The efficiency of home composting programmes and compost quality

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ABSTRACT

The efficiency of home composting programmes and the quality of the produced compost was evaluated in eight rural areas carrying out home composting programmes (up to 880 composting bins) for all household biowaste including meat and fish leftovers. Efficiency was analysed in terms of reduction of organic waste collected by the municipal services. An efficiency of 77% on average was obtained, corresponding to a composting rate of 126 kg/person·year of biowaste (or 380 kg/composter·year). Compost quality was determined for a total of 90 composting bins. The operation of composting bins by users was successful, as indicated by a low C/N ratio (10-15), low inappropriate materials (or physical contaminant materials, mean of 0.27±0.44 % dry matter), low heavy metal content (94% of samples met required standards for agricultural use) and high nutrient content (2.1% N, 0.6% P, 2.5% K, 0.7% Mg and 3.7% Ca on average, dry matter). The high moisture (above 70% in 48% of the samples) did not compromise the compost quality. Results of this study show that home composting of household organic waste including meat and fish leftovers is a feasible practice. Home composting helps individuals and families to reduce the amount of household waste at the same time gaining a fertiliser material (compost) of excellent quality for gardens or vegetable plots.

Key words: Household organic waste; Waste prevention; Composting efficiency; Compost quality; Nutrients; Heavy metals

1. Introduction

Home composting has great potential for the sustainable management of organic waste generated in the home, gardens and vegetable plots. The implementation of home composting in recent years has been very intense in several areas of Spain, such as Galiza, Basque Country, Navarre, Catalonia and others (Soto, 2014). A similar trend is observed in many other parts of the world (Smith and Jasim, 2009; Adhikari et al., 2010; Faverial and Sierra, 2014). Adhikari et al. (2010) estimated a potential for decentralised composting systems to accommodate up to 50% of generated municipal organic waste in Europe and Canada, thus reducing costs and greenhouse gas emissions by 34 to 50 and 40%, respectively, as compared to standard landfill disposal.

Properly managed, important economic and environmental benefits are obtained by home composting (Andersen et al., 2012; Faverial and Sierra, 2014; Vázquez et al., 2015). The combined option of segregating domestic biodegradable waste at the source and directing it to home composting is considered a valuable preventative action which contributes to reducing the generation of household waste (Tatàno et al., 2015). Individuals or family users may benefit from a reduction in the rate of service of waste management, while gaining a fertiliser material (compost) with excellent quality for gardens or vegetable plots. Councils and other entities involved will benefit from a reduction in the costs of collection and waste treatment. This is important from the economic point of view, because waste collection is becoming more common in rural areas of low population density where it is usually accompanied by a revenue deficit. This deficit is caused because the costs of waste collection in rural areas are higher than the service tax applied. From the environmental point of view, the non-necessity of collection, transportation and treatment of this waste implies a clear benefit by reducing all kinds of impacts, in addition to saving fertilisers from other sources.

Some scientific studies assessed the environmental sustainability of home composting, comparing various operating options among them and with other waste treatment systems, such as industrial composting, incineration, landfilling or co-evacuation with wastewater (Martinez-Blanco et al., 2010; Chan et al., 2011; Andersen et al., 2012; Lleó et al., 2013; Adhikari et al., 2013). These studies were based on gas emissions monitoring and life cycle assessment and conclude that home composting is as, or even more, sustainable than other options of biowaste treatment and that the main impact factor is related to the greenhouse gas emissions. On the other hand, the intensity in the use of the domestic composters also affects the environmental balance of this alternative in organic waste management, since an analysis of the life cycle identified the composting bin manufacturing as one of the main factors causing emissions of greenhouse gases (Martinez-Blanco et al., 2010). However, the information about compost quality continues to be scarce and a lack of data exists about the efficiency of composting programmes, i.e. the fraction of biowaste diverted to home composting as a function of the number of composting bins used.

It is important to quantify the amount of waste processed by home composting, in order to determine the consequent reduction of organic waste at source (Torras, 2010). Because of the environmental impacts of composters manufacturing (Martinez-Blanco et al., 2010), a low use of composters could not justify the promotion of their installation by waste management responsible bodies. There are different procedures to calculate the amount of organic waste treated in compost, that is, to determine the efficiency of home composting (Puig et al., 2008; ADT, 2009; Resse and Bioteau, 2012). In this study, we chose to determine the real impact of home composting programmes in reducing amounts of organic waste managed by the municipal services of collection and disposal, in specific areas.

In rural areas where a high percentage of households have been equipped with home composting, the quantitative determination of the incidence of home composting programmes (i.e. the composting programme efficiency) in the amount of organic waste collected by local waste services is possible. In thesse areas the content of organic waste going into municipal bins should decline sharply, allowing the efficient use of a single waste container for collecting the resulting dry fraction. This would lead to a sharp reduction in costs of collection, transportation and waste treatment in rural areas.

The destination of domestic compost is always the vegetable or family garden (Adhikari et al., 2010; Scheromm, 2015). The quality of domestic compost has environmental and public health significance to their users, and society in general (Domingo and Nadal, 2009). One of the crucial aspects of the quality is the chemical composition and the level of contamination with heavy metals, something that is regulated for commercial plant composts, for organic amendments and for compost use in agricultural activities. Other aspects of compost quality are its stability and fertiliser power (Vázquez et al., 2015), and the presence of physical contaminants resulting from inappropriate waste sorting at home.

Current limited scientific literature suggests the properties of home compost are within the compost quality limits and similar to industrial compost from separated organic waste sources (Martínez-Blanco et al., 2010; Andersen et al., 2012; Karnchanawong and Suriyanon, 2011), except for moisture content, which was usually higher. However, available data is scarce and restricted to only a few parameters, mainly moisture content, volatile solids, carbon and nitrogen, whilst other characteristics are rarely reported. Moreover, the majority of studies were carried out under well-controlled experimental conditions in small scale pilot composting bins but more rarely in field applications of home and other small scale composting systems (Smith and Jasim, 2009; Faverial and Sierra, 2014; Tatàno et al., 2015).

Therefore, the objectives of this research are: 1) to determine the efficiency of home composting programmes, and 2) to determine the quality of the compost produced in the local programmes of home composting. Composting efficiency has been determined in eight rural areas corresponding to three Galician councils whilst 90 compost samples from eight Galician councils were analysed in order to determine the compost quality.

2. Materials and methods

2.1. Programmes of analysed home composting

The efficiency of home composting has been evaluated in the composting areas of three councils: Oroso, A Laracha and Camariñas (Table 1). In these areas there was a single container for the collection of waste (apart from glass and paper bins and, occasionally, packaging waste bins), a situation that still occurs in most of the scattered rural areas, and that facilitates obtaining necessary information to determine the effectiveness of home composting. To select the study areas, the following requirements were taken into account:

- A well-defined geographical area in which the dwellings included exclusive use of a well defined number of containers of the waste collection service. That is, all the waste generated in these houses is delivered in the containers of the area, and in turn, these containers do not receive contributions from adjacent areas.
- A minimum of three containers per collection area.
- A high ratio of households participating in the composting programme, preferably above 50%.

An example field study is shown in Figure 1. This only contains part of the information about the fulfilment of the above requirements. Additional information (not shown) was obtained after the identification of all the dwellings and the respective waste containers that they use. When possible, sub-areas were selected depending on the specific characteristics such as the dominant economic activities.

Table 1. Features of the areas used for the study of home composting programmes efficiency.

Council	Sub-area	Housing (nº)	Composters (nº)	Waste bins (nº)	CPC[a]
OROSO	Camiño da Presa	18	11	3	0.61
OROSO	Vilanova	20	8	3	0.40
A LARACHA	Torás	36	13	3	0.36
A LARACHA	Amboade	16	12	3	0.75
A LARACHA	Proame	15	12	3	0.80
CAMARIÑAS	Pedrouzo-Sixto	28	18	4	0.64
CAMARIÑAS	Xaviña 1	12	9	3	0.75
CAMARIÑAS	Xaviña-Comercios	18	8	3	0.44
Total	-	163	91	25	0.56

[a] CPC (composting programme coverage) is the level of coverage of each home composting programme, defined as the ratio of number of composters/number of homes.

Table 1 shows the characteristics of the eight selected areas. Although initially the study planned to implement composters in more than 50% of the homes in the selected areas, some homes did not use the composter, which reduced this ratio in these areas. These areas include a total of 163 homes, 56% of them covered by the composting programme, while they have a total of 25 containers for non-segregated waste collection.

The quality of the compost produced was studied in the same areas of the three councils in which we evaluated the efficiency, along with five other areas corresponding to the following five other councils: A Illa de Arousa, Ames, Ordes, Carballo and Vilasantar. In these areas, there is no information regarding the coverage of composting programmes, but it is known that it was low in most of them. The number of composters in these areas varied between 50 and 450, with a total of 880 units, randomly selecting 90 composters for the study of characterisation, with a minimum of 10 units per area. In two councils (A Illa de Arousa and Ames), composting was carried out in 340 L plastic composter bins (Komp 340 Container Trading, Pettenbach, Austria, 76 x 76 cm (base) x 85 cm). In the other six councils, it was used a locally made 350 L plastic composter (Humus Vitae, Rotogal, Boiro-A Coruña, Spain, 83 x 77 cm (base) x 101 cm). The surveys were carried out from 2008 to 2011.

All composting programmes covered by this study, except the one in A Illa de Arousa, were implemented by *Asociación para a Defensa Ecolóxica de Galiza* (ADEGA), which was responsible for delivering the composters and information and training for the users. This educational project undertaken by ADEGA is the explanation to the users, in an affordable way, of both the composting process and the management of waste in general, and the related ecological and environmental aspects. For this, a track of the composters is carried out, and visits are scheduled in an intensive initial phase that lasts for about 4 to 6 months (Lafuente et al., 2012). With the composter bin, a small home composting manual that recommends composting all biowaste, including the remains of fish and meat, was given to the users (ADEGA, 2010). Using the same methodology, ADEGA co-ordinated a home composting programme to approximately 3000 homes in Galiza between 2002 and 2012 (Soto, 2014).

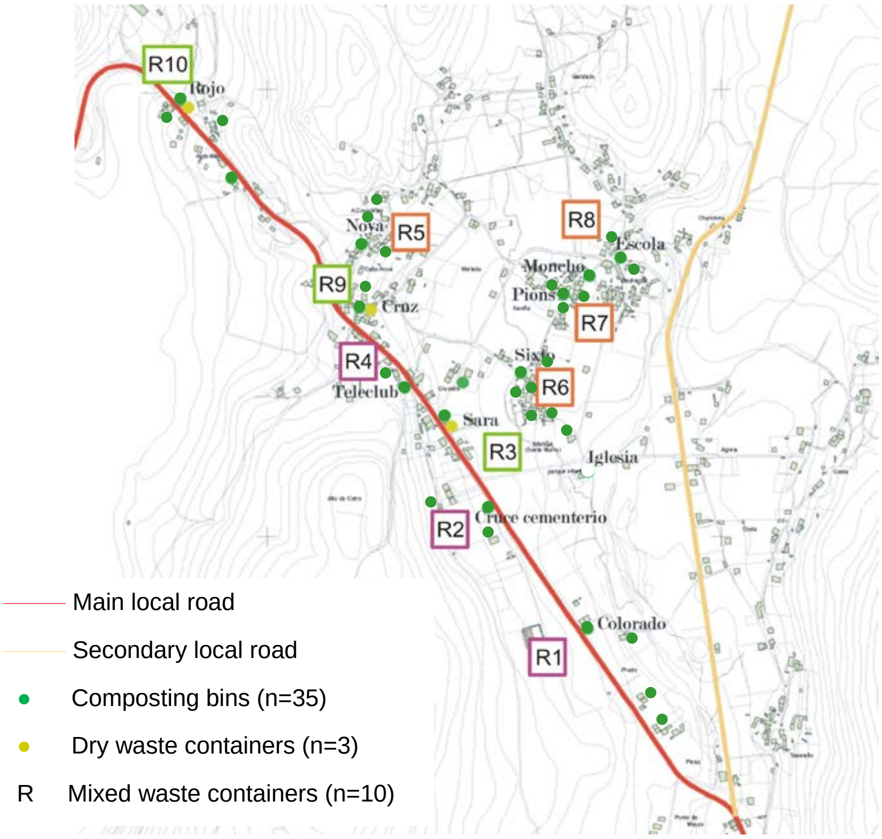

Figure 1. Example of the geographic sub-area of Camariñas Council, in which the study of the compost efficiency was conducted, showing the location of characterised waste bins (The different colours for mixed waste containers R correspond to the different areas of the efficiency study, Table 1: Pedrouzo-Sixto (R5, R6, R7, R8). Xaviña 1 (R3, R9, R10) and Xaviña-Comercios (R1, R2, R4).

2.2. Determination of home composting efficiency

In a preliminary experiment, three waste characterisations were performed (prior to the implementation of the domestic composting programme, 6 month later and a year later, respectively) in containers of the same area of home composting programmes, in order to understand the amounts and the specific kinds of waste that were generated and its variation after implementing the programme of self-composting. The results of this experiment showed the need to gain precision in defining both the initial and final status, so it was decided to perform a double characterisation in both cases. Moreover, the intermediate characterisation was considered of little value, since the pace of implementation of home composting was, in part, unpredictable and did not provide relevant information on the temporal evolution.

Thus, the procedure was as follows. With a difference of between 2 and 4 weeks, two campaigns of characterising the waste deposited in containers were held prior to the implementation of the domestic composting programme. A year later, with more than 6 months of implementation of the programmes, the characterisation campaigns were repeated, also with a difference between 2 and 4 weeks. Thus, the composition of the waste collected is determined in the same season, to avoid potential seasonal interference. In each container the content was rated in the following fractions:

- Organic matter or wet fraction (compostable).
- Rest or dry fraction (includes fractions of paper + cardboard, glass, plastic, metals, liquid cartons and other composite materials, textiles, medical textiles, household hazardous waste, wood, ceramic and aggregates, others).

Each of these fractions was weighed and the percentage composition was determined. The programme's effectiveness was evaluated in terms of the evolution of organic matter content in the containers of the areas defined in Section 2.1 (Table 1). An efficiency of 100% would be obtained if all the organic fraction of municipal solid waste (OFMSW) generated by a household with a composting unit is actually composted. This leads to a potential reduction of the OFMSW content in the collection containers. The final potential percentage of organic fraction in the containers ($OFMSW_{fp}$, %) corresponding to this efficiency of 100% is given by the following equation:

$$OFMSW_{fp} = [OFMSW_i - OFMSW_i \cdot (CPC)] / [100 - OFMSW_i \cdot (CPC)] \cdot 100 \qquad \text{Eq. 1}$$

where $OFMSW_i$ is the percentage of the initial organic fraction in the containers (before the implementation of the programme, expressed in %) and CPC is the fraction of homes equipped with composters in the concerned area (i..e. the level of coverage of each home composting programme, defined as the ratio of number of composters/number of homes).

The program efficiency, in turn, is defined as the ratio between the amount of the actual composted OFMSW and the amount of the potentially compostable OFMSW considering the fraction of homes utilising a composter. A mass balance applied to the management area leading to the following expression for the efficiency (E) of the home composting programme:

$$E (\%) = [OFMSW_i - OFMSW_f \cdot (100 - OFMSW_i)/(100 - OFMSW_f)] / [OFMSW_i - OFMSW_{fp} \cdot (100 - OFMSW_i)/(100 - OFMSW_{fp})] \cdot 100 \quad \text{Eq. 2}$$

where $OFMSW_f$ is the percentage of the final organic fraction in the containers (one year after the implementation of the programme, expressed in %).

This calculation formula is based on the hypothesis that the amount of other waste different from the OFMSW is not affected by the introduction of the composting programme.

2.3. Sampling and analysis

Sampling campaigns were carried out at least 6 months after the beginning of the composting programmes. Some operational parameters have been determined, such as temperature and moisture, volatile solids (VS) content and the carbon/nitrogen ratio (C/N), nutrient content, presence of inappropriate materials (IM) and chemical quality of compost regarding the heavy metal (HM) content. The temperature was determined *in situ* by a probe with a pointed metal shaft, trying to get the maximum value by three successive determinations on each composter. Then a sample of about 5 litres of compost representative of the area with more mature compost was extracted (bottom of the composter), avoiding fresh remains. This sample was collected in a 10-litre bucket and mixed well, breaking or cutting the lumps and larger pieces, and removing coarse bulking agent materials (such as pieces of wood or branches larger than 5 cm). From this homogenised sample, a representative sample of 0.5 litres was collected and placed in an airtight plastic container for subsequent laboratory analysis.

In the initial 5-litre sample, materials defined as "inappropriate" were separated, which were introduced in a bag for weighing in the laboratory. IM in the compost were those that were identified as not recommended for composting according to the composting guidelines used in home composting programmes. A size limit for IM was not considered, thus all particles detected by sight as inappropriate materials were included. These are usually non-biodegradable, physical contaminant materials. The percentage of IM was obtained on a dry basis considering the density and moisture of the sample.

The moisture content was determined by drying to constant weight (24 to 48 hours) in an oven at 90 °C and VS by ignition at 550 °C. The analysis of the nitrogen content (N), total carbon (C) and total organic carbon (TOC) were performed on an EA1108 elemental analyser (Carlo Erba Instruments) equipped with an AS200 autosampler. All samples were analysed in duplicate.

The quantitative analysis of metals was performed in triplicate in samples of 0.5 g (from a sample of approximately 100 g, previously dried and ground to homogeneity), by adding 10 ml of distilled cc HNO_3 and heating to 175°C for 10 min, according to the US EPA 3051A method (US EPA, 2007). All metal concentrations were determined using inductively coupled plasma mass spectrometry (ICP-MS Element XR or Element2 from Thermo Electron).

In order to facilitate interpretation, relative HM values are defined as the ratio of the metal concentration in compost sample to the regulation limit (Vázquez et al., 2015):

$$\text{Relative HM concentration} = C_i / C_{Ai} \text{ (adimensional value)} \qquad \text{Eq. 3}$$

where Ci is the concentration of metal i in compost sample and C_{Ai} is the concentration limit of metal i for Class A in the Spanish regulation.

Unless otherwise stated, mean and standard deviation values were used to assess the characteristics of compost samples. Data were subjected to one-way analysis of variance (ANOVA). A combination of the procedures for stepwise regression and regression with the best subsets of variables was used to select better multivariable models (Navidi, 2006). The suitability of the least-squares fit (linear regression) was evaluated by the square of the coefficient of determination (R^2), the adjusted R^2, the statistical *F*-

value and the probability (p). Where relevant, exclusion of outliers is indicated in the corresponding section. Statistical analyses were carried out in Microsoft Excel (Excel 2010 v. 15.0.4875.1000, Microsoft Corp., Redmond, WA, USA).

3. Results

3.1. The efficiency of home composting programmes

The results for the composition of the waste collected in the containers of the municipal service before and after the start of composting programmes in the eight areas of study are shown in Table 2, together with the data required to calculate the efficiency.

Table 2. Efficiency of home composting programmes in the areas of three Galician councils.

Area (council) [a]	**MSWi (kg)**	**MSWf (kg)**	**$OFMSW_i$ (%)**	**$OFMSW_f$ (%)**	**CPC**	**$OFMSW_{fp}$ (%)**	**E (%)**
Camiño da Presa (O)	116.7	82.8	54.1 ± 7.5	32.3 ± 22.4	0.61	31.5	97.6
Vilanova (O)	140.7	141	57.6 ± 2.3	42.2 ± 4.3	0.40	44.9	115.6
Torás (AL)	195.8	98.6	47.6 ± 16.7	36.0 ± 8.3	0.36	36.8	105.8
Amboade (AL)	160.5	124.1	36.1 ± 19.4	29.0 ± 7.1	0.75	12.4	36.9
Proame (AL)	151.8	101.1	31.6 ± 2.2	15.8 ± 10.4	0.80	8.5	74.2
Pedrouzo-Sixto (C)	161.4	178.3	53.0 ± 0.3	37.7 ± 5.0	0.66	27.7	70.2
Xaviña 1 (C)	141.8	92.4	38.7 ± 37.9	26.9 ± 23.5	0.75	13.6	55.6
Xaviña Comercios (C)	95.2	193.2	44.0 ± 20	36.1 ± 13.5	0.45	30.2	62.4
Average	(1163.9)[b]	(1011.5)[b]	**45.3 ± 9.3**	**32.0 ± 8.2**	**0.60**	**25.7**	**77.3**

O: Oroso, AL: A Laracha, C: Camariñas, MSW: municipal solid waste, i: initial, f: final, fp: final potential. $OFMSW_{fp}$ (%) and efficiency E (%) obtained according to the equations 1 and 2, respectively. [a] The size and other characteristics of the sampling areas are giving in Table 1. [b] These figures indicate the total amount of MSW characterized at the initial and final campaigns.

The total amount of waste collected changed from 1164 kg before the implementation of the programme to 1012 kg a year later, reduced by 13%. Non-organic waste increased by 8%, organic waste collected in containers reduced by 39% from 527 kg before the implementation of the programme to 324 kg. The percentage of organic matter in the initial situation for all the study areas was 45.3% and decreased to 32.0%, which provides an average reduction of 13.3 percent after the adoption of the composting programmes. According to Table 2, all areas of study registered a reduction in the percentage of OFMSW in the containers variable between 7 and 22 percent. An analysis of variance indicated that the organic matter content in the containers was statistically lower (F = 9.2, p = 0.01) after adoption of the programmes.

Efficiencies higher than 100% are possible because both numerator and denominator terms of Eq. 2 as well as $OFMSW_{fp}$ (OFMSW final potential, corresponding to E 100%) were obtained experimentally. Although a large deviation of E above 100% would indicate poor results for the model validation, the referred cases with E of 106% and 116% are considered compatible with a reasonable reliability. E higher than 100% occurs when $OFMSW_f$ (%) is lower than $OFMSW_{fp}$ (%), but in both cases showing E higher than 100%, $OFMSW_{fp}$ (%) fall into the variation range estimated for $OFMSW_f$ (%). These results indicate that selecting larger areas of study or increase the number of sampling campaigns would be required to increased method precision.

On the other hand, Table 2 shows $OFMSW_{fp}$ (%) and E (%) calculated according to the equations 1 and 2, respectively. These results show that for an average amount of 60% of households with composters in the areas studied, the percentage of biowaste in containers should be reduced from 45.3% at the beginning, to 25.7% at the end. However, a percentage of the final OFMSW in containers of 32.0% has been obtained, which gives an average efficiency of 77.3%. This efficiency refers to the initial provision of composters in the programme and concludes that their use has been very effective, both for most of the homes covered by the programme and compared with composting of most of the fermentable waste.

From the data in Table 2, various correlations are obtained, some of which are shown in Figure 2. The $OFMSW_{fp}$ depends only on the $OFMSW_i$ and the relation CPC (Eq. 1). In practice, the correlation between $OFMSW_{fp}$ and CPC is linear (R^2 0.831, p 0.002) as well as the correlation between $OFMSW_{fp}$ and $OFMSW_i$ (R^2 0.810, p 0.002). These regression coefficients indicate that the variation of $OFMSW_{fp}$ is determined to a similar extent by both variables. However, as discussed below, $OFMSW_f$ depends on a greater proportion of $OFMSW_i$.

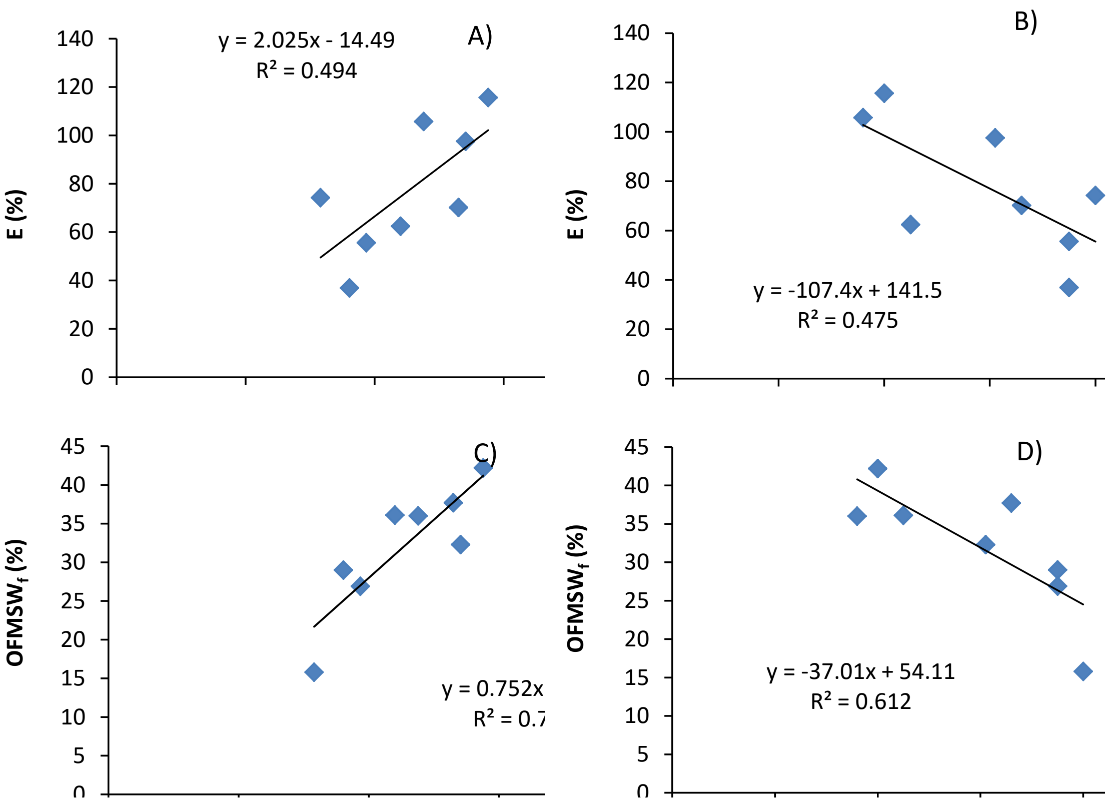

Figure 2. Influence of the initial organic fraction of municipal solid waste ($OFMSW_i$) and the composting programme coverage (CPC) on the efficiency of home composting programmes (E) and the final content of $OFMSW_f$ in the containers of waste collection.

On the other hand, an efficiency of 100% is related to a complete collaboration of homes with composters, and thus, the value of the efficiency indicates the level of cooperation of the population involved in the composting programme. Correlations in Figure 2A show that the efficiency increased with the percentage of initial $OFMSW_i$ (R^2 0.494, p 0.052), which means that the houses that generate a greater proportion of organic waste made full use of the composter. Moreover, the effectiveness decreased with the level of coverage of the composting programme (Figure 2B, R^2 0.475, p 0.059).

The best correlation for $OFMSW_f$ is obtained depending on $OFMSW_i$ (Figure 2C, R^2 0.739, p 0.006). However, $OFMSW_f$ also depended on the coverage of the programme, decreasing with the increasing of CPC (Figure 2D, R^2 0.612, p 0.022). Thus, a multiple correlation analysis indicates $OFMSW_i$ and CPC determined the 82% of the variation of $OFMSW_f$.

3.2. Physical and chemical characteristics of home compost

The results related to the physical and chemical characteristics of compost from eight home composting areas of Galician councils are presented in Table 3. Table 4 shows several correlations between some of the chemical and physical parameters. Temperature in composting bins ranged from 7 to 35 ºC for individual composters, while mean values for composting areas ranged from 12.5 to 27.4 ºC. Thus, thermophilic temperatures were not registered in this study of home composting. Composting temperatures below the thermophilic range in home composters have been previously reported by Smith and Jasim (2009), Ermolaev et al. (2014) and Faverial and Sierra (2014). In this way, temperature in home composters can remain only a few degrees above ambient temperature, thus varying seasonally and from region to region, as pointed out by Vázquez et al. (2015). Tatàno et al. (2015) reported mesophilic temperatures in one composting bin and thermophilic temperatures in the other and stated that higher moisture contents presumably contributed to restrain the matrix temperature regime. However, a correlation between temperature and moisture content was not obtained for data of each of the composting programmes of our study (R^2<0.14, p>0.27). Higher mean temperaturas in Table 3 corresponded to the summer and lower temperatures for the winter sampling campaigns. Finally, some cases of the biodegradation process being retarded because of too little moisture content have been found (3 cases of 90, see Table 3 footnote h). Similar situations were reported by Barrena et al. (2014) and Storino et al. (2016b).

The average content in organic matter was of 48.1 ± 19.0% VS, the carbon content 25.1 ± 10.7% C and the nitrogen content 2.1 ± 1.1% N (Table 3). These parameters (measured on a dry basis) are clearly correlated among them (Table 4). The correlation is stronger between C and VS, while the lowest value for the correlation coefficient is between the content in N and VS due to the behaviour in the area of Camariñas, which showed distinctly higher VS/N ratio and C/N ratio. In turn, the total organic carbon is practically equal to the total carbon (TOC/C =0.95, R^2 = 0.98, n=57). Furthermore, the C/N ratio presents a reduced variability (average of 12.8 ± 3.5) and shows no correlation with the content in VS or C, but with the N content (Tables 3 and 4), so that the compost with a higher content of N shows slightly lower ratios C/N.

Table 3. Physico-chemical characteristics of compost samples from different home composting areas (mean followed by standard deviation in parentheses).

Council	n[a]	T (ºC)	IM[b, c] (%)	Density[b] (kg/L)	Moisture[b] (%)	VS[c] (%)	TOC[c] (%)	C[c] (%)	N[c] (%)	C/N
A Illa de Arousa	15	15.6 (4.7)	0.52 (0.59)	0.44 (0.10)	65.5 (19.3)[h]	67.6 (10.9)	nd	37.8 (6.4)	3.15 (0.76)	12.5 (2.9)
Ames	18	24.0 (4.5)	0.24 (0.38)[f]	0.72 (0.14)	66.9 (7.6)	44.2 (15.5)	nd	22.3 (8.0)	1.80 (0.75)	12.8 (1.8)
Ordes	10	27.4 (3.2)	0.13 (0.16)[g]	0.61 (0.21)	70.9 (7.4)	58.6 (15.0)	29.5 (9.6)	30.3 (10.2)	3.04 (1.35)	10.3 (1.9)
Carballo	11	13.7 (2.4)	0.16 (0.32)	0.79 (0.20)	64.0 (9.5)	36.2 (12.9)	19.7 (7.0)	20.9 (7.7)	1.71 (0.68)	12.0 (2.5)
Oroso	10	12.5 (5.4)	0.10 (0.31)	0.82 (0.21)	69.0 (13.6)	46.5 (22.3)	21.5 (11.2)	22.5 (11.5)	2.0 (1.0)	11.7 (1.9)
A Laracha	10	nd	0.48 (0.63)	0.83 (0.11)	69.2 (11.6)	39.2 (14.8)	18.5 (7.9)	19.6 (8.6)	1.6 (0.8)	13.1 ((3.4)
Camariñas	10	15.1 (5.6)	0.25 (0.34)	0.65 (0.18)	67.8 (9.6)	48.4 (20.0)	22.1 (10.3)	23.4 (10.2)	1.6 (0.9)	16.9 ((6.4)
Vilasantar	6	21.3 (6.9)	0.05 (0.08)	0.57 (0.24)	53.6 (17.1)[h]	31.5 (11.7)	15.6 (5.3)	17.7 (4.6)	1.4 (0.8)	11.3 ((1.6)[d]
Overall										
Number of samples[e]		77	80[g]	90	87[h]	90	57	90	90	89[i]
Maximum		35.4	1.84	1.26	84.4	84.9	42.2	47.2	5.3	29.7
Minimum		7.0	0.00	0.18	47.1	14.9	6.0	6.2	0.2	7.3
Average (SD)		18.6 (7.0)	0.27 (0.44)	0.68 (0.21)	68.1 (9.6)	48.1 (19.0)	21.5 (9.7)	25.1 (10.7)	2.1 (1.1)	12.8 (3.5)

[a] Number of samples in each area, [b] IM (inappropriate materials), [c] Dry basis, [d] n=5, [e] Number of samples for each parameter, [f] IM data is only available for 9 out of 18 samples, [g] Excluded one sample from Ordes with very high IM conten (11.96%), [h] Excluded two samples from A Illa de Arousa and a sample from Vilasantar with very low moisture content (range 16-23%), [i] Excluded a sample from Vilasantar with a very high C/N ratio (C/N = 88).

VS: Volatile Solids (organic matter), TOC: Total Organic Carbon, N: Total Nitrogen, C: Total Carbon, C/N: Carbon/Nitrogen ratio (average of individual samples), nd: not determined.

Table 4. Correlation between some physico-chemical characteristics of domestic compost.

y	x	Correlation	R^2 (*p*)	n
C (%)	VS (%)	y = 0.516x + 0.34	0.845 (0.00)	90
N (%)	VS (%)	y = 0.0461x – 0.13	0.647 (0.00)	90
N (%)	C (%)	y = 0.0868x – 0.09	0.721 (0.00)	90
C/N	VS (%)	y = -0.0228x + 13.9	0.015 (0.26)	89
C/N	N (%)	y = -1.57x + 16.1	0.231 (0.00)	89
TOC (%)	C (%)	y = 0.972x – 0.56	0.981 (0.00)	57
H_2O (%)	VS (%)	y = 17.04 ln(x) + 3.8	0.633 (0.00)	87
H_2O (%)	N (%)	y = 10.622ln(x) + 62.1	0.448 (0.00)	87
H_2O (%)	Density (kg/L)	y = -12.32x + 76.6	0.069 (0.014)	87
Density (kg/L)	VS (%)	y = -0.0067x + 1.0	0.357 (0.00)	90

R^2: correlation coefficient, *p*: probability, n: number of data included in the correlation (see notes h and i at the bottom of Table 3).

The moisture content recorded in the compost samples stood between normal and high. In 7 of the 8 programmes the average moisture content stood between 65% and 70%, and altogether 48% of the samples exceeded 70% moisture content. Three samples appeared very dry (about 20% moisture content), while excluding these three samples, the minimum result was 47%. For this reason, reviewing the drainage for the composter bins and protection against heavy rain was recommended. The correlations in Table 4 indicate that the moisture content increased slightly with both the organic matter content and N content to values of 50% VS and 1.5% N, to remain steady at higher values. On the contrary, the density varied in the opposite direction, being lower as it increased the organic matter content, but this happens in a less pronounced way than the moisture. Contrary to what might be expected, the relation between density and moisture content was weak, although significant, with values of moisture content slightly lower at high densities. Thus, higher values of density corresponded with higher mineral matter content and lower water retention capacity. IM in composting bins ranged from 0% to 1.8% for individual composters, while mean values for composting areas ranged from 0.05% to 0.5% (Table 3). IM more frequently found were stubs, bottle caps, plastic corks, plastic and aluminum wrappers (mainly for food and sweets), pull- rings, fruit stickers and yogurt lids (of plastic and aluminum). No correlation was found between IM and the other parameters of Table 3 (R^2<0.03).

The C/N ratio lay generally in the range of 10-15, indicative of an advanced process of composting and a good retention of the nitrogen content, which favoured the conservation of nitrogen as a nutrient and ensured a high fertilizer value. Similar values of C/N ratio were reported by Faverial and Sierra (2014) while Andersen et al. (2011) reported somewhat higher C/N ratio values ranging from 15.8 to 18.0. Tatàno et al. (2015) found more variable C/N ratios ranging from 5 to 20 or higher. Several authors make use of the C/N ratio as an indication of the stabilisation of the organic matter, considering a compost sufficiently stabilised when the C/N ratio is less than 12 (Iglesias et al., 2008). Vázquez et al. (2015) reported a correlation between C/N ratio and respiration index for compost from university canteen waste. Furthermore, these authors (Vázquez et al., 2015) reported that samples from home composting showing mean C/N ratios of 12.6±1.7 exerted a respiration index of 0.29±0.28 mg O_2/g VS·h lower than the threshold for compost stability (1 mg O_2/g VS·h), thus being considered as stable compost. C/N ratio in the present study was in the same range of that of Vázquez et al. (2015) indicating that it was stable compost.

The correlation of %N and C/N ratio versus a set of variables including C, VS, H_2O and density was studied by means of multivariate analysis. The results indicate that no set of variables improved the single correlations shown for N content in Table 4. Respective to C/N ratio, the best multivariate model was that of C/N as a function of (N, C, density), which showed R^2 0.695 and p-values of 0.000, 0.000 and 0.027 for N, C and density, respectively. Including H_2O instead density, the results were very similar (R^2 0.692 and p-values of 0.000, 0.000 and 0.039 for N, C and H_2O, respectively). However, the model with both H_2O and density in adition to C and N, gave worse results because of p-values higher than 0.05 for both H_2O and densitiy. These models slightly improved the correlation for C/N as a function of (N, C) (R^2 0.676 and p-values of 0.000, 0.000), indicating that C/N ratio mainly depended of C and N content and, to a less degree, of moisture content and density. Lower values of C and higher values of N, H_2O and density favoured lower values of C/N ratio. It is probable that high moisture content favoured carbon degradation whilst low density was related to high carbon content of the raw materials.

3.3. Nutrient content of home compost

In four of the areas (Oroso, Laracha, Camariñas and Vilasantar, n=36) the content in different nutrient elements was determined (Table 5). The average values for these programmes were 1.65 ± 0.88% in nitrogen, 0.61 ± 0.42% in phosphorus and 2.53 ± 1.64% in potassium. The nutrient content showed average rates which were not very high but sufficient in N and P_2O_5 (1.4%) and higher in K_2O (3.0%) when compared to the recommended values in the Spanish rule RD 506/2013 (BOE, 2013). This rule recommends >1% content for each nutrient, expressed as N, P_2O_5 and K_2O, and that the sum for the set of three nutrients exceeds 4 %. There were marked differences between the samples analysed within each area, probably due to the variability in the composition of the waste used. However, the variability was strongly reduced when the nutrient average values from one area to another are considered.

Positive correlations were also found between the contents in P, K and Ca and the content in VS, C and H_2O (R^2 0.10-0.4; $p<0.05$), increasing the concentration of these nutrients as the content in VS, C and H_2O increased (data not shown). Instead, the Mg content presented a negative correlation (R^2 0.11-0.16; $p<0.05$) with the content in VS and C, decreasing as the content in VS and C was increased, and a positive correlation with density (R^2 0.16, p 0.02), but not with moisture content. Meanwhile, the density did not influence the content of N, P, K and Ca. In summary, the contents of N, P, K and Ca increased with the increasing of organic matter and the water holding capacity, while the Mg content increased with the increase of the mineral fraction and compost density. The results also indicate that high or very high moisture content, more than 80%, does not compromise the nutrient content of the compost.

Information on the chemical composition of domestic compost is very scarce. In the Spanish context, *Amigos de la Tierra* (ADT, 2009) reported typical contents of total nitrogen lower than 0.5% and maximum values of 0.75%, while the average phosphorus content was 0.4% and potassium of 1.1%. The low nitrogen content can be due to the exclusion of the composting of meat and fish remains and the low weight of the organic waste from the kitchen in relation with the total composted waste. In this study, concentrations of these nutrient elements (Table 5) which double or triple those indicated by ADT (2009) were obtained. Storino et al. (2016a) found that the presence of meat waste as raw feedstock for composting in bins can improve the activity of the process, the physicochemical characteristics and maturity of the compost obtained, increasing N, K and Mg content. Recently, the Spanish Ministry of Agriculture, Food and Environment recognized that all biowaste fractions could be treated by home composted, including meat and fish leftovers (MAGRAMA, 2013).

Table 5. Nutrient concentration [a] of the compost of some home composting areas

	Oroso	**A Laracha**	**Camariñas**	**Vilasantar**	**Total**
n [b]	10	10	10	6	36
N	1.96 (52.8)	1.59 (50.7)	1.56 (58.5)	1.39 (54.4)	1.65 (53.3) (14.8) [c]
P	0.50 (47.6)	0.60 (45.4)	0.48 (71.4)	1.02 (73.5)	0.61 (69.8) (38.4) [c]
K	2.75 (52.3)	2.93 (72.8)	2.27 (63.9)	1.94 (75.6)	2.53 (64.8) (18.3) [c]
Mg	0.67 (24.1)	0.75 (32.3)	0.73 (87.8)	0.79 (80.7)	0.73 (59.6) (7.0) [c]
Ca	2.02 (67.2)	3.53 (58.8)	4.49 (109.7)	5.50 (151.5)	3.70 (118.6) (38.2) [c]

[a] Average values (%) and coefficient of variation (%, in parentheses). [b] Number of samples in each area. [c] Coefficient of variation for the averages of the different areas.

The nutrient content (N, P and K) was in the range of values previously reported for domestic composting programs from other countries (Smith and Jasim, 2009; Faverial and Sierra, 2014). Phosphorus content is similar or somewhat higher than that found in other industrial composts (0.3-0.67 % P for compost from either municipal solid waste, kitchen waste, green waste, straw, and fruit and vegetable waste, as reported by Wei et al. (2015)) and in home composts, which range from 0.24-0.7 % dm (Smith and Jasim, 2009, Kanchanawong and Suriyanon, 2011, Andersen et al., 2012, Faverial and Sierra, 2014). With regard to K, Mg and Ca, content values in Table 5 were higher than those reported by Vázquez et al. (2015) for compost from several sources of decentralised composting.

3.4. Heavy metals in home composting

Table 6 and Figure 3 summarise the results of the analysis of heavy metals. The content of HM was first analysed in relation to quality limits for agricultural use according to the Spanish legislation (BOE, 2013). Dependant on the maximum content of seven metals (Hg, Cd, Pb, Cr, Ni, Cu and Zn), three classes are established: Class A, Class B and Class C (Table 6).

Table 6. Concentration of heavy metals in compost samples (n=90) of home composting in the Galician councils.

Metal	General trend (mg/kg) [a]					Contaminated samples (mg/kg) [b]					Legal limit (mg/kg) [c]		
	Mean	SD	Max	Min	n	Ordes 4	Ordes 2	Oroso 2	Camariñas 1	Vilasantar 1	Class A	Class B	Class C
Cd	0.38	0.32	2.09	0.08	88			2.95		6.20	0.70	2.00	3.00
Hg	0.09	0.07	0.38	0.01	88	56.86	4.33				0.40	1.50	2.50
Pb	21.3	18.0	94.5	1.0	87	2561.0	202.4			234.2	45.0	150.0	200.0
Cr	20.7	24.8	139.4	1.0	89					1078.0	70.0	250.0	300.0
Ni	15.2	13.8	72.3	1.0	90						25.0	90.0	100.0
Cu	39.7	23.2	166.2	9.2	89					542.8	70.0	300.0	400.0
Zn	148.8	90.9	642.2	42.5	87			3460.0	1037.0	2232.1	200.0	500.0	1000.0
As	13.6	14.6	64.3	1.1	89					286.0	na	na	na
Co	6.5	6.4	25.8	0.4	89						na	na	na

[a] Mean values, standard deviation (SD), maximum and minimum for n=87-90, excluding abnormally high figures also specified in the Table.

[b]Abnormally high figures (>Class C) and corresponding samples (Ordes 4, Ordes 6, Oroso 2, Camariñas 1, Vilasantar 1).

[c] Limits for Classes A, B and C in Spanish legistation RD 506/2013 (BOE, 2013). na: not available.

HM limits for Spanish Class A compost are stricter than those for Class 1 compost of the EU biowaste directive (2nd draft) and are similar to EU level limits for organic agriculture (Vázquez et al., 2015). Compared with heavy metal limit values for selected EU countries with strict compost qualities (Andersen et al., 2012), such as Austria, Denmark, Germany and Netherlands, Spanish Class A standard is a demanding quality indicator and may be used as quality reference indicator. On the other hand, unlimited or near unlimited (up to 30 tonnes dm per hectare per year) agricultural use of compost is allowed for Spanish Class B and European Class 2 (2nd draft biowaste directive), respectively. HM content limits for Class B and Class 2 are between 2 and 4.3 times higher than limits for Class A, depending on the considered heavy metal. Spanish Class C compost, with HM levels 4-6.3 higher than Class A is also allowed for agricultural use at reduced doses of 5 tonnes dm per hectare per year (BOE, 2013; Vázquez et al., 2015).

As a first step in the analysis of data on heavy metal content, all those samples with a concentration in one of the elements higher than the amount of Class C were identified. In 5 of the 90 samples, some HM exceeded the values of Class C. These values are indicated specifically in Table 6 as outliers, so they were excluded from the acquisition of the remaining statistical parameters shown in Table 6 (mean value, standard deviation, maximum and minimum). These contaminated samples appeared in Ordes (two samples) and Oroso, Camariñas and Vilasantar (one each); while in the councils of Ames, A Illa de Arousa, Carballo and Laracha none of the samples analysed presented appreciable contamination. Except for one of the samples (Ordes 4), which showed very high content in Hg (23 times the level of Class C) and Pb (13 times the level of Class C), the rest of the contaminated samples exceeded the levels of Class C in a moderate factor between 1.0 and 3.6 times the level of Class C. In these samples, the contamination affected to Hg and Pb (Ordes), Pb and Zn (Camariñas), Cd and Zn (Oroso), and Cd, Pb, Cu and Zn (Vilasantar). Therefore, in the case of Vilasantar, contamination was more widespread, and recorded an unusually high value for As in this locality (Table 6), although for this element there is no limit established on the legislation about compost.

Both the average values and the standard deviation ranges were in all cases below the limit of Class B (Table 6). Even the maximum values were below the limit of Class B, with the exception of two samples (Cd in one sample and Zn in the other one) with slightly higher values. Considering Class B establishes the limit for heavy metals for agricultural use of compost without restrictions, this data indicates that 94% of the samples correspond to suitable compost for agricultural use, with regard to the content in heavy metals.

The average values for the whole samples, excluding the anomalous cases, are also lower than the limits establish by the Class A. In order to analyse in more detail the quality of the domestic compost related to Class A, the relative average value and the associated standard deviations are represented in Figure 3 for each area of composting (calculated as indicated by Eq. 3). The average values in 8 of the 9 areas are lower than the limit for Class A. The exception occurred in the case of Vilasantar, where the content of Ni and Zn exceeded this threshold. Thus, the content of heavy metals was higher in Vilasantar (average concentration relative to Class A of 1.0), followed by Carballo (0.8), and finally the other areas (0.3-0.5). Overall, considering all the areas and the seven regulated metals, the average presence of heavy metal was 54% of the Class A limit. The different elements regarding this threshold are listed in the following descending order of relative concentration: Zn (0.84), Ni (0.69), Cu (0.60), Cd (0.56), Pb (0.53), Cr (0.35) and Hg (0.22). Therefore, it is easier for the domestic compost to exceed the threshold of Class A in Zn, Ni and Cu, and less likely to exceed Cr and Hg. An advanced maturation of compost implies a further reduction of the total mass and an increase in the concentration of metals, so that concentrations of Zn, Ni and Cu can easily get to exceed the thresholds of Class A. Instead, high concentrations of Cr or Hg could be indicative of accidental contamination sources outside the process and the composting suitable materials. The Pb and Cd are in an intermediate situation and high values of Cd can be caused by both accidental contamination sources like Cd content in food waste, as it has been previously found in waste compost of university canteens (Vazquez et al. 2015). As singular cases to emphasise, relatively high values of Cd appeared in A Illa de Arousa and Ni in Oroso, and clearly lower values of Ni in A Illa de Arousa, Hg in 3 areas and Cr in other 4 areas (Figure 3).

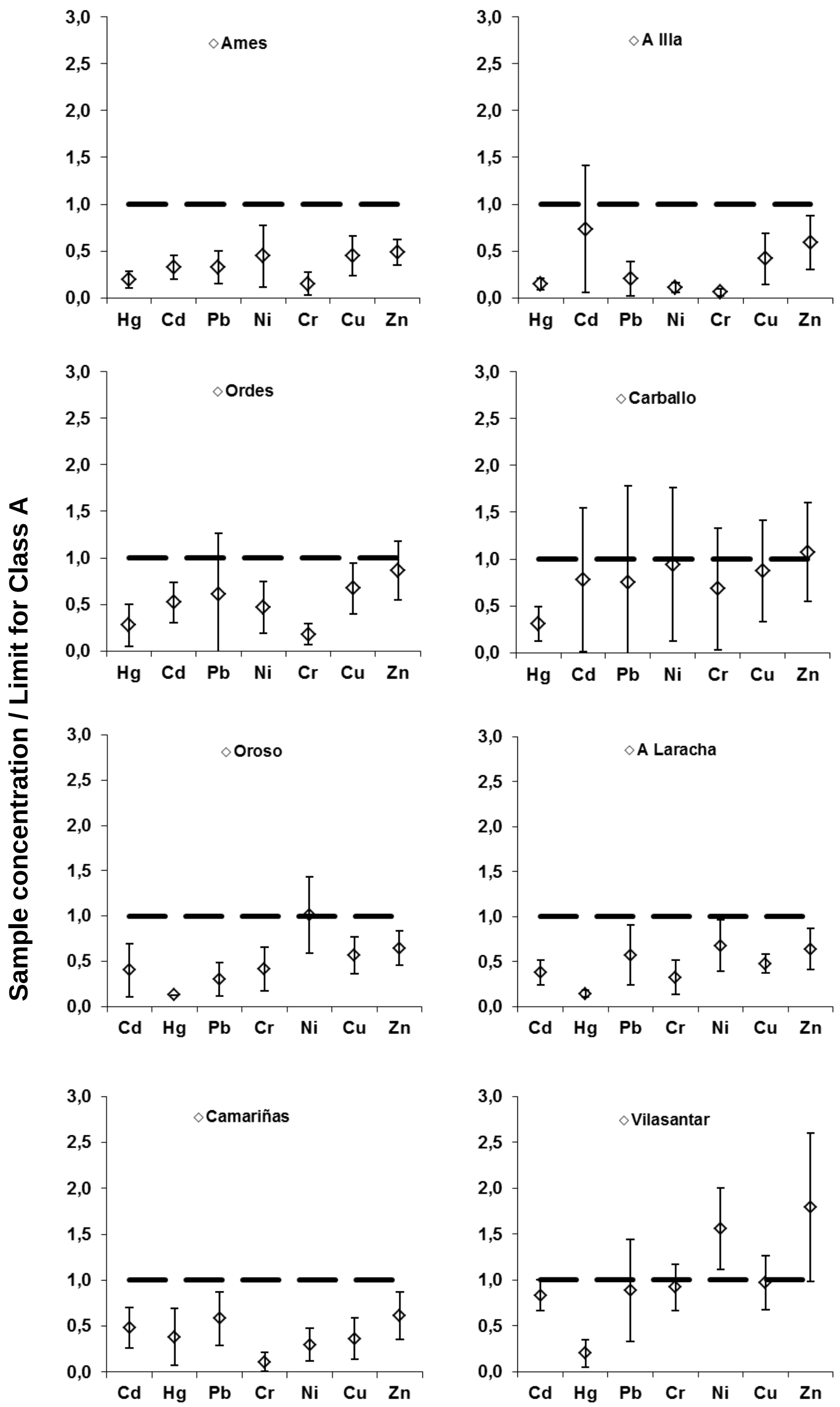

Figure 3. Mean concentration and standard deviation (bars) of heavy metals in samples from eight home composting programmes in Galiza. Average values and standard deviation, in relative values to Class A limit of Spanish rule RD 506/2013 (BOE, 2013), calculated as indicated by Eq. 3, and compared with the limits of Class A (relative value=1; see Table 6 for absolute values). The 5 most contaminated samples were excluded from the data (2 in Ordes, 1 in Oroso, 1 in Camariñas, 1 in Vilasantar) (total number of data n= 85, out of 90 samples). The number of samples in each programme is indicated in Table 3.

4. Discussion

4.1. Assessment of the organic waste amounts managed by home composting

Determining the amount of waste destined for composters is considered an important aspect to know the role of these systems in waste reduction at source and waste management (Puig et al., 2008; Smith and Jasim, 2009; Cox et al., 2010; Torras, 2010; Resse and Bioteau, 2012). Some of the procedures for calculating the amount of organic waste treated are as follows:

- From the estimation of the amounts of biowaste generated in the house: potential quantities.
- From the volume of compost obtained by applying a conversion coefficient of domestic organic waste into compost.
- From a series of explanatory variables as the number of residents and the area of the vegetable plot or home garden, and applying a mathematical model ("Composting calculator").
- By weighing the waste destined for composting.
- From the real impact of the selfcomposting programme in the amount of biowaste delivered to the collection systems (the method used in this study).

The methods of quantification or estimation may therefore vary from one case to another. Table 7 indicates the amounts managed by a home composting bin reported by several authors. One option to calculate the potential of self-composting is from the volume of compost obtained (ADT, 2009), multiplied by the density of the compost (average density reference 0.59 kg/L) and the factor of mass loss during the process (factor reference medium 3.0). The composters are emptied occasionally, a few times per year, therefore obtaining the volume of compost produced is straightforward; this is information that can be directly offered by the users (ADT, 2009).

Table 7. Waste diversion rates in home composting programmes.

	kg OFMWS/ household·year	kg OFMWS/person·year			Reference
		Kitchen waste	Garden waste	Total	
United Kingdom	151-198				Cox et al., 2010
United Kingdom	73-270 [a]				Sharp et al., 2010
Surrey (UK)	370 [b]				Smith and Jasim, 2009
Catalonia (Spain)	231 [c]				Puig et al., 2008
Rennes (France)		40	80-100	120-140	Resse and Bioteau, 2012
Pamplona (Spain)		73	148	221	Compostaenred, 2013
Spain		69	147	216	ADT, 2009
Spain		107	274	381±151	Blanco, 2010
Galiza (Spain)	380 [d]	126	nd	nd	This study

[a] Plus 5 kg/household·week of garden waste, in summer in some waste prevention projects. [b] Percentage distribution of 29, 2 and 69% of kitchen, paper and garden waste, respectively. [c] 2 to 4 people per household. [d] 3 people per household. nd: Not determined.

A study conducted in Rennes, France (Resse and Bioteau, 2012) concluded that weighing the waste destined for the composters by the users and determining the residual organic fraction in garbage leads to the same results. These authors also found no seasonal variability in the amounts of kitchen biowaste produced, so the study proposed a simple method to determine the incidence of home composting programmes, which consisted in determining the amount of biowaste collected for centralised treatment plant. In conclusion, a standard method for the determination of the impact of composting on biowaste recycling requires, basically, a periodic weighing of the garbage produced (Resse and Bioteau, 2012).

In our study, the composition of the organic fraction in the collected waste was determined, being 45% before the introduction of the programmes, with reference to kitchen organic waste. The average generation in the areas studied is estimated at 1 kg/person per day (Xunta, 2011). This leads to a generation of 164 kg OFMSW/person per year. An average efficiency of 77% of OFMSW composted was determined, which leads to 126 kg OFMSW/person per year composted effectively, or for an average of three people per dwelling, 380 kg OFMSW/composter bin per year. This figure is higher than most of the figures given above for organic waste from the kitchen. This can be explained by the indications of composting all the waste from the home, including the remains of meat and fish (ADEGA, 2010), which is not common in many other composting programmes (Storino et al., 2016a).

The results of this study show that the organic matter content in the containers in the areas with high coverage of home composting can be reduced by up to 20% (Figure 2D), which lets the user use a single waste container to collect the dry fraction with a high potential of recycling. A maximum of 20% of organic waste in recycling bins (80% dry fraction) is a quality target of many programmes of separate collection to allow higher percentages of recycled municipal waste. With the consolidation of this alternative, the costs of collection, transportation and treatment of garbage in rural areas would be greatly reduced.

4.2. Sources of compost contamination with heavy metals

IM values in Table 3 are clearly lower than those found for OFMSW entering centralized treatment plants, as reported by Amlinger et al. (2004) either for doorstep collection systems (2.3% on average) or road container systems (4.9%), and by Montejo et al. (2015) for pretreated OFMSW in mechanical-biological composting plants (38.8%). Amlinger et al. (2004) stated that increasing IM in the range of 1% to 10% significantly increases the heavy metal content of compost. In our study, no metal showed correlation with IM (R^2<0.03). Besides, contaminated samples indicated in Table 6 showed IM (<0.1% dm) lower than the mean, which indicates that physical contaminants identified as IM were not the source of heavy metal contamination.

Positive correlations among all metals have been found, but with different levels of correlation and statistical probability. Cr, Ni and Co appear strongly correlated (R^2 0.77-0.86, p 0.000), followed by Cu with these three metals and with Zn (R^2 0.25-0.40; p 0.000). There exists a weak but significant correlation between the remaining pairs of metals (R^2 0.15-0.25; p<0.01), except for Hg and Cd. Hg is only correlated with Pb (R^2 0.12; p<0.01), and Cd with Cu and Zn (R^2 0.19-0.27, p<0.01). Moreover, the content in the majority of the metals (Cr, Ni, Co, Pb, As) decreases with the increase in organic matter content (VS, N, C, COT) (R^2 0.20-0.36; p 0.000) and increases with the density (R^2 0.07-0.17, $p<0.015$). Hg and Cu have a weaker correlation with the organic matter content (R^2 0.05-0.1; $p<0.05$), but not with the density ($p>0.05$) and Cd and Zn do not correlate with any of these variables ($p>0.05$).

In summary, there are five metals (Ni, Co, Cr, Cu and As) that show positive correlation with each other and negative with the organic matter content (and thus, positive correlation with ash content), as they are the metals that have fewer cases of high contamination (3 cases, Table 6). This behaviour agrees with the findings of Andersen et al. (2012) who indicated that most heavy metals are found in the remaining ash fraction and heavy metals are correlated to the ash content. Conversely, Pb presents a lower level of correlation and a greater number of cases of strong contamination (3 cases), and lastly, Hg, Cd and Zn, with 7 cases of strong contamination, lack the correlation between them and with most other metals, nor do they have correlation with organic matter content. Thus, compost contamination with metals such as Pb, Hg, Cd and Zn could be attributed to independent sources (Vázquez et al., 2015).

Although these contaminated samples are less than 6% of the total number of samples analysed, the presence of contamination is indicative of the need for awareness-raising and environmental information to the rural population. In some cases, the cause of the contamination was identified. In the case of samples Ordes 4 and Ordes 6, contaminated with Hg and Pb (Table 6), grass cuttings stained with paint had been put in the composter bin. In the case of Vilasantar, the origin of the contamination was in the burning of wood treated with creosote (railway sleepers), and the ashes of this wood were added to the compost. This contamination would also incorporate polyaromatic hydrocarbons and other contaminants. The presence of this contamination should not be attributed to the practice of home composting, since without this practice it would be equally present in the field of housing or livestock farm. Thus, the practice of composting should be considered as an opportunity to eradicate such incidents.

HM content is similar to that found in other programmes of home composting, although the available information is scarce. In this study five samples heavily contaminated by heavy metals were found, from 90 samples analysed. Excluding these samples, the average values in 7 of the 8 areas studied offered quality A, while the rest offered quality B. While some authors found similar low heavy metal concentrations (Martínez-Blanco et al., 2010; Andersen et al., 2012), in other cases, higher concentrations have been reported (Soto, 2014). In some programmes of home composting in Spain, the compost was classified in class B or C with exceptions due to Hg, Cd or Pb (ADT, 2009), attaining 40-75% of cases with class A in some programmes (Blanco, 2010; Aguirre et al., 2010, Artola, 2012, Vázquez et al., 2015). According to Smith (2009), the compost obtained from waste segregated at source presents, in general, concentrations between 2 and 10 times lower than those of compost obtained by mechanical separation at destination, so home composting presents lower contaminant levels. Besides, these low levels of HM content contrast with the high levels of Cd, Pb, Zn and Cu in industrial municipal solid waste compost in the same region (Barral et al., 2007) that were above the limit of class C, showing that source separation in that case was not as efficient as in home composting. However, the domestic compost may exceed guidance limits when printed papers are added to composters, which certain compost user guides recommend (Smith, 2009). Soil contamination existing previously in the site has been another reported source of contamination for domestic compost (Aguirre et al., 2010).

5. Conclusions

Home composting is a promising efficient and sustainable decentralised route for municipal organic waste management. In this study we reported the chemical characteristics of the compost produced and the efficiency or rate of composting bins used in areas of eight Galician councils that have adopted home composting programmes. An average efficiency of 77% of OFMSW composted by the housing equipped with composter bins was achieved, corresponding to a rate of 126 kg OFMSW per person and year. This high value may be a consequence of the recommendation for composting the entire biowaste fraction, including meat and fish remains. The efficiency of home composting was higher in homes that generate a higher proportion of organic waste, and decreased with the coverage level of composting programmes. In spite of this, the results of this study show that the organic matter content in the waste-bins of the home composting areas can be reduced to less than 20%. This allows using a single container to collect the dry waste fraction with high potential for recycling and reducing the cost of collection, transportation and treatment.

The average content of organic matter in compost was 48 ± 19% VS, the carbon content of 25 ± 11% and nitrogen content of 2.1 ± 1.1%. C/N ratio is usually in the range of 10-15, indicating an advanced composting process and good nitrogen retention, favouring its conservation as a nutrient and ensuring a high fertilizer power. In addition, the content of other nutrients such as P (0.6%) and K (2.5%) was somewhat higher than that reported for several types of compost. The high moisture (above 70% in 48% of the samples) did not compromise the compost quality. A high percentage of samples presented the higher compost quality (Class A, compatible with its use in organic farming) while 94% had at least quality B (conventional agriculture) and only 5% of samples presented contamination with heavy metals. The presence of samples highly contaminated cannot be attributed to the home composting practice, because contamination sources were already present in the field of the housing or farm, so the promotion of home composting is shown as an opportunity to eradicate these incidents, through environmental education and awareness that should accompany home composting programmes. Overall, these results indicate correct operation and handling of the composters and excellent separation of waste at source, as the percentage of inappropriate materials was below 1.8% and averaged 0.27% dry matter.

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5. REFERENCES

ADEGA, 2010. Manual de compostaxe caseira. Available from: http://adega.gal/web/media/documentos/manual__compostaxe.pdf (last access: 22/10/2015)

Adhikari, B.K., Trémier, A., Martinez, J., Barrington, S., 2010. Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada. Waste Manage. Res. 28, 1039-1053.

Adhikari, B.K., Tremier, A., Barrington, S., Martinez, J., Daumoin, M., 2013. Gas emissions as influenced by home composting system configuration. J. Environ. Manage. 116, 163-171.

ADT (2009). Experiencias realizadas 2004-2008. Manual de Compostaje. Amigos de la Tierra. Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid. Available from: http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/Manual_de_compostaje_experiencias_realizadas_2011_PAGINAS_25-120_tcm7-181451.pdf (last access: 15/10/2015).

Aguirre, A., Ansorena, J., Gundín, A., 2010. La red de compostaje doméstico de Gipuzkoa. *Proceedings of II Jornadas de la Red Española de Compostaje*, Universidad de Burgos, Universidad de Valladolid, Burgos-Palencia, 1-3 Juin.

Amlinger, F., Pollak, M., Favoino, E., 2004. Heavy metals and organic compounds from wastes used as organic fertilisers. Final report. ENV.A.2./ETU/2001/0024 - July 2004. Available at http://ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf. (last access: 10/01/2017).

Andersen, J.K., Boldrin, A., Christensen, T.H., Scheutz, C., 2012. Home composting as an alternative treatment option for organic household waste in Denmark: An environmental assessment using life cycle assessment-modelling. Waste Manage. 32, 31–40.

Artola, A., 2012. Analítica del compost: escolar, comunitario, casero. Universidad Autónoma de Barcelona. *Proceedings of II Seminario sobre Compostaje Doméstico y Comunitario.* Composta en Red, Barcelona, 15 de mayo de 2012. Available from: http://compostaenred.org/proyectos/JonadasBarcelona2012/presentaciones/ZW-XFont_raquelUAB.pdf (last access: 25/10/2015).

Barral, M.T., Moldes, A., Cendón, Y., Diaz-Fierros, F., 2007. Assessment of municipal solid waste compost quality using standardized methods before preparation of plant growth media. Waste Manage. Res. 25, 99–108.

Barrena, R., Font, X., Gabarrell, X., Sánchez, A., 2014. Home composting versus industrial composting: Influence of composting system on compost quality with focus on compost stability. Waste Manage. 34, 7, 1109-1116.

Blanco, B., 2010. Conclusiones de la experiencia en compostaje doméstico en distintos territorios. Programa de compostaje doméstico del PNIR. *Proceedings of Congreso Internacional "Suelos y Materia Orgánica: Entre la Directiva y la Nueva Ley"*. Consejería de Medio Ambiente de la Junta de Castilla y León, European Compost Network (ECN), Instituto para la Sostenibilidad de los Recursos. Valladolid, 17-18 November.

BOE, 2013. Real Decreto 506/2013, del 10 de julio, sobre productos fertilizantes. Available from: http://www.boe.es/diario_boe/txt.php?id=BOE-A-2013-7540 (last access: 15/05/2015).

Chan, Y.C., Sinha, R.K., Wang, W., 2011. Emission of greenhouse gases from home aerobic composting, anaerobic digestion and vermicomposting of household wastes in Brisbane (Australia). Waste Manag. Res. 29(5), 540-548.

Compostaenred, 2013. Boletín trimestral de la Red Estatal de Entidades por el Compostaje Doméstico y Comunitario nº 12. Available from: http://www.compostaenred.org/ (last access: 25/10/2015).

Compostaenred, 2011. Boletín trimestral de la Red Estatal de Entidades por el Compostaje Doméstico y Comunitario nº 6. Available from: http://www.compostaenred.org/ (last access: 25/10/2015).

Cox, J., Giorgi, S., Sharp, V., Strange, K., Wilson, D.C., Blakey, N., 2010. Household waste prevention – a review of evidence. Waste Manage. Res. 28, 193–219.

de Vega, C., Pérez, R., Rodríguez, V., Villaverde, X.M., Soto, M., 2004. Xestión sustentábel de residuos orgánicos: a experiencia en Galiza. *Proceedings of II Congreso Internacional de Ingeniería Civil, Territorio y Medio Ambiente*. Santiago de Compostela, 22-24 September, pp. 1623-1635.

Domingo, J.L., Nadal, M., 2009. Domestic waste composting facilities: A review of human health risks. Environ. Int. 35, 382–389.

Ermolaev, E., Sundberg, C., Pell, M., Jönsson, H., 2014. Greenhouse gas emissions from home composting in practice. Bioresour. Technol. 151, 174–182.

Faverial, J., Sierra, J., 2014. Home composting of household biodegradable wastes under the tropical conditions of Guadeloupe (French Antilles). J. Clean. Prod. 83, 238-244.

Iglesias-Jiménez, E., Barral-Silva, M.T., Marhuenda-Egea, F.C., 2008. Indicadores de la estabilidad y madurez del compost. In: Moreno, J., Moral, R. (ed), Compostaje. Mundi-Prensa, Madrid, pp 243-283.

Karnchanawong, S., Suriyanon, N., 2011. Household organic waste composting using bins with different types of passive aeration. Resour. Conserv. Recy. 55, 548–553.

Lafuente, M., Pérez, R., Soto, M., 2012. Dez anos de compostaxe caseira e un ano de compostaxe comunitaria. In: *Simón, X. e Copena, D. (Coord.). Proceedings of IV congreso internacional de Agroecoloxía e Agricultura Ecolóxica. Iniciativas* *agroecolóxicas innovadoras para a transformación dos espazos rurais.* Vigo 21-23 Juin 2012. Ed. Grupo de Investigacion en Economia Ecoloxica e Agroecoloxia, Universidade de Vigo, pp. 1335-1347. (Available from: http://economiaecoloxica.webs.uvigo.es/docs/6/libro_do_iv_congreso_de_agroecoloxia.pdf, last access: 25/10/2015).

Lleó, T., Albacete, E., Barrena, R., Font, X., Artola, A., Sánchez, A., 2013. Home and vermicomposting as sustainable options for biowaste management. J. Clean. Prod. 47, 70-76. doi: 10.1016/j.jclepro.2012.08.011.

MAGRAMA, 2013. Gestión de bioresiduos de competencia municipal: Guía para la implantación de la recogida separada y tratamiento de la fracción orgánica. Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA), 342 pp. Accessible at: http://www.mapama.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/guia_mo_def_tcm7-285227.pdf (in Spanish, last access: 07/03/2017).

Martínez-Blanco, J., Colón, J., Gabarrell, X., Font, X., Sánchez, A., Artola, A., Rieradevall, J., 2010. The use of life cycle assessment for the comparison of biowaste composting at home and full scale. Waste Manage. 30, 983–994.

Montejo, C., Costa, C., Márquez, M.C., 2015. Influence of input material and operational performance on the physical and chemical properties of MSW compost. J. Env. Manage. 162, 240-249.

Navidi, W., 2006. *Statistics for engineers and scientists*. México: McGraw-Hill.

Puig, I., Freire, J., Rodrigo, J., 2008. Estudio del compostaje doméstico en Cataluña. Ent, environment and management. Barcelona (Available from: http://www20.gencat.cat/docs/arc/Home/Ambits%20dactuacio/Recollida%20selectiva/Residus%20municipals/Materia%20organica%20(FORM%20-%20FV)/Jornades,%20estudis%20i%20enllacos/calculadora_es.pdf, last access: 25/10/2015).

Resse, A., Bioteau, T., 2012. Impact of individual home-composting on the quantities of MSW collected. Irstea Rennes. Rennes Cedex, France. Available from: http://www.miniwaste.eu/mediastore/fckEditor/file/Report_Individual%20Composting.pdf (last access: 24/10/2015).

Sharp, V., Giorgi, S., Wilson, D.C., 2010. Delivery and impact of household waste prevention intervention campaigns (at the local level). Waste Manage. Res. 28, 256–268.

Scheromm, P., 2015. Motivations and practices of gardeners in urban collective gardens: The case of Montpellier. Urban For Urban Gree 14(3), 735–742. doi: 10.1016/j.ufug.2015.02.007.

Smith, S.R., 2009. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environ. Int. 35, 142–156.

Smith, S.R., Jasim, S., 2009. Small-scale home composting of biodegradable household waste: overview of key results from a 3-year research programme in West London. Waste Manag. Res. 27, 941-950. doi: 10.1177/0734242X09103828.

Soto, M., 2014. Formas de autogestión de la fracción orgánica de los residuos urbanos: vermicompostaje y compostaje doméstico o comunitario, In: Sánchez A. et al. (Eds), De residuo a recurso: El camino hacia la sostenibilidad (Vol. 1.4: Residuos urbanos). Mundi-Prensa, Madrid, pp 257-292.

Storino, F., Arizmendiarrieta, J.S., Irigoyen, I., Muro, J. Aparicio-Tejo, P.M., 2016a. Meat waste as feedstock for home composting: Effects on the process and quality of compost. Waste Manage. 56, 53-62.

Storino, F., Menendez, S., Muro, J. Aparicio-Tejo, P.M., Irigoyen, I., 2016b. Effect of feeding regime on composting in bins. Compost Science & Utilization. Doi.org/10.1080/1065657X.2016.1202794.

Tatàno, F., Pagliaro, G., Di Giovanni, P., Floriani, E., Mangani, F., 2015. Biowaste home composting: experimental process monitoring and quality control. Waste Manage. 38, 72-85.

Torras, A., 2010. Situación del compostaje doméstico y comunitario en el Estado Español. Primera fase 2010. I Seminario sobre Compostaje Doméstico y Comunitario. Composta en Red, Pamplona, 21 de octubre de 2010. En http://compostaenred.org/proyectos/JonadasNavarra2010/Ponencias/ATorras.pdf (last access: 25/10/2015).

US EPA, 2007. Method 3051A microwave assisted acid digestion of sediments, sludges, soils, and oils. Revision 1 February 2007. https://www.epa.gov/sites/production/files/2015-12/documents/3051a.pdf (last access: 09/01/2017)

Vázquez, M.A., Sen, R., Soto, M., 2015. Physico-chemical and biological characteristics of compost from decentralised composting programmes. Bioresour. Technol. 198, 520–532.

Wei, Y., Zhao, Y., Xi, B., Wei, Z., Li, X., Cao, Z., 2015. Changes in phosphorus fractions during organic wastes composting from different sources. Bioresour. Technol. 189, 349-356.

Xunta, 2011. Plan de xestión de residuos urbanos de Galiza (PXRUG) 2010-2020. Consellaría de Medio Ambiente e Desenvolvemento Sostible. Xunta de Galicia. Santiago de Compostela. Available from: http://sirga.cmati.xunta.es/plans-programas-e-normativa-relacionada (last access: 25/10/2015).