**Title:** The impact of improper materials in biowaste on the quality of compost

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## Abstract

Separate collection of biodegradable waste provides a better-quality raw material for the production of fertilisers than material obtained from the mechanical separation of municipal solid waste. Source-collected biowaste can be used for the production of compost, and its quality will depend on factors ranging from the presence of improper materials—*inter alia*, glass, and plastic—to the duration of the treatment process. This study performs a statistical analysis of the factors influencing the quality of compost produced at 20 plants in Catalonia (Spain). A primary focus is on the effects caused by the presence of improper materials in the biowaste, followed by other variables associated with the technical specifications of the plants, and material flows. Main results indicate that the presence of improper materials may lead to a negative impact on various parameters of quality compost, notably the concentration of heavy metals, electrical conductivity, and the maximum temperature in the self-heating test. Other potential factors influencing compost quality are decomposition and maturation technology, the input of green waste, the screening size of the product, and the saturation level of the treatment plants. The findings of this study support a necessary reduction in the quantity of improper materials, both through the improvement of waste separation at the source and at treatment plants prior to treatment.

*Keywords:* Biological treatment plants; biowaste; improper materials; compost; Catalonia.

## 1. Introduction

The source collection and biological treatment of the organic fraction of municipal solid waste (OFMSW) allows for the removal of a significant amount of waste from landfills and incinerators. This results in various positive effects, including alignment with the European Union's (EU) Council Directive 1999/31/EC (European Council, 1999) on landfill waste, reduction in costs paid by municipalities by avoiding sending waste to landfills or incineration plants, lower levels of greenhouse gases emitted in comparison to the two previous types of waste management, and a higher optimisation of natural resources by using OFMSW for compost generation. In addition, Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 (European Parliament and Council, 2018), amending Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 (European Parliament and Council, 2008) on waste and repealing certain Directives stipulates in Article 1, Amendment 19, that member states shall ensure that, by 31 December 2023, biodegradable waste (biowaste) is either separated and recycled at its source or collected separately and not mixed with other types of waste.

Biowaste separated at the source holds a lower proportion of improper materials (e.g. paper, plastic, metals, and glass) in comparison to biowaste obtained from undifferentiated collection (López et al., 2010a). The Spanish regulation on waste—*Ley 22/2011, de 28 de julio, de residuos y suelos contaminados* (Congreso de los Diputados, 2011) (Law 22/2011 of 28 July on waste and contaminated soil)—considers that only the separately collected OFMSW can be used to obtain compost. This means that the organic fraction of residual municipal waste treated at mechanical biological treatment (MBT) facilities may become, at most, a biostabilised material, which has a more limited use than compost. Nevertheless, separation at the source of biowaste does not, in and of itself, guarantee the absence of improper materials. This means that municipalities performing source collection may differ in terms of the levels of improper materials found in the OFMSW.

The quality of biowaste as a raw material is directly linked to its origin, which may determine its content in terms of nutrients or heavy metals. The presence of improper materials may contribute to a lower-quality compost. Some of the main reasons include the transfer of contaminants to the organic matter; the impact of contaminants on the treatment process by affecting composting requirements such as water, air, and nutrient balance; and the presence of contaminants in the final product, in the form of small impurities (Malamis et al., 2017; Montejo et al., 2010). Weithmann et al. (2018) presents an example of a detrimental effect caused by the presence of impurities in compost. It refers to the potential increase of microplastics in the environment with the application of compost containing plastic-based impurities in agriculture and gardening.

Another factor that influences compost quality is the processes taking place prior to waste treatment, such as collection and storage, where some potential chemical reactions occurring in the organic matter can affect the state of the composting material. This can lower the compost quality in a way that is hardly recovered during the treatment process. The characteristics of the facilities and their respective treatment processes can also affect the compost quality. Examples of these include the type and maintenance of the treatment system used for biowaste decomposition and maturation, duration of the production process, availability and quality of other inputs (e.g. water), and the skills of workers. Both the quality of the raw material and the biowaste handling processes can affect the quality and stabilisation of the final product (see Figure 1).

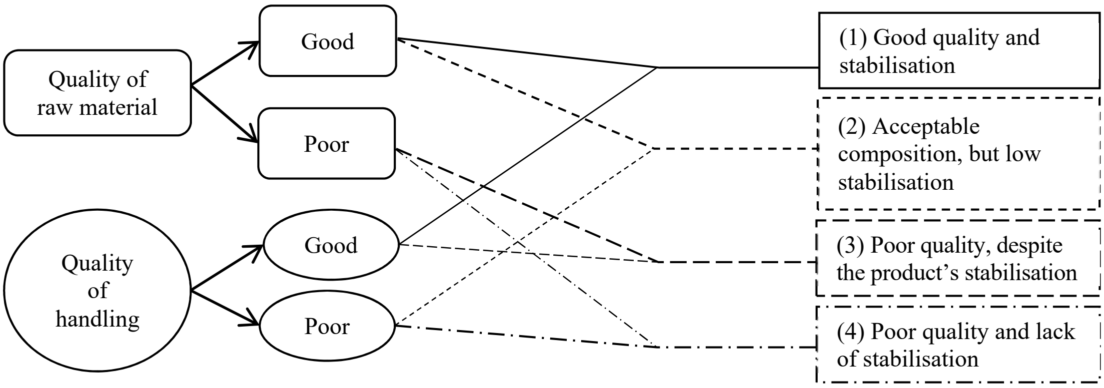


**Figure 1.** Possible product quality levels, as determined by the quality of the raw materials and handling

Compost can be used in agriculture and gardening, although it must meet certain quality standards that ultimately influence the options for its application. The Spanish regulation for fertilisers—*Real Decreto 506/2013, de 28 de junio, sobre productos fertilizantes* (Ministerio de la Presidencia, 2013) (Royal Decree 506/2013 of 28 June about fertiliser products)—stipulates compost-related limits on the content of heavy metals by establishing three quality classes of compost (A, B, and C), the moisture content (< 40%), the organic matter content (> 35% wm), the carbon-to-nitrogen (C/N) ratio (< 20), the particle size, and impurities content for its use as an organic amendment.

At the EU level, the Circular Economy Package includes "Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003" (European Parliament and Council, 2019). This regulation presents the requirements for the composition of EU fertilising products. Among other components, these products may contain compost obtained from the treatment of different (authorised) materials that include source-collected biowaste but exclude mixed municipal household waste. The regulation also indicates that compost must comply with limits on polycyclic aromatic hydrocarbons ($PAH_{16}$) (≤ 6 mg/kg dm); impurities made of glass, metal, or plastics bigger than 2 mm (≤ 3 g/kg dm), with tighter restrictions for plastic after 16 July 2026; the sum of the impurities made of the glass, metal, and plastics (≤ 5 g/kg dm); and biological activity (≤ 25 mmol $O_2$/kg dm/h; Rottegrad ≥ III). Moreover, the use of EU fertilising products as organic soil improvers must comply with the following requirements. The presence of contaminants is limited as follows: cadmium (Cd), ≤ 2 mg/kg dm; hexavalent chromium (Cr VI), ≤ 2 mg/kg dm; mercury (Hg), ≤ 1 mg/kg dm; nickel (Ni), ≤ 50 mg/kg dm; lead (Pb), ≤ 120 mg/kg dm; and inorganic arsenic (As), ≤ 40 mg/kg dm. Copper (Cu) content in an organic fertiliser is limited to a maximum of 300 mg/kg dm and zinc (Zn) to no more than 800 mg/kg dm. The presence of bacteria is limited as follows: *Salmonella spp.* is absent in a 25 g sample of the product and *Escherichia coli* and *Enterococcaceae*, ≤ 1,000 CFU/g. The content of dry matter must be ≥20% and the content of organic carbon (C) ≥7.5% by mass.

The main aim of this study is to assess the impact of improper materials found in source-collected biowaste and, complementarily, the impact of other variables related to the technical specifications of the plants on the quality of compost. For that purpose, the study performs descriptive and regression analyses applied to biowaste treatment in 20 plants processing the source-collected biowaste of Catalonia (Spain) for the period 2010–2014.

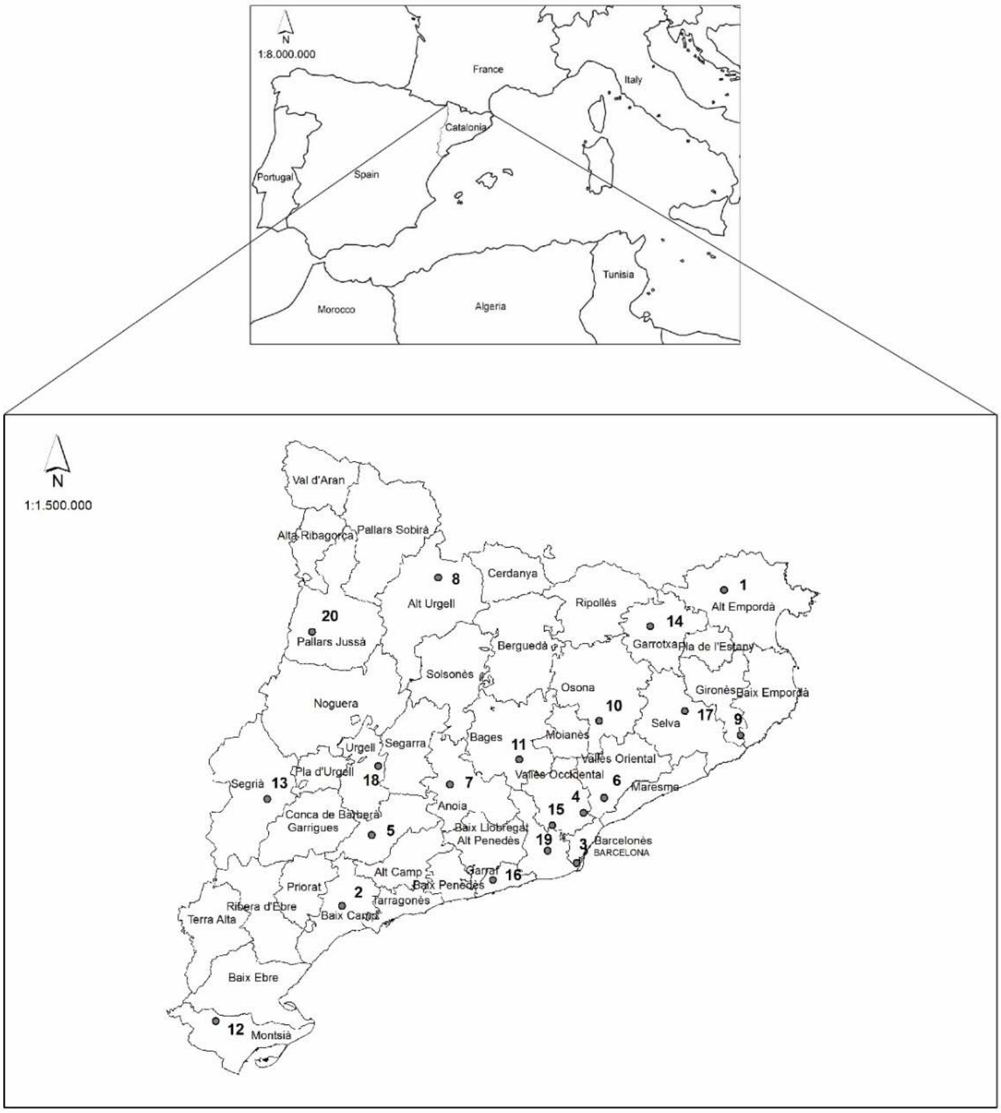
Examples of other studies assessing the quality of compost obtained from biowaste are presented as follows. The main aim of Zennaro et al. (2005) was to assess the concentration of heavy metals in various stages of the composting process at a plant in Lombardy (Italy). The analysis indicates that a higher presence of improper materials at the beginning of the process leads to a higher content of heavy metals in the compost. The study also proposes different solutions for the reduction of heavy metals in the final product. Huerta et al. (2010) evaluated compliance with various quality parameters of the compost produced in 58 composting plants in Spain (63 samples of compost from 22 plants treating OFMSW from mechanical selection, and 115 samples from 36 facilities treating OFMSW from separate collection) with the requirements of the (derogated) *Real Decreto 824/2005, de 8 de julio, sobre productos fertilizantes* (Ministerio de la Presidencia, 2005) (Royal Decree 824/2005 of 8 July on fertiliser products). The study observed a higher heavy-metal content in compost obtained from plants treating OFMSW from mechanical selection (e.g. MBT plants), in comparison to compost produced in plants dealing with OFMSW from separate collection. Montejo et al. (2015) assessed the quality of 30 samples of municipal solid waste (MSW) compost produced at 10 MBT plants in Spain. The analysis compared the composition of the raw material entering the plants, the separation process, and other specifications of the composting process to the composition of the produced compost.

Important strengths of the present study are the analysis of a significant number of facilities dealing with the treatment of OFMSW from separate collection, and the statistical assessment of a high number of variables and observations associated with the technical specifications of the plants and the compost quality. In all the previous studies, it was observed that improper materials affected the concentration of heavy metals in compost. The present study goes one step further by developing a regression analysis to assess the quantitative effect of improper materials, both general and specific (e.g. special waste and plastic bags), as well as other factors (e.g. decomposition and maturation technology, the input of green waste) on the quality of compost.

## 2. Methods and materials

### 2.1 Biological treatment plants

This study assesses 20 biological treatment plants in Catalonia (Spain). The treatment plants are distributed throughout the territory, with a higher concentration in the proximity of metropolitan Barcelona, where the largest facilities can be found (plants numbered three, four, and six; see Figure 2).



**Legend:** The map of Catalonia is divided into territorial units corresponding to the administrative level of comarques, or groups of municipalities. These are identified within brackets for each one of the following plants. 1. *Boadella i les Escaules (Alt Empordà)*, 2. *Botarell (Baix Camp)*, 3. *Ecoparc 1–Barcelona (Barcelonès)*, 4. *Ecoparc 2–Montcada i Reixac (Vallès Occidental)*, 5. *Espluga de Francolí (Conca de Barberà)*, 6. *Granollers (Vallès Oriental)*, 7. *Jorba (Anoia)*, 8. *La Seu d'Urgell (Alt Urgell)*, 9. *Llagostera (Gironès)*, 10. *Malla (Osona)*, 11. *Manresa (Bages)*, 12. *Mas de Barberans (Montsià)*, 13. *Montoliu de Lleida (Segrià)*, 14. *Olot (Garrotxa)*, 15. *Sant Cugat del Vallès (Vallès Occidental)*, 16. *Sant Pere de Ribes (Garraf)*, 17. *Santa Coloma de Farners (Selva)*, 18. *Tàrrega (Urgell)*, 19. *Torrelles de Llobregat (Baix Llobregat)* and 20. *Tremp (Pallars Jussà)*. The municipality of Barcelona is identified in the map.

**Figure 2.** Catalonia biological treatment plants assessed in the study

Sources: Own elaboration based on Institut Cartogràfic i Geològic de Catalunya (2016) and Agència de Residus de Catalunya (2017a).

Note: For purposes of confidentiality, the treatment plants are not identified in the remaining sections of this paper.

## 2.2 Database

This study analyses a unique database managed by the Catalan Waste Agency (Agència de Residus de Catalunya—ARC), which includes information about 20 biowaste composting plants in Catalonia, structured on a quarterly basis for the period 2010–2014. This database comprises the following three groups of data:

- **Group 1. Characteristics of the plants**—Contains information about constant qualitative (e.g. type of management and technology used for biowaste decomposition) and quantitative (e.g. annual treatment capacity and sieving size) variables.

- **Group 2. Material flows**—Characterises the input (e.g. biowaste, green waste, and improper materials) and output (e.g. compost and refuse) materials on a regular quarterly basis. The characterisation of the biowaste collection circuits was made on a quarterly basis since 2006. The data were already analysed in Puig-Ventosa et al. (2013), whose main focus is identifying the drivers behind the presence of improper materials in source-collected biowaste. These include socioeconomic variables, such as urban density, and factors related to the waste collection model and its performance, such as type of collection, separate collection rates, or requirements to use compostable bags. Data on the proportion of improper materials found in source-collected biowaste were obtained by analysing various collection routes and were calculated as a weighted average. Improper materials comprise the following categories: pruning residues, paper, plastic packaging (including beverage cartons), plastic bags, glass, ferrous metals, nonferrous metals, textiles, sanitary products, bulky waste (i.e. more than 50 cm in length or 25 l in capacity), special waste (e.g. materials such as batteries, medicines, and paint cans, which require special prevention measures during their collection, storage, transport, treatment, and disposal, since they can present an occupational and public health risk), and others (e.g. coffee capsules, cigarette butts, ceramic materials) (Agència de Residus de Catalunya, 2017b).

- **Group 3. Compost quality**—Includes information about nonconstant quantitative variables measured on an irregular quarterly basis (e.g. content of heavy metals, electric conductivity, self-heating test).

In total, 93 variables were assessed in this study, notably: six identification variables related to the analysis period, the studied biological treatment plants, and the period of compost production and quality assessment; 18 variables related to the characteristics of the plants; 28 variables related to the plants' material flows (inputs and outputs), including 18 variables characterising improper materials; and 41 variables associated with the characterisation of compost quality. Table A.1 presents the complete list of variables.

### 2.3 Statistical analysis

The statistical analysis performed in this study aims to assess the potential effect of independent (explanatory) variables related to database groups one and two (i.e. characteristics of the plants and material flows) on the dependent (response) variables related to database group three (i.e. compost quality).

This study followed two main methodological steps. First, it conducted a descriptive statistical analysis of individual variables related to the aforementioned database groups one to three. This included an evaluation of the quality of compost obtained in the studied plants, in terms of its compliance with a set of recommended values by the ARC, as well as with the Spanish regulation for fertilisers—*Real Decreto 506/2013* (Ministerio de la Presidencia, 2013) (Royal Decree 506/2013). This regulation limits the presence of heavy metals in compost, classifying the final product according to three classes (A, B, and C). These classes represent a descending order of quality, and are associated with limitations on the use of the compost. As an example, compost corresponding to class C can only be applied at a proportion of 5 t of dry matter per hectare per year. If the content of heavy metals in the compost exceeds the limit of class C, its use in agriculture is prohibited. Other considerations in the previous regulation relate to pathogen content, total organic matter content, C/N ratio, impurities content, and particle size.

Data related to compost quality correspond to quarterly measurements taken at the studied plants. Most parameters have observations for a significant number of quarters in the analysis period, and a few have more than one observation for some of the assessed quarters. To handle the data referring to the latter type of parameters, the average value of the observations corresponding to the same quarter was calculated prior to the descriptive statistical analysis.

Second, this study also developed various regression models aimed at assessing the potential factors affecting the quality of compost. Equation 1 provides a general schematisation of this process, where $Q$ corresponds to the quality of the compost produced in plant $i$ at time $t$, measured by quality parameters (e.g. heavy metals content, electric conductivity, and self-heating test). The compost quality is represented as a function of the type of materials entering the plant ($M$) including special attention paid to improper materials, the plant characteristics (C), and a random, unobserved component ($\mathcal{E}$).

$$Q_{it} = f(M_{it}, C_{it}) + \varepsilon_{it} \tag{1}$$

In the regression analysis, the generalised least squares (GLS) method for unbalanced panel data was applied because some observations were missing for certain variables characterising the compost quality. Independent and dependent variables were modified to obtain the models with the best fit (e.g. through the creation of categorical dummy variables and the logarithmic transformation of variables). The regression analysis tested a large number of quality parameters with the software Eviews (v7.1). The models presented in this paper were selected according to their statistical validation, in terms of the individual and global significance of the parameters, distribution of the residues, heteroscedasticity, autocorrelation, and multicollinearity. Section 3.2 provides more information about the selected models.

## 3. Results and discussion

### 3.1 Descriptive statistical analysis

#### *3.1.1 General overview of the plants characteristics*

Table 1 presents the main plants characteristics according to 2014 data. There is an equal share of privately and publicly managed facilities. A significant majority of these (85%) are exclusively composting plants, and the remaining facilities also implement anaerobic digestion (15%). Half of the plants remain within an annual biowaste treatment capacity range of 4,875 to 18,500 t, and the other half are subdivided into smaller (< 4,875 t) and larger (> 18,500 t) plants. The majority of the plants use either dynamic (turned) windrows or static (in vessel) technology for biowaste decomposition, whereas dynamic windrows are the most adopted system for the maturation process. The total treatment process (biowaste decomposition plus compost maturation) lasts, on average, 82 days.

**Table 1.** Main plants characteristics, 2014

| | % |
|---|---|
| **Type of management** | |
| Public | 50 |
| Private | 50 |
| **Treatment system** | |
| Composting | 85 |
| Anaerobic digestion plus composting | 15 |
| **Treatment capacity** (t/y) | |
| < 4,875 | 25 |
| 4,875–18,500 | 50 |
| > 18,500 | 25 |
| **Pretreatment trommel diameter** (cm) | |
| 80 | 100 |
| **Sieving trommel diameter** (cm) | |
| 10 | 75 |
| 12 | 10 |
| 16 | 15 |
| **Treatment system for biowaste decomposition** | |
| Anaerobic digestion | 15 |
| Dynamic (turned) windrows | 35 |
| Static aerated windrows | 10 |
| In vessel | 30 |
| Aerated channels | 10 |
| **Treatment system for compost maturation** | |
| Dynamic windrow | 55 |
| Nonaerated channel | 15 |
| In vessel | 15 |
| Aerated channel | 10 |
| Static aerated windrow plus aerated channel | 5 |
| **Duration of various processes** | **Mean (SD)** |
| Selection time of improper materials (d) | 14.5 (3.2) |
| Duration of biowaste decomposition process (d) | 24 (10.1) |
| Duration of compost maturation process (d) | 58.1 (22.2) |
| Duration of total process (decomposition plus maturation; d) | 82.1 (26.1) |

Source: Own elaboration based on data provided by the ARC.

### *3.1.2 Material flows*

Table 2 presents the material flows of the treatment plants for the period 2010–2014. The average quantity of biowaste treated per quarter and plant was 4,306 t, with a range of 8.7–31,122 t. The differences in terms of treatment capacity explain the wide range of minimum and maximum values observed in the rest of the indicators.

The average proportion of green waste input to treated biowaste was 14.3%. Green waste is considered a required material for composting organic waste (Haug, 1993) due to its ability, as a source of carbon, to balance the C/N ratio, as well as its bulking capacity to conserve aerobic conditions during the composting process. Some observations of this indicator were zero, which seems to indicate that those plants introduced very small quantities of yard trimmings in the treatment process. As a result, the raw material mixture would present a nutrient imbalance, leading to a poor C/N ratio. Another possible explanation for this outcome is that some plants might use more recirculated yard trimmings than others. This might affect the compost quality as a result of the concentrations of nutrients and heavy metals, and the impurities content that is not removed by sieving (López et al., 2010b).

The (weighted) average quantity of improper materials across all the treated biowaste was 10.7%. This translates to a mean value of approximately 1,712 t of refuse that needs to be managed through other systems—recovery or, most commonly, landfill or incineration.

Treatment plants produced an average of 461 t of compost per quarter, i.e. approximately 15% of the biowaste treated, which is consistent with the degradation ratios of the transformation of organic carbon into carbon dioxide ($CO_2$). This occurs due to the biological transformation of the materials entering the plants (loss of $CO_2$ and water), as well as physical losses in sieving. In the case of OFMSW, there is a high quantity of reduction between input and output materials, as a significant quantity of improper materials is removed during the biowaste treatment process.

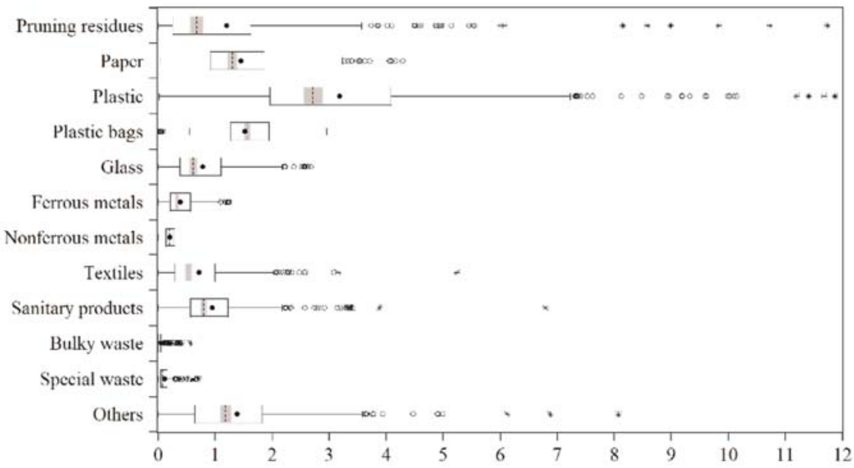
Figure 3 shows 12 categories of improper materials entering the studied plants. Although pruning waste is biodegradable and can be used in composting, it is still classified as an improper material whenever it is (inappropriately) disposed of in the organic container, rather than at the appropriate civic amenity site. According to Spanish Regulation—— *Ley 22/2011, de 28 de julio, de residuos y suelos contaminados* (Congreso de los Diputados, 2011) (Law 22/2011 of 28 July, on waste and contaminated soil)—only green waste of a small size, such as leaves, bunches, or dead plants, can be considered biowaste, whereas ligneous debris and larger particles cannot be included in the biowaste container.

The types of improper materials most commonly found in the organic bin and entering the plants included plastic packaging, plastic bags, and paper; they make up, on average, 3.2%, 1.5%, and 1.4%, of the treated biowaste, respectively. The larger presence of plastic can be mostly attributed to its use in food packaging, which often gets disposed of along with food waste. Moreover, one must consider that biowaste is often disposed of in nonbiodegradable plastic bags. These bags cannot be effectively removed through mechanical selection systems at the composting plants, meaning that they will remain in the compost as impurities (Cesaro et al., 2015).

**Table 2.** Descriptive statistics of material flows occurring in the biological treatment plants (quarterly observations, 2010–2014)

| Variables | n | Mean | Minimum | Maximum | SD |
|---|---|---|---|---|---|
| Biowaste treated per quarter (t) | 400 | 4,306.5 | 8.7 | 31,122.4 | 5,901.4 |
| Saturation (biowaste treated/treatment capacity, %) | 400 | 22.3 | 0.5 | 68.1 | 9 |
| Green waste input per quarter (t) | 400 | 369.4 | 0 | 3,401.9 | 595.4 |
| Green waste input/biowaste treated (%) | 396 | 14.3 | 0 | 76.3 | 13.6 |
| Input of improper materials per quarter (t) | 400 | 603.1 | 0.02 | 4,687.6 | 999.9 |
| Input of improper materials/biowaste treated (%) | 400 | 10.7 | 0.1 | 30.2 | 5.8 |
| Total refuse output (t) | 400 | 1,711.9 | 0 | 14,016.4 | 3,145.9 |
| Refuse output/biowaste treated (t/t) | 400 | 0.2 | 0 | 92.6 | 0.2 |
| Input of improper materials/refuse output (t/t) | 400 | 0.8 | 0 | 10.3 | 1.001 |
| Total compost output (t) | 400 | 460.7 | 0 | 6,789.2 | 801.6 |
| Compost output/biowaste treated (%) | 400 | 14.6 | 0 | 87.2 | 13.1 |

Source: Own elaboration based on data provided by the ARC.



**Legend:** The mean is represented with a black dot, whereas the median corresponds to the vertical dashed line inside the rectangles of the box plots. Each rectangle comprises a lower and upper bound associated with the first and third quartiles, respectively. The horizontal lines in the exterior of the rectangles represent the variability outside the first and third quartiles, whereas the empty circles and plus signs represent the near and far outliers.

**Figure 3.** Box plot chart of improper materials entering biological treatment plants by percentage (quarterly observations, 2010–2014)

Source*:* Own elaboration based on data provided by the ARC.

### *3.1.3 Compost quality*

The characterisation of compost quality is presented in Table 3. The average values of the majority of the parameters comply with the limits defined in the *Real Decreto 506/2013* (Ministerio de la Presidencia, 2013) (Royal Decree 506/2013) for organic amendments and other general requirements. The *E. coli* content is the only parameter that does not meet the requirements, with an average value slightly higher than 1,000 CFU. Results for heavy metals indicate that Cd, chrome (Cr), Hg, Pb, and Ni show average values corresponding to class A, whereas Cu and Zn stay within class B. Regarding the recommendations of the ARC, some average values are slightly outside the proposed limits, namely those of electric conductivity and the Solvita test. Both parameters are indicators of compost maturity that reveal toxicity in seed germination and roots when reaching high values. Currently, regulations do not establish limits on electric conductivity, although its value should be indicated when the product is used in agriculture. The values for growing media substrates are expected to be low, preferably under 1-2 dS/m, to avoid negative effects on seed germination and root development. There is a higher tolerance regarding electric conductivity for other uses of compost, but high values can lead to a decrease in soil fertility.

Despite the majority of the values of the studied parameters indicating that compost can be applied in different uses (Waqasab et al., 2018), some remarks are warranted. The pH ranged around neutrality, tending to basicity, which can be expected due to the ammonia released in the latter stages of the process. The stability parameters related to respiration (i.e. self-heating test, respiration rate, and Solvita test) indicate that, on average, the produced compost has not achieved sufficient stability (TMECC, 2002; Bernal et al., 2009). The average value of ammoniacal nitrogen (over 0.4%) (Bernal et al., 2009) and the pathogen and germination values also indicate this. Nevertheless, parameters such as the stability degree (over 50%) and C/N (below 20) (López et al., 2010c; Bernal et al., 2009) indicate that the materials are finished. As for the nutrients, the values of potassium (K) and phosphorus (P) are similar to those observed in home composting (Tatàno et al., 2015; Lleó, et al., 2013). The average values of the sum of metal, glass, and plastic impurities (below 2 mm) are similar to those observed in Cesaro et al. (2019), which studied OFMSW composting in Italy.

**Table 3.** Descriptive statistics of the main compost-quality parameters (average of quarterly observations, 2010–2014)

| Variables | n | Mean | Min. | Max. | SD | Limits of Royal Decree 506/2013 | Recommended by ARC |
|---|---|---|---|---|---|---|---|
| Dry matter (%) | 185 | 71.1 | 29 | 90.2 | 10.1 | - | > 60 |
| Moisture (%) | 185 | 28.9 | 9.8 | 71 | 10.1 | < 40 | - |
| pH | 183 | 7.9 | 6.1 | 9 | 0.6 | - | > 7 |
| Electric conductivity (dS/m) | 185 | 8.2 | 1.6 | 14.3 | 2.5 | - | < 8 |
| Total organic matter content (TOM; % db) | 185 | 52.3 | 24 | 76 | 8.6 | - | > 35 |
| Total organic matter content (TOM; % wb) | 185 | 37.3 | 13.1 | 60.8 | 8.7 | > 35 | - |
| Resistant organic matter (ROM; % db) | 122 | 30.6 | 13.1 | 44.7 | 5.7 | - | - |
| Degradable organic matter (% db) | 122 | 21.1 | 10.6 | 46 | 5.9 | - | - |
| Stability degree (%; ROM/TOM) | 122 | 59.5 | 34.4 | 77.7 | 7.1 | - | > 50 |
| Compost self-heating test (ºC) | 157 | 47.4 | 20 | 74 | 16.3 | - | < 40 |
| Respiration rate (AT4; mg $O_2$/g DM) [1] | 32 | 21.02 | 1.2 | 57.4 | 16.8 | - | < 15 |
| Humic acids (% db) | 32 | 12.4 | 4.1 | 20.5 | 3.9 | - | - |
| Solvita test (scale of 1–8) | 32 | 5.2 | 1 | 7 | 1.5 | - | < 5 |
| *Escherichia coli* (CFU) [1] | 163 | 1,105 | 2 | 64,000 | 6,157 | < 1,000 | - |
| *Salmonella* (CFU) | 163 | 0.02 | 0 | 2 | 0.2 | Absence in 25g | - |
| Nitrogen (% db) | 185 | 2.7 | 1.3 | 4.4 | 0.5 | - | > 2 |
| Ammoniacal nitrogen ($NH_4$; % db) | 185 | 0.4 | 0.03 | 1.04 | 0.2 | - | - |
| C/N | 185 | 9.9 | 6.7 | 19.4 | 1.8 | < 20 | - |
| Phosphorus (P; % db) | 185 | 0.99 | 0.3 | 1.8 | 0.3 | - | - |
| Potassium (K; % db) | 185 | 1.6 | 0.6 | 2.7 | 0.5 | - | - |
| Calcium (Ca; % db)[1] | 184 | 8.3 | 2.1 | 16.9 | 2.3 | - | - |
| Iron (Fe; % db) | 185 | 0.96 | 0.3 | 2.5 | 0.3 | - | - |
| Magnesium (Mg; % db) | 185 | 0.7 | 0.2 | 1.5 | 0.2 | - | - |
| Sodium (Na; % db) | 20 | 0.7 | 0.1 | 1.2 | 0.3 | - | - |
| Cadmium (Cd; mg/kg db) [1, 2] | 184 | 0.6 | 0.04 | 2.5 | 0.3 | 0.7; 2; 3 | - |
| Chrome (Cr; mg/kg db) [1, 2] | 185 | 25.1 | 6.4 | 92.5 | 16 | 70; 250; 300 | - |
| Copper (Cu; mg/kg db)[2] | 185 | 119.1 | 32 | 574 | 64.5 | 70; 300; 400 | - |
| Lead (Pb; mg/kg db)[2] | 185 | 45.03 | 13 | 192 | 25.6 | 45; 150; 200 | - |
| Mercury (Hg; mg/kg db) [1, 2] | 180 | 0.4 | 0.01 | 4.01 | 0.4 | 0,4; 1,5; 2,5 | - |
| Nickel (Ni; mg/kg db)[2] | 185 | 17.1 | 4 | 46 | 8.4 | 25; 90; 100 | - |
| Zinc (Zn; mg/kg db)[2] | 185 | 271.1 | 81 | 662 | 101.3 | 200; 500; 1,000 | - |
| Particle-size fractions > 20 mm (% db) | 109 | 0.02 | 0 | 2 | 0.2 | - | - |
| Particle-size fractions 10–20 mm (% db) | 109 | 0.98 | 0 | 10 | 2.3 | - | - |
| Particle-size fractions < 10 mm (% db) | 109 | 98.1 | 0 | 100 | 9.8 | - | - |
| Impurities: metals (% db)[1] | 109 | 0.1 | 0 | 0.1 | 0.1 | - | - |
| Impurities: stones and gravel (% db)[1] | 109 | 0.1 | 0 | 2.7 | 0.4 | - | - |
| Impurities: plastic (% db) [1] | 109 | 0.2 | 0 | 1.01 | 0.2 | - | - |
| Impurities: glass (% db) [1] | 109 | 0.3 | 0 | 2.8 | 0.6 | - | - |
| Impurities: metals, glass, plastic (% db) [1] | 139 | 0.4 | 0 | 3.3 | 0.6 | - | < 1.5 % wb[3] |
| Weeds test (seeds/4l) [1] | 89 | 0.1 | 0 | 5 | 0.5 | - | - |
| Germination percentage (%) | 116 | 71.1 | 29 | 90.2 | 10.1 | - | > 70 |

Source: Own elaboration based on data provided by the ARC and the Royal Decree 506/2013 (Annex I, Group VI, Subgroup compost) (Ministerio de la Presidencia, 2013).

Notes: [1] Some observations of these variables are displayed in ranges in the original database. The values of these observations were assumed to be equal to the maximum value of a range. [2] Values displayed in the last column correspond, in order, to the limits of compost classes A, B, and C. These refer to a descending order of quality in accordance with Royal Decree 506/2013 (Ministerio de la Presidencia, 2013). [3] This corresponds to the sum of metals, glass, plastics, stones, and gravel.

## 3.2 Regression model analysis

The selected regression models address the dependent variables associated with compost quality, namely the concentration of heavy metals of Cu, Pb, and Zn; the electrical conductivity; and the maximum temperature of the self-heating test. Other compost quality parameters were tested without significant results. Summary statistics presented for the selected models include the number of observations assessed and the F-statistic test and probability of F-statistic, the latter of which refers to the overall significance of the model by comparing it to another model featuring only the intercept. The null hypothesis, i.e. that the fit of both models is the same, can be rejected in all of the selected models, meaning that the addition of the studied variables improved the model significance. The Durbin-Watson (DW) statistic, which tests multicollinearity and autocorrelation, can also be rejected.

### *3.2.1 Heavy metals*

a) Cu

In this model, the dependent variable corresponds to the natural logarithm of Cu (in its original configuration, measured in mg/kg), which allows for normalisation of the distribution of this variable. The set of independent variables includes the input of improper materials, measured as a percentage of the treated biowaste, and categorical coded variables, with effects coding linked to the type of decomposition technology. For the latter type of variables, the levels of static and dynamic decomposition are compared with the reference (omitted) level of anaerobic digestion.

The results presented in Table 4 show that, on average, the presence of Cu in the compost rises 1.76% for each one percent increase in the proportion of improper materials in treated biowaste. On average, plants using static decomposition technology present 42.6% less Cu in the compost, in comparison with plants that use anaerobic digestion. This finding can be explained by the possibility of the digested material's being composed of less organic matter compared to fresh, selectively collected biowaste, as well as by the low solubility of Cu. The results for dynamic decomposition technology are not significant.

**Table 4.** Regression model estimates addressing the presence of Cu in the compost

| | **Coefficient** | **Standard Error** | **T Statistic** | **P-value** |
|---|---|---|---|---|
| C (constant) | 4.7827*** | 0.2087 | 22.9146 | 0.0000 |
| Input of improper materials/biowaste treated (%) | 0.0175** | 0.0082 | 2.1192 | 0.0354 |
| Static decomposition[1] | -0.5549** | 0.2457 | -2.2585 | 0.0251 |
| Dynamic decomposition[1] | -0.3104 | 0.2247 | -1.3813 | 0.1689 |
| **Summary Statistics** | | | | |
| Observations | 185 | | | |
| F-statistic | 4.9098 | | | |
| Prob. (F-statistic) | 0.0026 | | | |
| DW statistic | 0.9695 | | | |

Notes: For every unit increase in the independent variable, the dependent variable increases e (Euler's number) raised to the power of the coefficient of the independent variable due to its natural logarithmic transformation. By subtracting one from this result and multiplying by 100, it is possible to estimate the percentage change in the dependent variable.

Reference level: [1] Anaerobic digestion.

### b) Pb

As in the previous model, the dependent variable (Pb) shows a logarithmic transformation. Three independent variables are included in this model: the input of improper materials over the treated biowaste and two categorically coded variables with effects coding for the trommel screen diameter. These refer to the sizes of 12 mm and 16 mm, in comparison with a reference level of 10 mm, which is the most common size for sieving compost.

The results presented in Table 5 indicate that, on average, the content of Pb in the compost rises 1.82% for each one percent increase in the proportion of improper materials to treated biowaste. The presence of Pb in improper materials stems from several sources: *inter alia*, old water pipes, ceramics and enamels, and glasses and pigments used in colouring, painting, or labelling of various materials.

On average, the facilities with trommel screen diameters of 12 mm and 16 mm present 42% and 19.57% less Pb in the compost, when compared to plants with trommel screens of 10 mm. Potential explanations for these results include: trommel screens with diameters bigger than 10 mm may contribute to a smaller quantity of degraded particles and, therefore, result in lower concentrations of mineral matter, and larger particles may be composed of green waste, which has a lower concentration of Pb. Knoop et al. (2017) observed that the heavy metal concentration in the OFMSW digestate increased with the decrease in particle size. Green waste can also be come from pruning trees in urban areas and along roads. The types of fuel used by the vehicles in these areas may contribute to a higher or lower concentration of Pb.

**Table 5.** Regression model estimates addressing the presence of Pb in the compost

| | **Coefficient** | **Standard Error** | **T Statistic** | **P-value** |
|---|---|---|---|---|
| C (constant) | 3.5280*** | 0.1212 | 29.1063 | 0.0000 |
| Input of improper materials/biowaste treated (%) | 0.0181*** | 0.0064 | 2.8390 | 0.0050 |
| Trommel screen diameter 12 mm[1] | -0.5447*** | 0.2015 | -2.7039 | 0.0075 |
| Trommel screen diameter 16 mm[1] | -0.2171** | 0.0980 | -2.2161 | 0.0279 |
| **Summary Statistics** | | | | |
| Observations | 185 | | | |
| F-statistic | 3.9309 | | | |
| Prob. (F-statistic) | 0.0095 | | | |
| DW statistic | 1.5621 | | | |

Notes: For every unit increase in the independent variable, the dependent variable increases e (Euler's number) raised to the power of the coefficient of the independent variable due to its natural logarithmic transformation. By subtracting one from this result and multiplying by 100, it is possible to estimate the percentage change in the dependent variable.

Reference level: [1] Trommel screen with a diameter of 10 mm.

### c) Zn

The dependent variable Zn is assessed in this model without consideration for the outliers greater than 600 mg/kg db, allowing for better results, in terms of the distribution of residues and the model significance. Identification of the outliers was done by analysing the box plot of Zn and following the procedure presented in Hoaglin and Iglewicz (1987), in which the outliers were identified by defining the higher and lower quartiles as well as the outliers' range. As for independent variables, the model includes the proportion of improper materials to the treated biowaste and two categorical variables associated with the decomposition technology of biowaste. These variables relate to the levels of static and dynamic decomposition that are compared with the reference level of anaerobic digestion.

Table 6 shows that, on average, the presence of Zn in the compost increases 4.6 mg/kg for every one percent increase in the proportion of improper materials to treated biowaste. On average, facilities with static decomposition and those with dynamic decomposition present 116.7 mg/kg and 104.7 mg/kg less Zn in the produced compost, respectively, when compared to plants with anaerobic digestion.

Regarding the interpretation of these results, it is expected that a higher presence of improper materials may lead to an increase in heavy-metal content because of the potential for improper materials to contaminate incoming biowaste. Results showing a potential higher presence of Zn in plants with anaerobic digestion can be explained by the low solubility of this metal and the difficulty of extracting it when it is mixed with the liquid fraction of the digested material. The implementation of anaerobic digestion before composting promotes a higher degradation of the organic matter, which can lead to a higher concentration of heavy metals.

**Table 6.** Regression model estimates addressing the presence of Zn in the compost (in mg/kg)

| | **Coefficient** | **Standard Error** | **T Statistic** | **P-value** |
|---|---|---|---|---|
| C (constant) | 301.7078*** | 47.0714 | 6.4096 | 0.0000 |
| Input of improper materials/biowaste treated (%) | 4.6390** | 2.2066 | 2.1024 | 0.0369 |
| Static decomposition[1] | -116.6644*** | 40.6915 | -2.8671 | 0.0046 |
| Dynamic decomposition[1] | -104.7222** | 46.8180 | -2.2368 | 0.0265 |
| **Summary Statistics** | | | | |
| Observations | 183 | | | |
| F-statistic | 9.0006 | | | |
| Prob. (F-statistic) | 0.00001 | | | |
| DW statistic | 1.7640 | | | |

Note: The symbols *** and ** indicate statistical significance at 1% and 5%, respectively.

Reference level: [1] Anaerobic digestion.

### *3.2.2 Electric conductivity*

Soil salination poses a risk to crop fertility and quality and can limit the availability of nutrients (Meena et al., 2019). The use of compost can reduce the salinity caused by chemical fertilisers. In the case of compost obtained from municipal waste, the content of improper materials in the initial material can affect the salinity of the product.

This model aims to explain the effect of two types of improper materials—special waste and plastic bags—as well as the variables related to the proportion of green waste input to biowaste treated, and to maturation technology, on compost quality, here measured by electric conductivity. The variable corresponding to the maturation technology is presented as a dummy variable, holding a value of zero for static maturation and one for dynamic maturation.

The results presented in Table 7 show that, on average, a one percent increase in the proportion of improper materials over the treated biowaste, corresponding to the categories of special waste and plastic bags, leads to a rise in electric conductivity of 4.7 dS/m and 0.8 dS/m, respectively. Special waste includes highly pollutant materials, such as batteries, electronics, medicines, and solvents, which can transfer saline components into organic matter, increasing its electric conductivity. Plastic bags also increase salinity, although less so than special waste, as the cause can mainly be attributed to the pigments used to colour them.

The results also indicate that, with a one percent increase in the proportion of green-waste input to treated biowaste, conductivity rises 0.04 dS/m. This might be explained by the fact that processing plants with a higher proportion of green waste to treated biowaste tend to have longer treatment processes. The higher salinity of the compost can be attributed to a higher mineralisation (Sharifi and Renella, 2015), occurring during a longer composting process, rather than to the contribution of mineral matter in green waste.

On average, plants with dynamic maturation technology show 1.3 dS/m higher salinity to those with static maturation. One possible interpretation of this result is that the physical turning of the material contributes to a reduction in the size of the particles, which may expose them to a higher degradation and mineralisation, increasing salinity.

**Table 7.** Regression model estimates addressing the electric conductivity of compost

| | **Coefficient** | **Standard Error** | **T Statistic** | **P-value** |
|---|---|---|---|---|
| C (constant) | 5.1764*** | 0.8030 | 6.4461 | 0.0000 |
| Special improper materials/biowaste treated (%) | 4.7260*** | 1.1468 | 4.1209 | 0.0001 |
| Improper materials (plastic bags)/biowaste treated (%) | 0.7620** | 0.3352 | 2.2734 | 0.0242 |
| Green waste input/biowaste treated (%) | 0.0378*** | 0.0141 | 2.6726 | 0.0082 |
| Maturation technology regarding movement[1] | 1.2997** | 0.5327 | 2.4399 | 0.0157 |
| **Summary Statistics** | | | | |
| Observations | 185 | | | |
| F-statistic | 5.7598 | | | |
| Prob. (F-statistic) | 0.0002 | | | |
| DW statistic | 1.3827 | | | |

Notes: The symbols *** and ** indicate statistical significance at 1% and 5%, respectively.

Reference level: [1] Dummy variable represented by a value of zero for static maturation and one for dynamic maturation.

### *3.2.3 Compost self-heating test*

This model deals with the effects of independent variables—the proportion of improper materials made of plastic bags over the treated biowaste, saturation, decomposition technology regarding movement, and trommel screen diameter—on compost quality, measured by the indicator of the compost self-heating test. Regarding the transformation of the original variables, the model includes two dummy variables for the technology: decomposition and trommel screen diameter.

The results displayed in Table 8 indicate that, on average, a one percent increase in improper materials made of plastic bags results in a 5.6ºC increase in the temperature of the self-heating test. Plastic bags may, in fact, affect biological treatment by representing a physical barrier for the circulation of air, thereby creating conditions for anaerobiosis.

The results also point to a rise of 0.3ºC in the compost self-heating test, with a one percent increase in saturation level. A possible explanation for this effect is that processing plants that handle more biowaste than their capacity may be less efficient. This can mean a lower transformation of organic matter and lower stabilisation, which can lead to a higher temperature.

As for the effect of the variable associated with the decomposition technology, the study shows that compost samples obtained from plants with static and dynamic decomposition show, on average, a 10.4ºC higher temperature in the self-heating test than with anaerobic digestion plants. In the latter type of plants, the raw material is anaerobically digested before the biological aerobic process is initiated. This contributes to more stabilised material at the end of the process, presenting lower values in this test.

The facilities sieving material through trommels with a diameter of 12 mm or 16 mm show an increase in temperature of 7.2ºC in this test, compared to plants that have trommels with a diameter of 10 mm. Bigger particles are generally less degraded, leading to a more unstable final product, which may explain the higher temperature found in this test.

**Table 8.** Regression model estimates addressing the compost self-heating test

| | **Coefficient** | **Standard Error** | **T Statistic** | **P-value** |
|---|---|---|---|---|
| C (constant) | 21.4298*** | 5.5194 | 3.8827 | 0.0002 |
| Improper materials (plastic bags)/biowaste treated (%) | 5.6348** | 2.3582 | 2.3894 | 0.0181 |
| Saturation (%) | 0.2811** | 0.1330 | 2.1142 | 0.0361 |
| Decomposition technology regarding movement[1] | 10.4499** | 4.2089 | 2.4828 | 0.0141 |
| Trommel screen diameter[2] | 7.2346** | 3.5926 | 2.0137 | 0.0458 |
| **Summary Statistics** | | | | |
| Observations | 157 | | | |
| F-statistic | 4.9115 | | | |
| Prob. (F-statistic) | 0.0009 | | | |
| DW statistic | 1.6051 | | | |

Notes: The symbols *** and ** indicate statistical significance of 1% and 5%, respectively.

Reference levels: [1] Indicates a dummy variable taking the value of one for static and dynamic decomposition technologies and of zero for anaerobic digestion. [2] Indicates a dummy variable taking the value one for diameters of 12 mm and 16 mm and of zero for a diameter of 10 mm.

## 4. Conclusions

This study performs a statistical analysis of a unique database managed by the ARC, which includes data about the technical specifications, material flows, and compost quality of several biological treatment plants of the OFMSW in Catalonia, for the period 2010–2014.

The main results of the regression analysis indicate that a higher presence of general and specific (e.g. special waste and plastic bags) improper materials in biowaste has a negative impact on all the assessed parameters of compost quality, including the concentration of heavy metals Cu, Pb, and Zn, the electrical conductivity, and the maximum temperature of the self-heating test.

Other significant results of the regression analysis indicate that, on average, processing plants with anaerobic digestion are associated with a higher presence of heavy metals in the produced compost than with processing plants that use static and dynamic decomposition technology. Plants using trommel screens with larger diameters (12 mm and 16 mm) present less Pb and higher values in the self-heating test, when compared to plants with narrower trommel screens (10 mm diameter). Higher levels of saturation—measured by the percentage of biowaste treated at the plants compared to treatment capacity—may lead to an increase in the temperatures of the self-heating test, possibly due to less stabilised organic matter.

The regression analysis tested a high number of dependent and independent variables, but only a restricted number of variables featured in the selected models. It is important that the analysis of factors contributing to higher compost quality be continued.

Suggestions for future research include the following: a more detailed analysis of the less likely outcomes of the regression analysis, such as the positive causal relationship between the proportion of green waste input into biowaste and electric conductivity; assessment of the data using specific groups of processing plants, as there is a high level of heterogeneity among the 20 studied plants in terms of characteristics such as biowaste treatment capacity and the technology used for biowaste decomposition and maturation; and analysis of more compost quality parameters, which might be possible through more data collection for variables with a high number of missing observations and a more precise measurement for some variables that are displayed as ranges in the original database (e.g. impurities and weeds test).

The findings of this study support the argument to reduce the quantity of improper materials present in selectively collected biowaste to increase compost quality. Some actions that could contribute to this goal may involve improving waste separation at the source, adopting waste collection systems that favour a higher quality of raw material, and performing a better separation of improper materials prior to treatment. Specific measures could also target the most predominant improper materials, plastic packaging (3.2% of the biowaste treated), plastic bags (1.5%), and paper (1.4%).

When compared to low-quality products, premium compost can not only be used in more applications, e.g. from gardening to organic agriculture, but can also have a lower environmental impact. The data assessed in this study about compost quality can contribute to the improvement of the thresholds and parameters used to assess compost quality from a legal point of view.

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# Appendix

**Table A.1. Contents of the ARC database**

| Category | Variable | Measurement Levels/Units |
|---|---|---|
| **Identification Variables** | Year of analysis | 2010, 2011, 2012, 2013, 2014 |
| | Quarter of analysis | 1, 2, 3, 4 |
| | Name of the plant | Boadella i les Escaules; Botarell; Ecoparc 1—Barcelona; Ecoparc 2—Montcada i Reixac; Espluga de Francolí; Granollers; Jorba; La Seu d'Urgell; Llagostera; Malla; Manresa; Mas de Barberans; Montoliu de Lleida; Olot; Sant Cugat del Vallès; Sant Pere de Ribes; Santa Coloma de Farners; Tàrrega; Torrelles de Llobregat; Tremp. |
| | Compost sampling date for quality analysis | dd/mm/yy |
| | Compost production quarter | 1, 2, 3, 4 |
| | Start date of the production process | dd/mm/yy |
| **Plants Characteristics** | Type of management | Public; private |
| | Treatment system | Composting plants; anaerobic digestion plus composting plants |
| | Technology used for biowaste decomposition | Anaerobic digestion; dynamic (turned) windrows; static aerated windrows; in-vessel; aerated channels |
| | Technology used for biowaste decomposition (regarding aeration) | Anaerobic digestion; nonaerated; aerated |
| | Technology used for biowaste decomposition (regarding movement) | Anaerobic digestion; dynamic; static |

| Category | Variable | Measurement Levels/Units |
|---|---|---|
| | Technology used for compost maturation | Dynamic windrow; nonaerated channel; in vessel; aerated channel; static aerated windrow plus aerated channel |
| | Technology used for compost maturation (regarding aeration) | Anaerobic digestion; nonaerated; aerated |
| | Technology used for compost maturation (regarding movement) | Anaerobic digestion; dynamic; static |
| | Annual treatment capacity | t/y |
| | Quarterly treatment capacity | t/quarter |
| | Treatment starting time | Immediately; at a later stage |
| | Duration of the biowaste decomposition process | d |
| | Duration of the compost maturation process | d |
| | Duration of the decomposition and maturation processes | d |
| | Duration of the compost production process | d |
| | Selection time of improper materials | d |
| | Pretreatment trommel diameter | mm |
| | Sieving trommel diameter | mm |
| **Material Flows** | Biowaste input | t per quarter |
| | Biowaste output | t per quarter |
| | Biowaste treated | t per quarter |
| | Green waste input | t per quarter |
| | Green waste input | % over biowaste treated |
| | Saturation | % biowaste treated over quarterly treatment capacity |
| | Input of improper materials: total | t per quarter |
| | Input of improper materials: total | % over biowaste treated |
| | Input of improper materials: pruning residues | % over biowaste treated |
| | Input of improper materials: paper | % over biowaste treated |
| | Input of improper materials: plastic packaging and beverage cartons | % over biowaste treated |

| **Category** | **Variable** | **Measurement Levels/Units** |
|---|---|---|
| | Input of improper materials: plastic bags | % over biowaste treated |
| | Input of improper materials: plastic (total) | % over biowaste treated |
| | Input of improper materials: glass | % over biowaste treated |
| | Input of improper materials: ferrous metals | % over biowaste treated |
| | Input of improper materials: nonferrous metals | % over biowaste treated |
| | Input of improper materials: metals (total) | % over biowaste treated |
| | Input of improper materials: sum of glass, metals, and plastic | % over biowaste treated |
| | Input of improper materials: textiles | % over biowaste treated |
| | Input of improper materials: sanitary products | % over biowaste treated |
| | Input of improper materials: bulky waste | % over biowaste treated |
| | Input of improper materials: special waste | % over biowaste treated |
| | Input of improper materials: other | % over biowaste treated |
| | Refuse output | t per quarter |
| | Refuse output | % over biowaste treated |
| | Input of improper materials/refuse output | t |
| | Compost output | t per quarter |
| | Compost output | % over biowaste treated |
| **Compost Quality** | Dry matter | % wb |
| | Moisture | % wb |
| | pH | pH scale: 0–14 |
| | Electric conductivity | dS/m |
| | Total organic matter content (TOM) | % db |
| | Total organic matter content (TOM) | % wb |
| | Resistant organic matter (ROM) | % db |
| | Degradable organic matter | % db |
| | Stability degree (ROM/TOM) | % db |
| | Compost self-heating test | ºC |
| | Respiration rate (AT4) | mg $O_2$/g DM |
| | Humic acids | % db |
| | Solvita test | Scale: 1–8 |

| Category | Variable | Measurement Levels/Units |
|---|---|---|
| | Eschirichia coli | CFU |
| | Salmonella | CFU |
| | Total nitrogen | % db |
| | Ammoniacal nitrogen ($NH_4$) | % db |
| | C/N | Ratio |
| | Phosphorus (P) | % db |
| | Potassium (K) | % db |
| | Calcium (Ca) | % db |
| | Iron (Fe) | % db |
| | Magnesium (Mg) | % db |
| | Sodium (Na) | % db |
| | Cadmium (Cd) | mg/kg db |
| | Chrome (Cr) | mg/kg db |
| | Copper (Cu) | mg/kg db |
| | Lead (Pb) | mg/kg db |
| | Mercury (Hg) | mg/kg db |
| | Nickel (Ni) | mg/kg db |
| | Zinc (Zn) | mg/kg db |
| | Particle size fractions > 20 mm | % db |
| | Particle size fractions 10–20 mm | % db |
| | Particle size fractions < 10 mm | % db |
| | Impurities: metals | % db |
| | Impurities: stones and gravel | % db |
| | Impurities: plastic | % db |
| | Impurities: glass | % db |
| | Impurities: metals, glass, and plastic | % db |
| | Seeds germination test | Seeds/4 l |
| | Germination percentage | % |

*Source:* ARC.