equal concentrations of N, P, K, which almost equate to a mineral fertiliser with formulation 2.5:2.5:2.5. VeC, on the contrary, presents the lowest concentration of macronutrients, since it is a product that requires a longer and more controlled maturity phase, which gives it a status more typical of a growing media than of a fertiliser. This longer process would also become evident in the lower content of ammonium N of this typology when compared with the others. The same happens with GrC, whose registered samples have relatively low concentrations of macronutrients, especially of P₂O₅, which is also indicative of its potential applications, more linked to gardening and the elaboration of growing media than to conventional agricultural applications.

When comparing these macronutrients contents with the concentration of the wastes used in its production (Fig. 1), a positive connection is visible between the use of animal manures and the N and potassium concentration levels in the resulting products.

Regarding other nutrients content (Table 3), however, VeC stands out due to its high concentration levels

Table 5. Analysis of the compliance with legal requirements (shown in Table 1) of the materials-type studies.

	OaC	MaC	GrC	VeC
Council Regulation No. 2092/91 (EEC, 1991)	✗	✗	✓	✓
End-of-waste criteria on biodegradable waste subject to biological treatment (2014; Final document)	✓	✓	✓	✓
COM Decision 2015/2099 eco-label to growing media (EC, 2015)	✗	✓	✓	✓
Spain - RD 506/2013 on Fertiliser Products (BOE, 2017)	B	B	A	A
Austria - Compost Ordinance BGB1. II 292/2001 (Austrian Compost Ordinance, 2001)	B	A	A+	A+
Canada – Guidelines for Compost Quality Canadian Council of Ministers of the Environment (CCME, 2005)	A	A	A	A
Portugal – Law Decree (No 103/2015) on Fertiliser Products (DRE, 2015)	II	II	I	I

✗ throw over; ✓ Fullfill.

of some of them, especially Ca and Mg. This higher concentration of Ca in VeC compared to any other compost type is a common thing due to the combined effect of earthworms and fungi in the environment (Spiers *et al.*, 1986; Das *et al.*, 2012), which provokes a higher excretion of that element to the environment. Equally, the widest use of animal manures in the production of the registered vermicomposts is also a reason for the higher concentration of Ca in the environment (Arancon *et al.*, 2008). In this respect GrC is the product with the poorest concentration of these nutrients, with much lower levels than all the others are. Among the four analysed compost typologies, OaC has the most balanced concentration levels and the biggest quantity of nutrients.

Other physico-chemical parameters

Regarding the rest of the physico-chemical parameters stated for these products, some differences are appreciated related to the kind of biological process and its scope, and to the initial composition of organic wastes (Table 3). In this way, it can be observed that contents of organic matter and organic carbon are lower in VeC (a more stable product requiring longer and more intense process times, so it is more degraded). On the contrary, the highest values belong to GrC, which is subjected to a more limited process due to the lower biodegradability of the original materials (Puyuelo *et*

al., 2011) and to the influence of process parameters, such as the particle size or the greatest difficulty to control humidity of materials during the different phases.

As regards indicators of the process' duration or the stability of the final product, there are other indicative parameters, such as the content of humic substances, where it is observed that minimum and maximum levels correspond respectively to MaC and VeC. The first one corresponds to a very intense degradative process, due to the composition of the initial raw materials (high content of protein substances and low C/N) with high biodegradability. The maximum concentration values of humic acids are found in VeC (highly spread), corresponding to a more complex process deriving in a greater stability of the final product. (Jimenez & Pérez, 1992; Haddad *et al.*, 2015; Martínez *et al.*, 2016).

Other parameters, such as conductivity and chloride content, are also affected by those factors related to the evolution of the biological process. Lowest values are registered in those products with more potential applications as growing media (VeC and GrC).

Assessment of the quality rates

Figure 2 shows the obtained Fertility and Clean indicators for the composts analysed in this study and

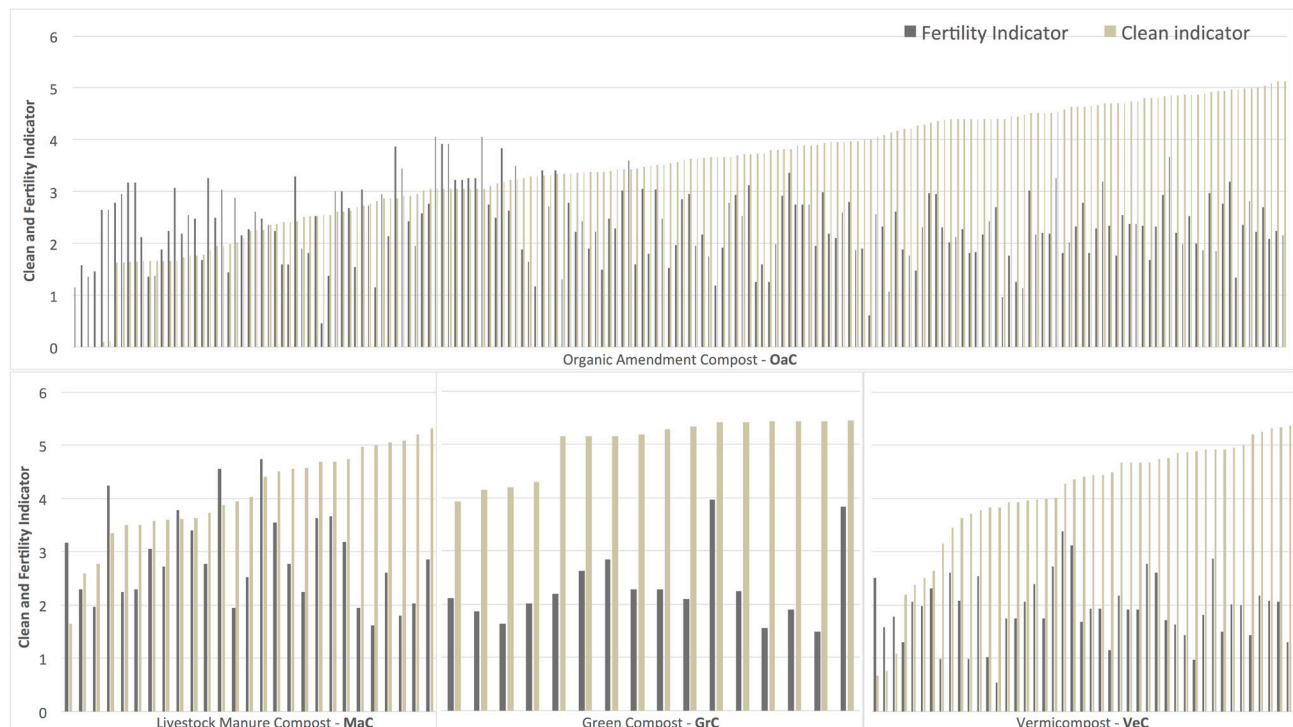


Figure 2. Clean and fertility indicator of the Spanish compost of officially registered as organic fertilisers in Spain (MITECO, 2018).

registered in the MITECO's database, being distinguished by typologies (OaC, MaC, GrC and VeC). As can be seen, there is no correlation ($r^2 < 0.01$) between the FI and the CI for any of the studied compost typologies. In type OaC, there are products with void CI (showed at left side on the graph) since, as already mentioned, some of the registered products do not include values of the heavy metals content.

Assessment of the fertility indicator (FI)

Table 6 shows, for each studied compost typology, the percentage of registries included under the different scores of the FI. Overall, it is noticeable that most of the samples have an average FI value of around 2-3. As OaC and MaC are the products elaborated from organic wastes with the highest proportional content in macronutrients (livestock manures, agro-industrial wastes, biowastes, etc.), they also include the largest percentage of samples with high FI values (above 4). For its part, VeC presents the lowest FI values. Nevertheless, the result of the degradative activity of earthworms, together with the great variety of microorganisms involved in this process, provoke the creation of certain compounds that facilitate germination and the development of vegetables (Zhang *et al.*, 2000; Arancon *et al.*, 2008), which are not considered among the required analysis. Altogether, no products have been obtained, in any of the established compost typologies, whose calculated FI had a final global value of the highest category (>5).

Table 6. Classification of composts registered in the MITECO's database according to the obtained fertility indicator (FI) and clean indicator (CI).

	OaC	MaC	GrC	VeC
FI				
<1	1.6%	0.0%	0.0%	8.9%
>1 – <2	31.9%	18.5%	37.5%	48.9%
>2 – <3	49.5%	44.5%	50.0%	37.8%
>3 – <4	15.9%	25.9%	12.5%	4.4%
>4 – <5	1.1%	11.1%	0.0%	0.0%
>5	0.0%	0.0%	0.0%	0.0%
CI				
<1	3.3%	0.0%	0.0%	2.2%
>1 – <2	9.9%	0.0%	0.0%	2.2%
>2 – <3	15.4%	7.4%	0.0%	11.1%
>3 – <4	35.2%	37.1%	0.0%	26.7%
>4 – <5	30.7%	33.3%	18.8%	44.5%
>5	5.5%	22.2%	81.2%	13.3%
Total samples	188	28	17	48

Assessment of the clean indicator (CI)

Table 6 shows, for each studied compost typology, the percentage of registries included under the different scores of the CI. The CI proves the low heavy metals content of the samples included in types MaC, VeC and, mainly, GrC, even though this contrasts with the low FI of this last category. In OaC, even if it presents the largest number of samples with the lowest CI (3.3%), there are more than 70% of the samples with CIs in the highest categories (CI >3). It is also observed that in all typologies of compost there are products with CIs higher than 5, but mainly in GrC, where 81.2% of the registries have concentration values of heavy metals lower than the legally required minimum (Spanish Fertilisers RD) for the highest quality (Class A). In this type of compost, Cd and Hg are the most limiting heavy metals.

After the elaboration of this exhaustive analysis of the current compost registered in the Spanish database, it can be concluded that most of the composts registered in the MITECO's database (Spanish Registry of Fertiliser Products) main nutrients content is, in average, relatively low. Regarding heavy metal contents, the composts with highest percentage of samples with the maximum Class ('A' according to the Spanish RD) are, in this order, green compost (GrC), manure compost (MaC), vermicompost (VeC) and organic amendment compost (OaC). Considering the parameters registered in the MITECO's database (Spanish Registry of fertiliser products), a new methodology to assess and classify the global compost quality is proposed based on two indicators: fertility indicator (FI) and clean indicator (CI). However, in the future quality of marketed compost should be classified considering physico-chemical parameters that could determine the use of a compost, such as: compost stability and/or maturity, phytotoxicity, density or porosity.

Acknowledgments

The authors are especially grateful to Ms. Ara Calavia Beltrán for her time and support in supervising the writing of the manuscript.

References

- AEAT, 2017. Estadísticas de comercio exterior [Foreign Trade Statistics]. Agencia Española de Administración Tributaria [Tax Administration Agency, Dept. of Customs & Special Taxes]. https://www.agenciatributaria.es/AEAT.internet/Inicio/La_Agencia_Tributaria/Aduanas_e_

- [Impuestos_Especiales/_Presentacion/Estadisticas_de_Comercio_Exterior/_DESCARGA_Y_DATOS/Datos_estadisticos/Datos_estadisticos.shtml](#)
- Arancon NQ, Edwards CA, Babenko A, Cannon J, Galvis P, Metzger JD, 2008. Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse. *Appl Soil Ecol* 39: 91-99. <https://doi.org/10.1016/j.apsoil.2007.11.010>
- Austrian Compost Ordinance, 2001. Verordnung über Qualitätsanforderungen an Komposte aus Abfällen (Kompostverordnung). BGBl II 292/2001, Wien. <http://extwprlegs1.fao.org/docs/pdf/aut90980.pdf>
- BOE, 2011. Law 22/2011, of 28th July, on waste and contaminated soils. Boletín Oficial del Estado (España) No. 181, 29 Jul 2011. <https://www.boe.es/eli/es/l/2011/07/28/22>
- BOE, 2017. RD 999/2017, de 24 de noviembre, por el que se modifica el RD 506/2013, de 28 de junio, sobre productos fertilizantes. Boletín Oficial del Estado (España) No. 296, 6 Nov 2017. <https://www.boe.es/eli/es/rd/2017/11/24/999>
- Brinton WF, 2000. Compost quality standards and guidelines. [Final Report]. Woods End Res Lab Inc., USA. <http://compost.css.cornell.edu/>
- CCME, 2005. Canada – Guidelines for compost quality. PN 1340. Canadian Council of Ministers of the Environment. https://www.ccme.ca/files/Resources/waste/organics/compostgdlns_1340_e.pdf
- Cerda A, Artola A, Font X, Barrena R, Gea T, Sánchez A, 2017. Composting of food wastes: Status and challenges. Review. *Bioresour Technol* 248: 57-67. <https://doi.org/10.1016/j.biortech.2017.06.133>
- Das D, Bhattacharyya P, Ghosh BC, Banik P, 2012. Effect of vermicomposting on calcium, sulphur and some heavy metal content of different biodegradable organic wastes under liming and microbial inoculation. *J Environ Sci Health B* 47: 205-211. <https://doi.org/10.1080/03601234.2012.634346>
- DRE, 2015. Law Decree 103/2015 of June 15th. Diário da República (Portugal), 1^a serie No. 114 15 June 2015. <https://dre.pt/application/conteudo/67485179>
- EC, 2003. Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 Oct 2003 relating to fertilisers. 21 Nov 2003. <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32003R2003>
- EC, 2008. Directive 2008/98/EC of the European Parliament of the Council of 19 November 2008 on waste and repealing certain directives. 19 Nov 2008. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098>
- EC, 2015. Commission Decision (EU) 2015/2099, of 18 Nov 2015, establishing the ecological criteria for the award of the EU Ecolabel for growing media, soil improvers and mulch. 10 Feb 2001. <https://publications.europa.eu/en/publication-detail/-/publication/6fefebf7-8f53-11e5-983e-01aa75ed71a1>
- EEC, 1991. Council Regulation (EEC) No 2092/91, of 24 June 1991, on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs. 24 June 1991. <https://publications.europa.eu/en/publication-detail/-/publication/79cf3c57-e66f-4932-a653-c45dc68e3665>
- Genevini PL, Adani F, Borio D, Tambone F, 1997. Heavy metal content in selected European commercial composts. *Compost Sci Utiliz* 5: 31-39. <https://doi.org/10.1080/1065657X.1997.10701895>
- Govind P, Madhuri S, 2014. Heavy metals causing toxicity in animals and fishes. *Res J Anim Vet Fish Sci* 2: 17-23.
- Haddad G, El-Ali F, Mouneimne AH, 2015. Humic matter of compost: Determination of humic spectroscopic ratio (E4/E6). *Curr Sci Int* 4: 56-72.
- Hsu J, Lo S, 2000. Characterization and extractability of copper, manganese, and zinc in swine manure composts. *J Environ Qual* 29: 447-453. <https://doi.org/10.2134/jeq2000.00472425002900020012x>
- Hsu J, Lo S, 2001. Effect of composting on characterization and leaching of copper, manganese, and zinc from swine manure. *Environ Pollut* 114: 119-127. [https://doi.org/10.1016/S0269-7491\(00\)00198-6](https://doi.org/10.1016/S0269-7491(00)00198-6)
- Huerta O, López M, Soliva M, Zaloña M, 2008. Compostaje de residuos municipales: Control del proceso, rendimiento y calidad del producto. *Compostaje de residuos municipales*. ESAB-ARC, 330 pp.
- Huerta O, Gallart M, Soliva M, Martínez F, López M, 2011. Effect of collection system on mineral content of biowaste. *Resour Conserv Recycl* 55: 1095-1099. <https://doi.org/10.1016/j.resconrec.2011.06.008>
- Jasinski SM, 2017. US Geological Survey. Mineral commodity summaries.
- Jiménez EI, Pérez V, 1992. Determination of maturity indices for city refuse composts. *Agr Ecosyst Environ* 38: 331-343. [https://doi.org/10.1016/0167-8809\(92\)90154-4](https://doi.org/10.1016/0167-8809(92)90154-4)
- Ko HJ, Kim KY, Kim HT, Kim CN, Umeda M, 2008. Evaluation of maturity parameters and heavy metal contents in composts made from animal manure. *Waste Manage* 28: 813-820. <https://doi.org/10.1016/j.wasman.2007.05.010>
- Larsen Ib, 1993. Organic wastes. A resource or an environmental problem? A view at the European scene. Agency of Environmental Protection City of Copenhagen. 4th ed. 18.
- Liu F, Zhu P, Xue J, 2012. Comparative study on physical and chemical characteristics of sludge vermicomposted by *Eisenia fetida*. *Procedia Environ Sci* 16: 418-423. <https://doi.org/10.1016/j.proenv.2012.10.058>
- López Arias M, Grau Corbí JM, 2005. Metales pesados, materia orgánica y otros parámetros de la capa superficial de los suelos agrícolas y de pastos de la España peninsular. II: Resultados por provincias. INIA, MMA, MAPA. ISBN 84-7498-501-3.

- Martínez M, Ortega R, Janssens M, Angulo J, Fincheira P, 2016. Selection of maturity indices for compost derived from grape pomace. *J Plant Nutr Soil Sci* 16: 262-267.
- MITECO, 2018. Registro de Productos Fertilizantes. Ministry for the Ecological Transition, Spain. <http://www.magrama.es/app/consultaFertilizante/consultaFertilizante.aspx> [30 March 2018].
- Official Gazzete, 1985. Fertilisers Act 1985 No 5 (formerly Fertilizers Act 1985). 27 Nov. p 3324. India.
- Oviedo E, Torres P, Marmolejo L, Hoyos, L, González S, Barrena R, Komilis D, Sánchez A, 2015. Stability and maturity of biowaste composts derived by small municipalities: correlation among physical, chemical and biological indices. *Waste Manage* 44: 63-71. <https://doi.org/10.1016/j.wasman.2015.07.034>
- Pimentel D, Burgess M, 2013. Soil erosion threatens food production. *Agriculture* 3: 443-463. <https://doi.org/10.3390/agriculture3030443>
- Puig I, Campos LM, López M, Martínez X, 2016. Report: Analysis of the compost quality produced in Catalonia as a function of the percentage of inert materials included in the raw material (OFMSW). Catalan Waste Agency.
- Puyuelo B, Ponsá S, Gea T, Sánchez A, 2011. Determining C/N ratios for typical organic wastes using biodegradable fractions. *Chemosphere* 85: 653-659. <https://doi.org/10.1016/j.chemosphere.2011.07.014>
- Saha JK, Panwar N, Singh MV, 2010. An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. *Waste Manage* 30: 192-201. <https://doi.org/10.1016/j.wasman.2009.09.041>
- Saveyn H, Eder P, 2014. End-of-waste criteria on Biodegradable waste subject to biological treatment (2nd draft). Joint Research Center. Report EUR 26425 EN/SSN 1831-9424.
- Spiers GA, Gagnon D, Nason GE, Packee EC, Lousier JD, 1986. Effects and importance of indigenous earthworms on decomposition and nutrient cycling in coastal forest systems. *Can J For Res* 16: 983-989. <https://doi.org/10.1139/x86-172>
- Swati A, Hait S, 2017. Fate and bioavailability of heavy metals during vermicomposting of various organic wastes - A review. *Proc Safe Environ Prot* 109: 30-45. <https://doi.org/10.1016/j.psep.2017.03.031>
- Walsh DC, 2002. Urban residential refuse composition and generation rates for the 20th century. *Environ Sci Technol* 36: 4936-4942. <https://doi.org/10.1021/es011074t>
- Wang P, Changa CM, Watson ME, Dick WA, Chen Y, 2004. Maturity indices for composted dairy and pig manures. *Soil Biol Biochem* 36: 767-776. <https://doi.org/10.1016/j.soilbio.2003.12.012>
- Wang Y, Han W, Wang X, Chen H, Zhu F, Wang X, Lei C, 2017. Specification of heavy metals and bacteria in cow dung after vermicomposting by the earthworm, *Eisenia fetida*. *Bioresour Technol* 245: 411-418. <https://doi.org/10.1016/j.biortech.2017.08.118>
- Zdruli P, Jones RJA, Montanarella L, 2004. Organic matter in the soils of Southern Europe. European Soil Bureau Research Report. 15, EUR 21083 EN, 17. Office for Official Publications of the European Communities, Luxembourg.
- Zhang BG, Li GT, Shen TS, Wang JK, Sun Z, 2000. Changes in microbial biomass C, N and P and enzyme activities in soil incubated with the earthworms *Metaphire guillelmi* or *Eisenia fetida*. *Soil Biol Biochem* 32: 2055-2062. [https://doi.org/10.1016/S0038-0717\(00\)00111-5](https://doi.org/10.1016/S0038-0717(00)00111-5)