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Integration of food waste composting and vegetable gardens in a university campus

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ABSTRACT

Local composting (household, community and small scale applications) is considered a sustainable option for bio-waste recovery and is receiving increasing demand from society. Higher education institutions are no exception, but detailed and comprehensive long-term studies on composting programs on university campuses are lacking. The local composting program of the University of A Coruña (UDC) offers a decentralized service for the treatment of food waste from 11 university canteens using static and dynamic composters located in 9 different composting areas. Considering the three pillars of sustainability, this work describes the characteristics of the different composting technologies used and their investment and operational costs, the routine monitoring process and product quality, the integration of the composting systems as living labs for biotechnology and environmental engineering courses, and the use of compost in the university vegetable gardens. The agents involved in the project are the canteen staff, the university gardening company, external composting operators, university researchers and teachers, sustainability scholarship students and volunteer people. Organic waste is usually delivered directly by canteen staff to composters. The gardening service provides green waste from UDC campus (crushed pruning) that is used as bulking material. The monitoring and maintenance of the composting areas is currently in charge of external staff provided by a local NGO dedicated to cooperation and job reintegration of the unemployed. The service also allows the incorporation of volunteers and scholarship students as operators and process monitoring supervisors. The main result of this project was the prevention of a large amount of waste that did not require collection and transportation, or disposal or incineration. This is being done in an economically sustainable way, as decentralized composting costs have been lower than the average costs of municipal solid waste treatment in the region. The lower investment costs of static composters largely offset the higher labour costs and result in lower overall costs than those of the dynamic composter. The dissemination of composting practice to society was another important outcome of the project.

1. Introduction

Composting is considered a sustainable option to treat organic wastes and reuse them as a soil amendment and fertilizer (EMAF, 2015). In this way, composting can contribute to the goals of circular economy in both developed and developing countries (Salguero-Puerta et al., 2019; Bruni et al., 2020). The target for recycling (including composting and digestion) of municipal waste by 2030 is set to 60% in the revised legislative framework on waste in the “Circular Economy Package” of the European Union (EU). Bio-waste is the largest component of municipal waste in the EU-28, representing the 34% of the total (van der Linden and Reichel, 2020). Food waste represents 60% of the total municipal bio-waste in the EU-28.

Data for 2018 indicate that the EU reached 47.1% recycling of municipal waste (Eurostat, 2020), but there was a large difference among member states and particularly among state regions. Municipal waste recycling in Spain was only 36.0% in 2018, while Galiza Autonomous Community had only reached 12% of material recycling and 6% of low quality composting and digestion (XG, 2019). Spain and, particularly, Galiza are far from the EU objective of 50% recycling in 2020, and must make a great effort to meet the 2030 recycling goal of 60%. According to Bruni et al. (2020), local solutions on recycling and

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recovery of waste through composting are key in achieving and adopting the circular economy model in the coming years.

Total waste generation reached the amount of 0.08 kg/day per capita on average at Higher Education Institutions (HEIs). Biodegradable organic matter is usually the main component of total waste generated at HEIs ranging from 22 to 55% (Armijo de Vega et al., 2008; Smyth et al., 2010; Gallardo et al., 2016; Ramamoorthy et al., 2019). Considering the cited four reports, food waste (33% of total waste on average) and yard waste (3%) are the main bio-waste contributors. Other recyclable materials present in HEIs waste are paper and cardboard (29%) and plastic (8%), while metal, glass, electronic waste, hazardous waste and other are minor fractions. The non-hazardous waste is separated at source in several fractions, mainly paper-cardboard, lightweight packaging, glass and organic matter (Mason et al., 2004; Gallardo et al., 2016). The quality of source separation is important for all fractions but particularly for the organic fraction if the objective is to obtain a good quality composting product (Bruni et al., 2020; van der Linden and Reichel, 2020).

The universities and other HEIs have been pioneers in adopting composting programs at their campuses, seeking mainly for a sustainable solution for the organic and food waste from kitchens and catering services. Several universities in United States execute the composting program of their wastes at their sites since 2000 or even early (Sullivan, 2010). Appalachian State University has been composting on campus since 1999, upgraded composting installations with a forced aerated facility in 2010, a compost curing site in 2012 and a Compost Screener in 2016 (ASU, 2020). Composting originally began in 1986 at the University of Georgia and progressively upgraded from 2014 to 2020 (UGA, 2020). These and other HEIs incorporated the composting process in students learning activities (Waliczek et al., 2016), used compost in campus vegetable gardens and gardening and reported saving in CO_2 emissions or chemical fertilizers at the campus (Lleó et al., 2013).

Organic waste was collected separately and composted on site or transported to composting centres, either in the campus or outside the campus (Vasilivetsky, 2019; ASU, 2020). New composting and/or anaerobic digestion programs and technologies are being proposed for HEIs at both developed and developing countries (Sungsomboon et al., 2012; Shahariar and Rooney, 2017; Rajan et al., 2018). Several types of backyard static composters as well as small size in vessel (both dynamic and static) are being employed for composting at campus and other local programs (Sangamithirai et al., 2015; Waliczek et al., 2016; Vázquez et al., 2017; Vasilivetsky, 2019).

The composting program at the University of A Coruña (UDC) campus started in 2011, including the development of both static and dynamic composting technologies as well as the participation in the assessment of other local composting initiatives (Vázquez et al., 2015, 2017, 2020). Composted wastes at UDC campus includes pruning, grass cuttings and other vegetable wastes, as well as kitchen and food waste from various university canteens. Fish and meat remains were also included, with the aim of treating all bio-waste from university canteens (BWUC) generated on the UDC campus. The composting program was born linked to an urban vegetable garden project that was finally launched in 2013. The aim is to produce high quality soil amendment and organic fertilizers to be used in urban farmer and gardening at the campus. This configures an ideal situation in which two of the goals of the UDC's sustainability policy are realized: the dissemination and promotion of local-traditional and organic agricultural practices and the sustainable management of organic wastes (Vázquez et al., 2020). At the end of 2019, there were 9 composting areas in operation on the UDC campuses, treating approximately 80% of the BWUC generated.

The linkage between local composting and urban agriculture was pointed out by several authors. Considering that the current ways of managing waste, such as refuse collection and recycling, are failing to minimise waste in cities, Menyuka et al. (2020) stated that urban agriculture presents an opportunity to explore other means of sustainable food production as well as managing organic waste in cities. These authors highlight the challenges associated with urban agriculture, which include water availability and security issues, health and environmental problems, soil contamination and food safety. A main issue is the difficulty in segregating waste at source with the required quality, the proper management of organic wastes and the composting process, and the establishment of sustainable fertilizer practices when using the compost (Ackerson and Awuah, 2010; Heyman et al., 2019; Menyuka et al., 2020). Anastasiou et al. (2014) highlighted that some urban agriculture initiatives make use of urban organic waste on an innovative and sustainable way. Among the benefits of local composting and its use in urban agriculture are the low risk of pollution (including heavy metals), the absence of transportation and collection costs, the creation of social cohesion among citizens and an educational effect, showing people how food is produced and organic waste may be recycled (Anastasiou et al., 2014). All this should contribute to a more effective waste separation at source.

This is the first study to publish detailed, comprehensive, long-term results of the application of routine composting on university campuses. Most of the available studies were performed under well-controlled experimental conditions in short-term studies with the aim of describing aspects of the composting process or the technology used, on a laboratory or pilot scale. Other studies that describe the routine operation or implementation of composting systems on campus contain only very general information. Information on the overall costs of local composting systems at the campus level is particularly scarce, as well as on the use and acceptance of compost by urban vegetable garden users. The objective of this work is to describe the case study of food waste composting on the UDC campus addressing the three pillars (environmental, social and economic) of sustainability involved in the program. Therefore, the long-term technological and operational aspects are characterized first: composting areas, types of composters, monitoring and maintenance, and measurement of biological and physical parameters. On the social axis, the agents involved, the training of students and the satisfaction of end users of compost in the university vegetable gardens were described. The environmental pillar is characterized by the on-site recovery of resources while reducing the waste sent for disposal. Finally, the economic pillar was addressed by estimating the net cost of composting on campus. Following sections include the description of the case study methodologies, the main results and the conclusions and future prospects.

2. Materials and methods

2.1. Waste generation estimates and composting sites

The UDC involves a population of about 20,000 people, including students and staff and comprises 44 buildings (20 of them were study centres) and 14 canteen services. The inventory of organic waste generated by university canteens was obtained through a survey on the canteen responsible people. Data for the 9 canteens existing in the central campus of Elviña-A Zapateira was previously reported (Vázquez et al., 2020), indicating that waste generation rate ranged from 6 to 50 kg BWUC/working day on average for each one of the canteens. In this area, 1275 kg BWUC were estimated to be generated every week, which extrapolated to the entire UDC gives the amount of 1820 kg BWUC per week. Currently, the waste from 10 of the UDC canteens is being composted in 9 composting areas. These areas served the 79.7% of the UDC community, for which the estimated maximum amount of waste (if all organic waste was source separated for composting) reached 1450 kg BWUC per week during ordinary course periods. This equals the annual amount of 63 tonnes of canteen organic waste being potentially composted. On the other hand, BWUC included food scraps and food preparation waste in varying proportions, while the presence of inappropriate materials such as plastic and metal was very rare or sporadic (Vázquez et al., 2020). Improper materials have always been well below 1% of the raw material.

The geographical coordinates and main characteristics of the 9 composting areas currently in service are shown in Table 1. The basic criterion to implement the composting areas was that the canteen staff delivers the organic waste directly to the composting bin. This implied that each canteen would have the composting area at a distance below 50 m, usually at 10–30 m of the canteen service entrance. The second criterion was the selection of an appropriate place that avoid nuisance for the public and do not require expensive preparation works. Following these guidelines, the main campus of Elviña-A Zapateira brings together seven composting areas located within a radius of one km. The other two composting areas are elsewhere in the UDC located 4–6 km from the main campus.

The areas were progressively put into operation from 2011 to 2020. The total volume of composting bins reached 25.90 m^3, varying from 1.6 to 7.5 m^3 per site. The estimates indicated that these areas potentially served the canteens offering near 4000 meals a week with a composter capacity ranging from 2 to 12 L each 100 meals. This ratio was very low in FS&STA and TSE&FCS because these canteens diverted part of the waste to animal feeding uses and accordingly to the low generation rate of waste, the composting capacity of these areas was not completely developed.

2.2. Dynamic and static composters used at UDC composting areas

Fig. 1 shows the views of some of the composting areas at UDC campuses. Most of the composting areas were equipped with static composters following domestic (backyard) and community composting practices. Composting in seven of the areas was carried out in plastic composting bins (Komp Container® Trading, Pettenbach, Austria) of several volume ranging from 340 to 1400 L (Table 1, Fig. 1a and b). As examples, the dimensions of the 340 L Komp Container® are 76 × 76 cm (base) x 85 cm height while the 1050 L Komp Container® has 136 cm Ø and 107 cm height. The use and performance characteristics of the 340 L Komp Container® in the PF composting area was described in detail by Vázquez et al. (2020).

A different static composter design was used in the FEB composting area and experimented from February 2019 to March 2020. The area included three units of 1 m^3 each creating a modular composter system (Fig. 1c). This type of modular composters was first designed and installed in the Autonomous Community of Navarre (Spain) in 2012. It was developed thanks to the collaborative work between environmental companies, social insertion companies and experts in organic waste management (Plana, 2014), with the aim to improve process conditions and facilitate management and maintenance. Marketed by several companies (examples are Solteco, Vermican, Elkarkide, Alquienvas, LD Medio Ambiente ...), these modular composters are made with different materials, mainly recycled plastics, but all of them with common technical characteristics (Fertile Auro, 2019). The modular composters were purchased from Vermican, their characteristics being available on the company's website (Vermican, 2020).

The operating routine established the addition of the raw BWUC to the same composting bin until it is almost full, then the raw BWUC was directed to another composter, keeping the first one under aerobic degradation until complete maturation. Thus, in each composting area there is only one loading composter, while one or more composters are simultaneously in process of maturation after loading.

In order to compare efficiency parameters and costs, a reference composting volume of 3 m^3 was considered for composting areas type 1 and 2 (see that the real composting volumes for type 1 areas ranged from 1.58 to 3.49 m^3, Table 1). Vázquez et al. (2020) reported that stable compost (*Rottegrade* class IV-V) was obtained after 3.5 months in 340 L static composters treating 360.5 kg BWUC per batch on average, after maintaining thermophilic (51.5 ± 9.5 °C) temperatures for about 80 days. This feeding rate gives a volumetric feeding rate of 1060 kg BWUC/m^3 of composter volume per batch. Assuming the ideal duration of 3.5 month per batch, the maximum treatment capacity for static composters was set up at 10,903 kg BWUC/year for the reference composting area with 3 m^3 of installed composter volume.

In this study, the effective composting capacity used for a given composter run (static composters, composting areas type 1 and 2) was calculated from the BWUC mass fed per batch (Mfed, kg), the maximum capacity value of 1060 kg BWUC/m^3 determined by Vázquez et al.

Table 1
Main characteristics and localization of UDC composting areas.

Campus zone and composting area (geographical coordinates)[a,b]	Meals per week	Composters n°, size (Vc) and type [d,e]	Total volume (m^3)	Endowment (L/100 meals)	Starting year
A Zapateira campus zone					
FP (43.32532,-8.40829)	180	2 of 340L 1 of 900 L	1.58	8.78	2011
SA (43.32719,-8.41001)	650	Dynamic composter 1500 L [d] + Static maturation area 6000 L	7.50	11.54	2011
FS&STA (43.32736,-8.40848)	722	2 of 340 L 1 of 900 L	1.58	2.19	2013
Oza campus zone					
FHS&FPT (43.34697,-8.38639)	300 [c]	3 of 1050 L 1 of 340 L	3.49	11.63	2015
Elviña campus zone					
FES (43.33480,-8.41480)	350	1 of 1400 L 1 of 1050 L	2.45	7.00	2015
TSE&FCS (43.33271,-8.41003)	625	2 of 900 L	1.80	2.88	2017
FEB (43.33165, −8.41301)	505	3 of 1000 L [d]	3.00	5.94	2019
FL (43.33358, −8.41342)	650	3 of 900 L	2.70	4.15	2020
Bastiagueiro campus zone					
FPESS (43.34074,-8.35787)	239 [c]	2 of 900 L	1.80	7.53	2018
Total	3982	24 units	25.90	6.14	–

[a] Centre acronyms: FP: Faculty of Philology. SA: School of Architecture. FS: Faculty of Science. STA: School of Technical Architecture. FHS: Faculty of Health Science. FPT: Faculty of Physiotherapy. FES: Faculty of Education Sciences. TSE: Technical School of Engineering. FCS: Faculty of Computer Science. FEB: Faculty of Economy and Business. FL: Faculty of Law. FPESS: Faculty of Physical Education and Sport Sciences.
[b] Localization map: https://bit.ly/36IcZOF.
[c] Extrapolated from the data offered by Vázquez et al. (2020) for the other centres and considering the relative size of the university community.
[d] The size is indicated by the composter volume capacity (Vc), in L.
[e] Except the dynamic composter at SA, and the static composter model from Vermican, all the others are Komp Container® static composters.

Fig. 1. Views of composting areas at UDC campuses: a) TSE&FCS, b)FHS&FPT, c) FEB, d)SA, e)FPESS, f)FL (meaning of the acronyms in Table 1 notes).

(2020), and the total composter volume capacity (Vc, m^3) by applying the following equation:

$$\text{EUC (Effective used capacity, \%)} = \text{Mfed} / (1060 \cdot \text{Vc}) \cdot 100 \quad (1)$$

In the SA composting (Fig. 1d), waste processing was carried out in a continuous dynamic composter prototype (Plana Compost® design) with mechanical mixing, which acted as the first stage, receiving the raw BWUC. The subsequent maturation phase was nowadays carried out in in static heaps under roof (Fig. 1d). Previously, the maturation phase of the pre-composted waste from the dynamic composter was carried out either in 1050 L Komp Container® or directly in big-bags, both feasible options for this purpose (Fandiño et al., 2014; Vázquez et al., 2020). The characteristics and performance of the dynamic composter prototype were reported elsewhere (Vázquez et al., 2020). These authors stablished the maximum capacity for the 1.5 m^3 dynamic composter at 40–80 kg BWUC/day, from which the reference maximum value of 60 kg BWUC/day (21,900 kg BWUC/year) was used in the present study for the SA composting area. The effective composting capacity for a given period was calculated from the actual loading rate in that period (LR, kg BWUC/day) and the reference loading rate (Eq. (2)):

$$\text{EUC (\%)} = (\text{LR} / 60) \cdot 100 \quad (2)$$

2.3. Monitoring and maintenance of the composting units

The agents involved in the project were the canteen staff, the gardening company, external composting operators, university researchers and teachers, sustainability scholarship students and volunteer students. The composting practice followed the initial basic criteria described by Vázquez et al. (2020). The BWUC was mixed with a bulking material in a reference 1:1 vol Ratio. The bulking material consisted of finely shredded green waste (pruning included) also generated at the university campus, and provided by the garden maintenance company. The main part of the bulking material had about 5–10 mm grain size, although the proportion of large particles of 50–150 mm in size increased during the two last years because of changes in the available machinery by the gardening company. The moisture content (MC) of bulking material was variable (20–60%) and the C/N ratio was approximately 50. During the last two year, the driest bulking material was used for the dynamic composter at the SA composting site, a measure that prevented the generation of leachate and excess moisture.

Except in the case of the FS canteen, the canteen staff directly delivered the organic waste each day into the composting bin. In some of the composting areas, the canteen staff added a small volume of bulking material covering the organic waste, an action that helps in avoiding the presence of flies. Two times a week, usually on Wednesdays and always on Fridays (on Fridays later in the evening, after the canteen staff delivered the last waste of the week) the composting operators visit each composting area and carry out the mixing operations and add more bulking material or water depending on the situation. Composting operators also registered the amount of waste added (Mfed) and measured the temperature in the composting material (this before mixing the material). They also registered the level of odour, the presence of flies, the moisture content (following the hand-squeeze test), all of they in a qualitative 1–10 scale, as well as the questions posed by the canteen staff.

Composting operators varied over the time, the role being carried out mainly per scholarship students until the end of 2017. After February 2018, external personal provided by *Ecos do Sur*, a local NGO dedicated to cooperation and labour reintegration of unemployed people, was in charge of the monitoring and maintenance of the composting areas. Occasionally, volunteers carried out the operation of some composting area for short periods, after the necessary training. All the data generated by the composting operators was uploaded to an Excel shared file. Scholarship students devoted to the Green Campus programme at each centre survey the respective composting area. The general supervision corresponded to the person in charge of the composting service, at the Office for the Environment of the UDC (OMA).

The composting operators also transported twice a week the organic waste from the FS to the FS&STA composting area, because of the distance slightly higher than 50 m from the canteen. On the other hand, the gardening service provided the required bulking material and transported the final compost to the vegetable gardens or to other campus areas where it was to be used. This service was not accounted for composting costs, because it was offered for free by the gardening company during the contest phase as a sustainability measure in order to meet the requirements for green procurement. In practice, this option is aimed at valuing excess pruning waste generated on campus, which would otherwise be disposed of in unused spaces on campus after a simple chopping.

2.4. *Use of composting systems for the training of students in biotechnology and environmental engineering*

Composting areas at the A Zapateira campus zone offered an opportunity to field practices of several waste management and composting courses of the Science Faculty. These courses are part of the master's degrees in "Sciences, technologies and environmental management" and in "Advanced biotechnology". The students and teachers dedicate between 2 and 8 h to visit, inspect and take samples of the material in at least two of the different composting phases of one or more composting areas.

During students visit, composting phase assignment was made from the information received from the composters' maintenance service. Phase 1 included the waste loading periods as well as the two weeks of operation that follow (i.e. the thermophilic phase). Phase 2 followed Phase 1 until 2 months after the end of the loading period, and then Phase 3 started, corresponding to the final product.

On-site inspection by students included observation of the fresh BWUC and bulking material, the appearance of composting bins and perception of odours, flies and improper materials. On-site measurements include temperature, oxygen and qualitative moisture content (hand-squeeze test). Composting material samples (approximately 6 L) were taken and translated to the laboratory. The first lab step was to determine the bulk density, the content in improper material, the fraction of coarse material (all hard, shredding-resistant particles of several cm in size, that are removed from the sample), mixing and homogenizing the sample, and obtain a representative sample of 20–30 g for the quantitative MC determination. Depending on the qualitative diagnostic on MC, the samples was kept enclosed to avoid moisture loss or was subjected to drying at ambient temperature under an air current. The next day, using both the quantitative results for moisture content and the weight loss during drying (if the case), the MC was regulated to the range of 62–68% if required. Following, aliquots of the sample were used to determine material stability by the self-heating method (*Rottegrade*). Other analysis carried out at laboratory included organic matter content (volatile solids, VS), pH and electrical conductivity (EC). The same sample was processed by at least two students or pairs of students in order to check reproducibility.

2.5. *Investment and operational cost calculation*

The economic assessment included the identification of direct costs (cash flow) of investment and operation (labor, energy, and the avoided cost of purchasing fertilizers replaced by the compost produced). As in other studies (Mu et al., 2017; Keng et al., 2020), some costs were not taken into account, because they were considered insignificant (small consumables and water consumption), or they are not part of the direct costs in the local application scenario (supply of bulking material, transport of compost to the vegetable gardens, see section 2.3). A commonly considered saving is the cost of waste collection and treatment in the centralized municipal system. In the present study, this cost was not introduced as a saving but, once estimated, was used as a reference to assess the economic sustainability of the composting program at the UDC.

Therefore, the net direct costs of composting the BWUC on the UDC campus were obtained using the following equation (all terms expressed in €/t BWUC):

$$\text{Net cost of composting} = \text{Investment cost} + \text{Operational cost} - \text{Value of compost} \quad (3)$$

Most of the cost components were obtained from the turnover recorded in the UDC. All composting areas included four elements that contributed to the total investment cost: 1) material and works to adapt the composting site (mainly base bed and enclosure, but also area cover and electricity connection if applicable), 2) composting bins or bioreactor, 3) information panel and 4) container for bulking material. The investment cost corresponded to the sum of the cost of these concepts. All composting areas must have access to water supply, an item typically available at a convenient distance on campus. Otherwise, water was obtained from the dining room service. Thus, investment costs for water supply points were not considered. The cost of each item was obtained from the purchase invoices available at the OMA management office. An overall service life of 12 years was used (Martínez-Blanco et al., 2010), being considered that it included reposition and repair costs. The total investment cost were referred to the composting volume installed and later transformed into unitary investment costs per t of BWUC.

Operational costs included the hiring costs of current workers (all areas) and electricity supply (type 3 area only). Water consumption was not controlled and no derived costs were considered, nor was the cost of other fungible materials such as the gardening fork and bucket. However, it was estimated that these unaccounted costs would be less than 0.01 €/tonne and therefore negligible in terms of total costs. Finally, neither the supply of bulking material and the transportation of bulking material and compost (see section 2.3), nor the planning and supervision costs attributable to UDC staff were accounted for. Note that most planning and supervision costs are also not taken into account in the case of the reference centralized treatment system.

In order to enter in the economic balance the value of the compost produced, the price of a compost of similar chemical quality (class A taking into account the content in heavy metals established in the Spanish legislation: BOE, 2013), for sale by a local producer, was taken as reference. The price of commercial compost, referred to the nitrogen unit (as the main fertilizer element), was 15.29 €/kg N. The value of the compost produced on the UDC campus was obtained by multiplying the amount produced by the nitrogen content and by this price.

The economic analysis did not consider other indirect costs or externalities, both social and environmental, generally positive for the sustainability of decentralized composting (Lleó et al., 2013; Mu et al., 2017; Marcello et al., 2021). These would be the benefits derived from the use of composting facilities and processes in the academic training of UDC students and in the sustainability education programs of both the UDC community and the external public that visits them. This would also include environmental improvements compared to mechanical-biological treatment in the centralized plant (reduction of greenhouse gas emissions, carbon sequestration, eutrophication, acidification …). Although some of these costs could be estimated from the scientific literature and databases (Mu et al., 2017; Marcello et al., 2021), the authors considered that a correct evaluation in the case of UDC requires new studies not yet conducted.

2.6. Analysis and calculations

The temperature of the material in all composting units was routinely determined at three points of the composting mass to obtain the average and the maximum values. Oxygen in the interstitial atmosphere was determined in two points in some of the composting units. Dräger equipment (detector X-AM) and a thermometer with a HI 935005N probe were used to respectively register oxygen and temperature values. On the other hand, samples of both the composting material at different processing phases were collected for the determination of several parameters. These included pH, MC, EC, stability (*Rottegrade* test, Brinton et al., 1995), percentage of C and N, nutrients and heavy metals (HM). MC was determined by drying to constant weight (24–48 h) in an oven at 90 °C and volatile solids (VS) by ignition at 600 °C (1 h) (Vázquez et al., 2017). *E. coli* and *Salmonella* spp detection were measured following ISO 16649–2 and ISO 6579 standards respectively. Details for the analysis of the nitrogen content (N), total carbon (C) and total organic carbon (TOC), as well as for the quantitative analysis of metals were reported elsewhere (Vázquez et al., 2020).

Although not mandatory, the limits established in the Spanish standard for the use of compost as a commercial amendment have been taken as a reference to evaluate and discuss some properties of the compost produced. This applies for example to heavy metal content, pathogen content and other parameters such as organic matter content, C/N ratio, moisture content and particle size distribution.

The use of compost in UDC vegetable gardens was assessed through a user survey on Microsoft Forms in 2019 (OMA, 2020a). The survey contained 21 questions asking for different aspects of the vegetable garden management, including 5 questions relative to the amount and quality of the compost supplied. The anonymous survey was sent to the current 40 users as well as to 59 former users (period 2013 to 2018). The answers received were 26 (users) and 16 (former users), representing the 65% and 27% of the recipient, respectively. The evaluation by users of the compost supplied to the UDC orchards was obtained from the answers to the specific questions related to compost, as well as the general evaluation of the orchard, particularly the class and diversity of cultivated species and overall satisfaction with the service.

The suitability of the least-squares fit (linear regression) was evaluated by the square of the coefficient of determination (R^2), adjusted R^2, the statistical F-value and the probability (p). One-way analysis of variance was used to compare sets of data. Statistical analyses and data processing, including obtaining the mean and standard deviation values, were carried out in Microsoft Excel (Excel, 2010 v. 15.0.4875.1000, Microsoft Corp., Redmond, WA, USA).

3. Results and discussion

3.1. Characteristics of the composting areas: adaptation to the place and investment costs

The main characteristic of the composting areas are given in Table 1, including the geographical coordinates, the number, type and size of composters, the total volume, the endowment respective to the served community, and the starting year. The composting areas were permanently in operation after the starting year, except the SA area during the academic year 2015–2016 and the PF area during 2018–2019. In the first case, the dynamic composter was lent to be used in the initiation campaign of the Revitaliza project in Pontevedra (Mato et al., 2019), and in the second case because of the shutdown of the canteen service during that period.

The type of composters used are described in section 2.2. Besides the composters, other construction elements are of high importance and largely determine the investment cost. As indicated in Table 2 and Fig. 1, three main types of composting areas can be considered. The type 1 is based on the use of home or community level composters model Komp Container or similar. The type 2 is particular for modular composters. The type 3 uses the dynamic composter and an adapted maturation area.

Considering the placement of type 1 composting area, the best and cheaper option is a campus space partially surrounded by vegetation with unpaved ground. If this space is of a low slope (or after adapting it to less than 5% slope), it only requires the addition of sand 2–3 cm deep (if the soil permeability is low) and the placement of the metallic rodent proofing mesh on the ground, covering the base of the composters. This case is illustrated by Fig. 1a and b. However, in an open space, some sort of delimitation and protection is necessary (Fig. 1f), which increase the investment costs. In addition, measures may be necessary to reduce possible waterlogging in the area surrounding the composters and

Table 2
Main elements of the three composting area types at UDC campuses and investment costs.

Area type and places	Main elements	Reference capacity (m^3)	Unitary investment (€/m^3) [a]	Cost distribution (% typical value)			
				Info panel	Composters	Comp. Area	container for bulking material
Type 1: FS-STA, FP, FES, FL, FHS&FPT, FPESS	Sand, gravel, rubble or soil spall bed directly on the ground [b] Container® composting bins [c]	3	977(476–1396)	23.0	20.5	33.5	23.0
Type 2: FEB	Drainage bed with prefabricated latticework and gravel Modular composters (Vermican)	3	1594(1594–2198)	14.1	38.0	32.9	15.1
Type 3: SA	Dynamic composter Plana Compost® Covered and paved maturation area Connection for electricity	7.5	4192(nd)	2.1	66.0	29.7	2.1

Other common elements are.
A) Included in cost analysis: stainless steel mesh (8–10 mm) under the composting bins of types 1 and 2 composting areas; container for bulking material and tools in all areas.
B) Not included in cost analysis: water supplying point, gardening fork and bucket.
[a] Typical value and range of unitary investment.
[b] Composting area type 1: 327 €/m^3 (100–700 €/m^3 range).
[c] Container® composting bins (340 a 1400 L volume): 200 €/m^3 (150–250 range).

prevent the formation of mud by workers trampling.

The unpaved ground in type 1 areas facilitates the retention of the dirty water coming from rain that drips down from the external composter walls to the surroundings as well as the self-colonization of the composting material with earthworms. One of the areas has to been situated on a paved ground and it required the creation of a gravel bed under the composting area that facilitate both the recovery of the dirty water and the aeration of the composting material through the bottom (Fig. 1e). The base includes a plastic liner, metal mesh and gravel bed 15–20 cm deep, all that confined by a wooden frame. A buried pipe evacuated excess water to a nearby sewer.

Whether the place is paved or not, the modular composters model (Fig. 1c) required a drainage bed with prefabricated latticework, concrete and gravel. This is because the composter elements must be tightly anchored to the created pavement to maintain the structure and shape of the composter. Finally, the type 3 area uses a motorized composter (the model Plana Compost® in the SA area), a connection for electricity and a covered and paved maturation area (Fig. 1d).

In order to compare the investment costs, a reference composting volume of 3 m^3 was considered for composting area type 1 (see that the real composting volumes for this type ranged from 1.58 to 3.49 m^3, Table 1), while the real volumes of 3 and 7.5 m^3 were used for type 2 and 3, respectively. Note that the used of static composter for the centres with low waste generation rate and the dynamic composter for centres with waste generation rates above 20 kg/d were recommended by Vázquez et al. (2020) after the basic studies of the applicability of this type of technologies. Thus, Table 2 shows the real investments costs for areas type 2 and 3 as set up on UDC campuses, while type 1 was referred to a hypothetic 3 m^3 size area, similar to that of type 2.

To obtain the cost figures to type 1 composting area, mean values for composting bins and the elements of the base bed and enclosure of composting areas were considered, while typical values of the information panel and container for bulking material (the same in all areas) were considered. The investment cost figures for the type 2 area only varied in the cost of the construction of the drainage and composters bed. From the two requested budgets, it was chosen the lower for the FEB area, which is also considered as typical for the cost study. The other budget available led to the maximum investment cost for this area. Finally, it was considered the only real cost option available for the dynamic composting area, including the four constitutive main elements.

Data in Table 2 shows that the investment cost per unit of volume largely increase from type 1 to type 2 and type 3 composting areas. Furthermore, there is a large range of variation in the case of type 1 composting area because of the different requirements of the specific place where the composting area is located. Thus, the investment cost per m^3 of composting capacity on the UDC campus varied from 476 to 3424 €/m^3. On the other hand, the investment cost distribution among the four main elements indicates that the composter unit followed by the preparation of the composting area are the most contributing elements, particularly in the case of type 2 and type 3 areas.

The overall investment cost is of importance itself because two main reasons. Firstly, the implementation of the composting programme at UDC started in 2011 in the scenario of the economic crisis in Spain, a situation that clearly impair the decision to implement the on campus composting services if the investment had to be very high. Secondly but not less important, the knowledge of local composting (i.e. the on-site, decentralized and of small scale composting) was not spread in Galiza at that time, and even worldwide, the UDC initiative being pioneer and therefore subject to possible failure, for example due to lack of success in the quality of separate collection or rejection by possible inconveniences derived from composting areas such as bad smells and others. Finally, a reduced investment cost leaves a large margin to accommodate operational costs related primarily to labour and job creation, including education for sustainability.

3.2. Temperature profiles, feeding rates and effective used capacity

First, the operation of two composting areas representative of the systems applied on the UDC campuses is described. The selected areas are characterized by different static composting technologies, the first corresponding to the Faculty of Health Sciences and Physiotherapy (FHS&FPT), which uses Container® composters (Table 1, Fig. 1b), and the second corresponding to the Faculty of Economics and Business (FEB), which makes use of modular composting technology (Table 1, Fig. 1c). Figs. 2 and 3 show the temperature evolution for successive composting batches in these two areas.

Table 3 summarizes the main operational parameters for all static composting areas from approximately January 2018 to March 2020.

In the FHS&FPT area (Oza campus), 1050 L composters (C1, C2 and C3) took an average of 59 days to fill, a period during which thermophilic temperatures are maintained between 50 and 70 °C (Fig. 2). On

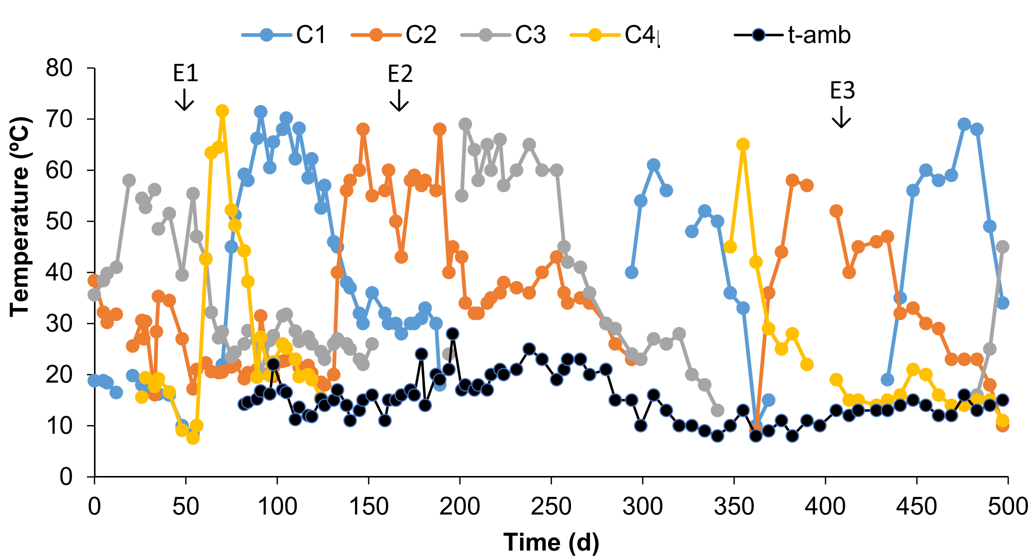

Fig. 2. Temperature evolution in successive composting runs in the FHS&FPT area (Oza campus) using Container composting bins of 1050 L (C1, C2, C3) and 340 L (C4). At time zero, composter C3 began receiving raw BWUC while C2 began the post-loading process and C1 was already maturing. The order of the thermophilic periods indicates the order of loading of the composters. E1, E2 and E3 indicate three main episodes of low temperature that are discussed in the text.

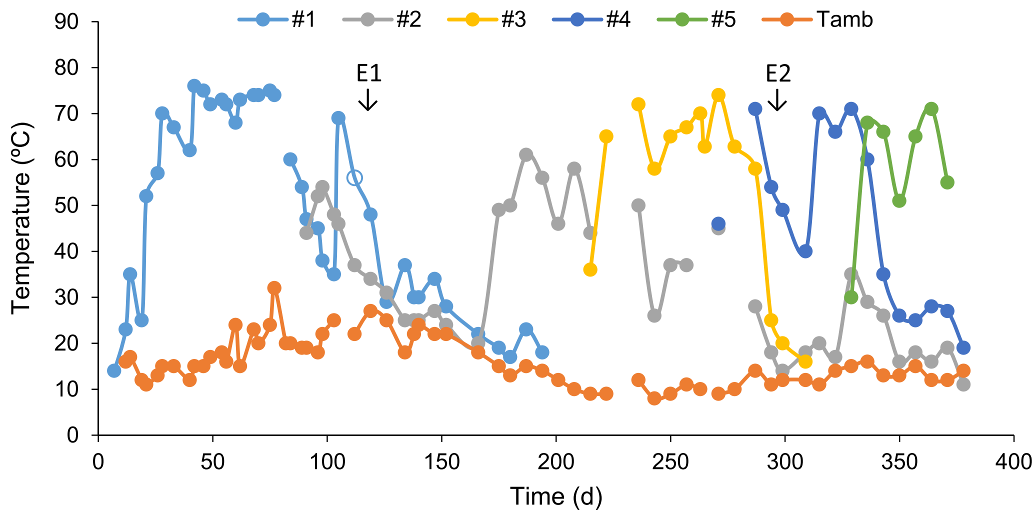

Fig. 3. Temperature evolution in successive composting runs in the FEB area (Elviña campus) using modular composters. In the chart, the loading period for a given run ends when the temperature curve for the subsequent run begins. E1 and E2 indicate two main episodes of low temperature that are discussed in the text.

Table 3
Operational data for different composting areas with static composters at UDC campuses.

Composting area	FHS&FPT	FEB	FS&STA	FPESS	FP	FES	TSE&FCS	FL
Batches (n°)	9	5	6	3	3	3	4	2
ThTm (°C)	54.2 (4.2)	59.0 (7.5)	49.9 (5.4)	45.4 (6.0)	49.5 (2.2)	52.2 (4.9)	44.5 (5.6)	53.5 (5.4)
t_{ThT} (days at ThT)	51.9 (17.5)	52.5 (21.6)	38.0 (15.5)	105.5 (71.4)	62.3 (11.6)	157.3 (39.1)	81.5 (29.3)	52.0 (8.5)
Tamb (°C)	14.2 (3.2)	14.6 (4.1)	18.0 (4.9)	15.8 (2.6)	13.6 (4.2)	15.0 (3.4)	14.3 (4.2)	11.4 (1.0)
Mfed (kg)	675 (310)	600 (234)	413 (293)	613 (292)	360 (202)	674 (360)	339 (231)	472 (15)
LR (kg/working day)	16.6 (3.4)	15.6 (2.7)	14.0 (4.4)	6.6 (1.7)	6.5 (2.4)	8.2 (0.8)	6.3 (1.3)	14.7 (4.5)
EUC (%)	70.4 (13.5)	56.6 (22.1)	75.1 (28.6)	64.2 (41.0)	49.2 (22.4)	48.4 (21.2)	35.6 (24.2)	49.4 (1.6)

Mean values followed by standard deviation in brackets. Acronyms: ThTm: thermophilic mean temperature (the thermophilic range corresponded to all temperatures above 40 °C), t_{ThT}: number of days at thermophilic temperature, Tamb: ambient temperature, Mfed: total mass fed during a composting run, LR: loading rate, EUC: Effective used capacity. For composting area acronyms, see Table 1.

the other hand, the 340 L composter (C4) was filled in less than 2 weeks and was only used if none of the other composters were available. However, the small composter also reached thermophilic temperatures very similar to those recorded in the large composter. The feeding rate in this area was 16.6 ± 3.4 kg BWUC/working day.

In Fig. 2 we can observe three main episodes of low temperatures, two of them coinciding with the Christmas holidays and consecutive non-school period devoted to January exams corresponding to the 2018–2019 academic year (day 48, E1) and the 2019–2020 academic year (day 413, E3), respectively. There is also a drop in temperature due to the complete cessation of waste loading from the end of July to the beginning of September 2019 (41 consecutive days in total), due to the cessation of activity for summer holidays. The drop observed on day 165–168 of operation (E2, Fig. 2) could be related to the effect of reducing the organic load during Holy Week and May 1st. In turn, the lowest temperature recorded during days 327–341 coincides with the lowest ambient temperature of the entire monitoring period.

Considering the different composting batch in the Oza area (n = 9, Table 3), the average temperature in the thermophilic phase was 54.2 ± 4.2 °C, remaining at that level for a period of 52 days in each run (21–26 days for the small composter, and 49–70 days for the large composters). Meanwhile, the ambient temperature ranged from 8 to 28 °C with an average of 14.2 ± 3.2 °C. The thermal gradient achieved was therefore 40 °C on average, maintaining thermophilic temperatures generally for a sufficiently long period of time to facilitate the sanitization of the material.

Fig. 3 shows the temperature evolution in 1000 L static modular composters at the FEB composting area. The temperature profiles in Fig. 3 corresponded to five successive composting batches. The first batch (#1) started in March 2019, receiving waste until June and reaching high thermophilic temperatures. Batch #2 received waste during the second half of June, and did not restart until early September, with a feeding rate (11 kg/working day) below the average, which explains why it did not reach high temperatures. Fig. 3 shows the temperature drop for the interruption of the feeding of waste during the months of July and August (E1: from day 112–174, 62 days in total), and during Christmas and January of the course 2019–2020 (E2: days 294–315).

Considering the different composting batches in the FEB area (n = 5, Table 3), the mean temperature in the thermophilic phase was 59.0 ± 7.5 °C, remaining in thermophilic temperatures for a period of 53 days per batch on average. Thus, the thermal gradient achieved was 44 °C on average, the highest of all UDC composting areas. It was common to exceed 60 °C and even 70 °C in specific conditions such as batch #1. In FEB area, modular composters took an average of 65 days to fill, a period during which thermophilic temperatures are maintained between 50 and 75 °C. The feeding rate in this area was 15.6 ± 3.4 kg/working day.

Table 3 summarizes the operational characteristics of the above described composting areas as well as those of the remaining areas with static composters. The rate of waste loading varied in the range of 6.3–16.6 kg/working day. Thermophilic temperatures varied from 44.5 to 59.0 °C on average over periods of time ranging from 38 to 157 days. Although the ambient temperature was very similar in all areas, means values in Table 3 are in the range of 11–18 °C, a variability mainly due to the different times of the year covered in the study period of each specific area.

The effective used capacity varied largely, showing mean values at each composting area ranging from 36 to 70% (Table 3). Individual values for each composting rum even varied between 5% and 111%. Small composters showed a somewhat higher EUC than big composters, as indicated by the following average values of EUC (%): 70.1 ± 21.4 for 340 L composters (n = 7), 57.2 ± 25.4 for 900–1050 composters (n = 26), and 54.8 ± 25.5 for 1400 L/composters (n = 2). Values higher than 100% are rare but possible because of the definition of the maximum reference capacity (Eq. (1)). This can occur because of the use of a lower bulking to BWUC ratio, or because of different waste composition and operation practices such as mixing effectiveness. However, the current trend is to use a bulking to BWUC ratio higher than the reference value of 1:1, which would contribute to a lower EUC. Other main reason for low EUC values was the interruption of the loading process during non-school periods and holidays, leading to the interruption of the run with a partial or even very low composter volume used. Finally, for practical reasons and depending on the operator criteria, the feeding period can be finalized once reached the filling of about 80–90% of the total composter volume. A lower loading rate could also lead to a higher EUC because of large reduction or the composting material during the loading period, but this potential effect was clearly countered by the feeding interruption, as indicated by the positive correlation between LR and EUC ($R^2 = 0.39$, $p = 0.000$, $n = 32$, excluded 3 outliers). As will be analysed later, the value of EUC is decisive to the final composting costs.

The correlation between the loading rate and the mean thermophilic temperature (ThTm) is shown in Fig. 4. A good correlation was obtained between ThTm and LR ($R^2 = 0.536$, $p = 000$, $n = 34$). The point corresponding to batch # 1 of FEB was clearly differentiated from the rest, by showing a much higher ThTm (69.1 °C). However, this behaviour was not repeated in the following composting runs at the same facility, and the ThTm in both the FHS&FPT and FEB composting areas were not statistically different ($p = 0.20$).

On the other hand, no correlation was found between ThTm and Tamb ($R^2 = 0.017$), nor between ThTm and the size of the composting units ($R^2 = 0.018$), which ranged in volume from 340 to 1400 L. However, there is some relationship between ThTm and Mfed ($R^2 = 0.17$) or EUC ($R^2 = 0.17$), but also between LR and Mfed ($R^2 = 0.19$) and particularly between LR and EUC ($R^2 = 0.23$ for all data, $n = 35$; $R^2 = 0.39$, $n = 32$). The correlation between LR and Mfed is due to the fact that larger composters were generally used for larger LRs.

Multiple correlation, introducing Tamb, Mfed or EUC along with LR, reduces R^2adjusted and the second variables are statistically no significant ($p > 0.3$). Thus, the only measured variable that explains the ThTm variation was the loading rate, which contributed to more than 50% of the observed variation in the level of thermophilic temperature reached. There were also clear observable differences between the composition or type of waste from one area to another (such as, for example, the proportion of fish and meat waste), as well as in its moisture content, but these factors were not determined in the present study. Another factor that affected ThTm was the variability in loading rate and the length of periods without load, as well as the point of the process in which shutdowns appeared. These are factors that have varied from area to area and are difficult to quantify. A qualitative assessment was provided

Table 4
Investment, operational and total cost per unit of canteen food waste.

Area type (reference area)	Type 1	Type 2	Type 3	Total UDC [a]
Reference volume capacity (m^3)	3.0	3.0	7.5	25.9
Maximum treatment capacity (kg BWUC/yr)	10903	10903	21900	88770
Unitary Investment cost at MTC (€/t BWUC) [b c]	22.4	36.5	119.6	–
Utilization factor (EUC, % maximum capacity)	56.0	56.6	50.0	54.5
Used treatment capacity (kg BWUC/yr)	6105.6	6171.0	10950	48465
Effective unitary investment cost (€/t BWUC)	40.0	64.6	239.3	–
Effective unitary operational cost (€/t BWUC)	149.5	147.9	65.6	–
Total unitary cost (€/t BWUC)	189.5	212.5	304.9	232.0
Value of compost produced (€/t BWUC)	47.3	47.3	47.3	47.3
Net unitary cost (€/t BWUC)	142.2	165.2	257.5	171.2

[a] The volume and treatment capacity for the overall UDC composting areas equals the sum of type 1 x (15.4/3) + type 2 + type 3; this is because all the descriptive parameters for type 1 area are referred to an hypothetical area of 3 m^3, while the total volume capacity of this type of area at UDC campus was 15.4 m^3 (see Table 1).
[b] MTC: maximum treatment capacity.
[c] A service life of 12 years was considered.

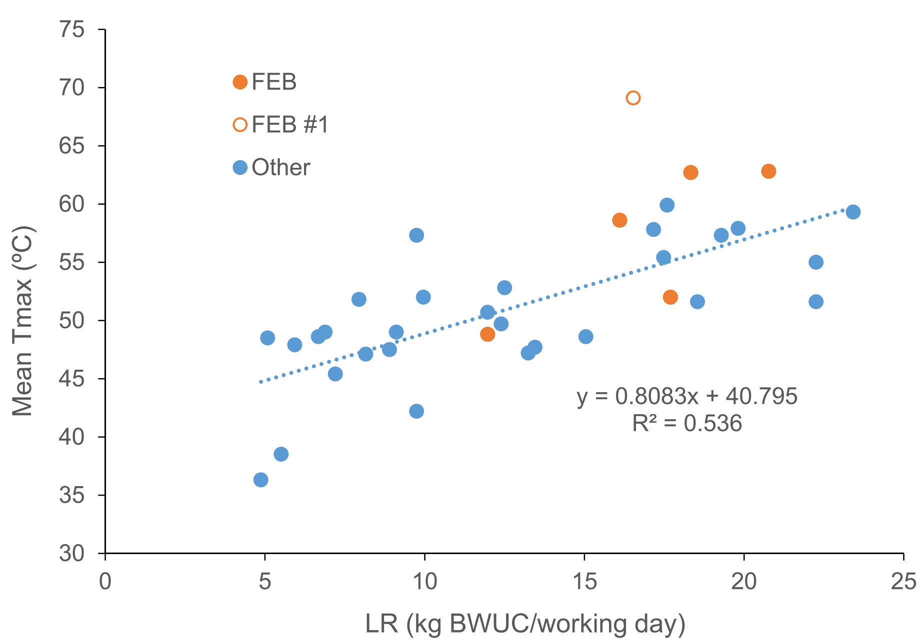

Fig. 4. Correlation between loading rate and mean thermophilic temperature (orange symbol: FEB; empty symbol (#1 FEB) excluded).

above when describing Figs. 2 and 3.

The temperatures reached are clearly higher than those recorded in home composting, which rarely reach the thermophilic range (Barrena et al., 2014; Vázquez et al., 2017). According to Storino et al. (2016a), the addition of larger amounts of waste increases composting temperature and maturity during the process, while decreasing or not producing effects on other characteristics such as salinity, phytotoxicity, microbial diversity, and gas emissions. The maintenance of thermophilic temperatures during composting of BWUC was previously reported by Vázquez et al. (2015). Thus, the effect of loading rate found in the present study agrees with these previous reports.

3.3. Net management costs

Table 4 shows several operational parameters as well as the investment, operational and total cost per unit of BWUC. For each reference area type, the maximum treatment capacity was obtained from design data as indicated in section 2.2. The volumetric investment costs indicated in Table 2 are then converted to investment cost per tonne of BWUC at maximum treatment capacity. Unitary Investment cost at maximum treatment capacity varied from 22.4 €/t BWUC for composting area type 1 to 119.6 €/t BWUC for composting area type 3. Using the effective used capacity, the effective unitary investment cost were calculated, which ranged from 40.0 €/t BWUC for composting area type 1 to 239.3 €/t BWUC for composting area type 3, while composting area type 2 presented an effective unitary investment cost of 64.6 €/t BWUC. On the other hand, the effective unitary operational cost, which corresponded mainly to the paid wages to composting operators (Section 2.2), were higher for composting areas type 1 and 2, at 148–150 €/t BWUC and lower for composting area type 3, at 66 €/t BWUC (Table 4). Finally, the value of the compost produced was estimated at 135 €/t final compost (wet basis), which equals 47.3 €/t BWUC, having the compost yield of 0.35 t Compost/t BWUC. The compost value became important in compensate composting costs, reduced the total cost in an amount ranging from 15 to 25%.

The net composting costs, as calculated from Eq. (3), were 142, 165 and 256 €/t BWUC for composting areas type 1, 2 and 3, respectively. Static composters clearly resulted in lower total costs compared to the costs of the dynamic composter. The main reason is the higher investment costs of the dynamic composter, which was 4 times higher than the cost of the static Komp Container® composters (on a maximum capacity basis, Tables 2) and 6 times higher on the basis of the effective used capacity (Table 4). Even, when the placement conditioning for composting area type 1 was low, the investment costs can be below 10 times less the investment cost for the type 3 composting area. The lower investment costs of the static composting areas largely compensate the higher manpower costs, which in turn result in local job creation.

Finally, the costs of the UDC decentralized composting service can be compared to the centralized municipal solid waste treatment service offered in the country. As reviewed by Puig (2018), overall Galician costs were 79.5 €/year per capita (very close to the mean Spanish cost of 78.3 €/year per capita) while mean Galician municipal solid waste generation was 1.091 kg/day (XG, 2019), giving the unitary cost of 199.6 €/t. Thus, net unitary costs for type 1 and 2 composting areas are lower than the current centralized management costs in the region, while costs for type 3 area are higher. Even considering all UDC systems, the average net cost of composting was € 171.2/t, which is only 86% of the regional average cost of municipal solid waste treatment. However, the treatment results of the current centralized management system are clearly worse in terms of performance and environmental sustainability, as indicated by the low recycling rate of 12% in the region and low chemical quality of the biostabilized waste from the mechanical biological treatment plants, not permissible for agricultural use according to Spanish standards (BOE, 2013) and the new European Union Regulation 2019/1009 (EC, 2019). As indicated in section 2.1, the annual generation of organic canteen waste was estimated at 63 t, of which 48.5 tonnes (77.0%) were effectively composted. Decentralized local composting and in situ use of the compost produced is considered as waste prevention (Vázquez et al., 2017). Thus, UDC composting systems are shown to be very effective with respect to the target waste stream and contribute to the prevention of 18.5% of the total waste generated in the UDC, estimated at 262.5 t/year (OMA, 2020b). The UDC's local composting program also contributes to the improvement of the separation of waste at source, as indicated by the figures achieved on the UDC campus (about 60%) higher than the average of 15% achieved in Galiza (OMA, 2020b).

The limitations of cost analysis are related to its dependence on the local situation and current factors that may change for other regions or spaces other than university campuses, as well as in the future. Some cost factors were not considered in the analysis, although most of them were estimated negligible (water consumption, supply of bulking material, and fungible materials). The cost of transporting bulking material and compost is the highest among these unconsidered concepts. It was estimated that its consideration could increase total costs by 5–10%, which would not change the main findings of the study. On the other hand, the unit cost of treated waste also depends on the effective capacity used, a situation similar to that reported by other authors (Mu et al., 2017). In fact, the effective capacity used clearly decreased in the 2020 and 2021 COVID health alarm situation (incidence not analysed in the study).

Mu et al. (2017) reported that the costs of composting food waste range from $ 21 to $ 453 per tonne. The present study offers intermediate and variable costs depending on the technology chosen. Composting costs vary depending on many factors, such as the technology chosen or the economic level of the country. For example Keng et al. et al. (2020) obtained costs of $ 31 per tonne for a community plant on the campus of the University of Nottingham, Malaysia. Waste disposal costs saved by composting practice do not always offset the direct costs of composting, as in the case of Malaysia (Keng et al., 2020), due to very low dumping rates. On the contrary, in the situation referred to by Mu et al. (2017) for the United States or by Marcello et al. (2021) for Italy, the high costs of centralized waste treatment make the decentralized composting alternative viable. In the present case, with intermediate costs of centralized treatment, economic viability requires the choice of low-cost decentralized composting technologies.

According to Mu et al. (2017) and Marcello et al. (2021), an extended cost-benefit analysis that includes externalities such as those derived from social and environmental benefits reveals that community composting is an economically and environmentally sustainable practice. These additional benefits are greater in the case of composting on a university campus, due to the intensive use of these facilities in formal and informal education (Mu et al., 2017). However, both contributions, educational and environmental benefits, were not included in the present study, requiring additional research.

3.4. Assessment of compost stability and characteristics

The results of the on-site inspection of composting systems and sample analyses are shown in Table 5. Approximately half of the samples corresponded to the SA area, with the first composting phase carried out in the dynamic composter, and the other half corresponded to the FP and FC&STA areas with static Komp Container® composters. As reported by Vázquez et al. (2020), the dynamic composter performed only a part of the thermophilic phase, usually reaching a class II active compost. Similar results were reported by Zarkadas et al. (2018) treating food waste in a continuous drum reactor. These authors indicated that the final product of the dynamic composter was not quite stable and that a maturation time may be required before its application as an organic fertilizer.

During these inspections, the mean temperature (Tm) in the thermophilic phase (Phase 1) reached 45.8 ± 16.7 °C. This value was lower than that recorded during the continuous monitoring carried out by the

Table 5
Results of the on-site inspection of composting systems and characteristics of samples from different composting phases at SA, FP and FS&STA composting areas.

Parameter	N (N per phase)*	Phase 1		Phase 2		Phase 3 (Final)	
Tm (mean T, °C)	23(7–8)	45.8	±16.7 [a]	26.1	±5.5 [b]	17.0	±3.6 [c]
Tmax (maximum T, °C)	23 (7–8)	51.3	±15.4 [a]	27.7	±5.3 [b]	17.9	±3.7 [c]
Mean O_2 content (%)	20 (6–7)	15.3	±3.6 [a]	19.4	±0.7 [b,c]	20.1	±0.8 [c]
pH	16 (4–6)	7.85	±0.69 [a]	7.67	±0.95 [a]	7.6	±0.8 [a]
Electrical conductivity (EC, µS/cm)	16 (4–6)	1939	±971 [a]	1907	±949 [a]	719.0	±431.3 [c]
Moisture content (MC, %)	25 (8–9)	65.8	±3.6 [a]	66.3	±3.3 [a,b]	69.5	±3.2 [b]
Volatile solids (VS, %)	15 (4–6)	79.9	±5.5 [a]	70.8	±4.8 [b,c]	65.0	±7.7 [c]
RTG (*Rottegrade* temperature gradient, °C)	25 (8–9)	46.0	±4.4 [a]	18.1	±10.9 [b]	6.0	±3.7 [c]
Rottegrade class **	25 (8–9)	I-II (81% = I)		II-V		IV-V (89%V)	

*N: number of determinations. ** The degrees of stability of *Rottegrade* classes are (Brinton et al., 1995): I (raw, just mixed ingredients, fresh compost), II (immature, young or very active compost), III (material still decomposing, active compost), IV (finished, moderately stable, curing compost), V (finished, very stable, well-aged compost). Different letters indicate significant differences at a probability level $p < 0.05$ ($p < 0.01$ if underlined letters).

operators (see Table 3), due on the one hand to the lower temperature expected to the dynamic composter (Vázquez et al., 2020) and on the other hand to the coincidence of inspections with low load moments (one of the sampling periods took place at the end of January of each year, so corresponding to the time immediately following the students examination period with lower waste generation). This also explains the high variability of temperatures measured at this stage. The temperature in the composting material dropped markedly in Phase 2 and finally in Phase 3, showing in these phases less variability.

The lowest oxygen values were registered for Phase 1 in the dynamic composter of the SA area, with values in the range of 11–14 mg O_2/L. However, the differences with oxygen level in static composters at the same Phase 1 (12–20%) were not statistically significant ($p = 0.07$). No significant differences were found for other parameters between the static and dynamic systems ($p > 0.1$). In the total set of measurements, the oxygen level was significantly higher in the final Phase ($p < 0.01$) and in the Phase 2 ($p < 0.05$) than in the Phase 1, while the difference between Phases 2 and 3 was not significant (Table 5). The oxygen levels recorded throughout the process and in the different systems indicates a very good oxygenation capacity, which was due to the use of bulking material in sufficient quantity and quality.

No differences in pH were found throughout the process (with a mean of 7.7 ± 0.7 for the total sample set). Differences were also very limited in moisture content (mean of 67.3 ± 3.6) due to irrigation practices, which aim to maintain a high moisture content at the end of the process to favour the activity of earthworms in later optional stages. The maximum moisture content indicated in the Spanish regulations for the use of compost as a commercial amendment is 40% (BOE, 2013). However, it was not considered necessary to lower the moisture content before application to the soil because the compost was taken directly from the compost maturation site to the place of use without intermediate storage.

Electrical conductivity was similar in Phases 1 and 2, and dropped markedly in Phase 3 ($p < 0.05$). EC was suitable for agronomic use, being always below the threshold of 3 mS/cm recommended by Oviedo-Ocaña et al. (2015). Low salinity is important because high values can cause phytotoxic and inhibitory effects on the growth of plants. Wu et al. (2019) found that the high salinity (over 0.2% in kitchen wastes) prevented earthworms from properly growing and had negative effects on quality of products in composting. Sangamithirai et al. (2015) reported higher EC values for compost from campus wastes, ranging from 4.9 to 9.0 mS/cm. The salinity content increased during the first weeks of composting and decreased during the later stage, suggesting precipitation of the mineral salts (Sangamithirai et al., 2015). These authors indicated that the use of that compost required dilution before its use as soil amendment.

The organic matter content also fell throughout the process, from 80% initial to 65% final on average. The reduction in organic matter content was more pronounced and significant between Phases 1 and 2 than between Phase 2 and final. Due to the nature of the raw materials, the final content of organic matter was well above the minimum of 35% indicated in the Spanish standard for the use of compost as a commercial organic amendment (BOE, 2013). The evolution of temperature and oxygen measured in situ, and of the organic matter content, are indicators of a good evolution of the process and potential stabilization of the waste. The *Rottegrade* assay confirmed this, showing the evolution from initial *Rottegrade* classes I-II to final classes IV-V. The drop in thermal gradient in the *Rottegrade* assay from one phase to another was always significant at a probability level <0.01 (Table 5).

Table 6
Correlation equations and regression coefficients for several monitoring parameters.

Correlation (y vs x)	Equation	R^2	p	N
Tm vs Tmax	$y = 1.071x + 0.61$	0.980	0.000	23
RTG vs Tmax	$y = 1.053x - 8.96$	0.648	0.000	22 [a]
RTG vs Tm	$y = 1.099x - 7.35$	0.538	0.000	22 [a]
RTG vs VS	$y = 1.475x - 80.13$	0.508	0.003	15
O_2 content vs Tmax	$y = -0.102x + 21.64$	0.387	0.003	20
O_2 content vs VS	$y = -0.262x + 36.54$	0.321	0.055	12
Tmax vs VS	$y = 1.012x - 41.82$	0.222	0.089	15

[a] Excluding the highest value of Tmax (82.4 °C) or Tm (79.6) that behaved as an outlier.

Table 6 shows the data for correlation between several monitoring parameters. A significant correlation was found between Tm and maximum temperature (Tmax) measured at the site ($R^2 = 0.980$, $p = 0.000$), while the *Rottegrade* temperature gradient (RTG) correlated at a significant level with Tmax ($R^2 = 0.648$, $p = 0.000$) and with VS content ($R^2 = 0.51$, $p = 0.003$). RTG also correlated with Tm, but the regression parameters were worse than for Tmax. In addition, there was a certain level of negative correlation ($p < 0.05$) between the O_2 content and Tmax, but not between the VS content and O_2 or Tmax ($p > 0.05$, Table 6). Despite this, all the equations in Table 6 show the expected trend of composting systems. The higher VS content occurred in the early stages of composting (Table 4) and led to lower O_2 content and higher temperatures.

As indicated, RTG correlated positively with both VS content and temperature during the composting process. However, the range of temperature variation is wider than that of the VS content, less dependent of the characteristics of the waste, and also easier and faster to measure. Thus, frequent temperature measurement as shown in section 3.2 (Figs. 2 and 3 as examples) is considered the best monitoring parameter and can be used as a criterion to decide when a compost batch is sufficiently stabilized for agricultural use.

The chemical composition of the final compost is shown in Table 7, which collects data from previously published and unpublished results. The final compost samples analysed were obtained over time since the start of the program in 2011 and correspond to 6 of the areas currently in operation. The average content in total carbon and organic carbon was 40.2 ± 3.1% and 36.4 ± 3.8%, respectively, while the nitrogen content

Table 7
Nutrient and metal content of final composts.

	N [a]	Mean	Standard deviation	CV (%)	HM Class [b]
C (%)	16	40.20	3.05	7.6	
TOC (%)	9	36.41	3.82	10.5	
N (%)	16	2.92	0.32	10.8	
C/N ratio	16	14.03	2.46	17.5	
Mg (g/kg)	12	2.72	0.53	19.5	
P (g/kg)	12	6.32	2.23	35.2	
Ca (g/kg)	12	76.20	29.89	39.2	
K (g/kg)	12	14.36	4.01	27.9	
Na (g/kg)	7	6.85	3.04	44.4	
Cd (mg/kg)	12	0.83	0.57	68.1	B (0.7)
Pb (mg/kg)	12	1.16	0.12	10.5	A (45)
Hg (mg/kg)	5	<0.05			A (0.4)
Cr (mg/kg)	12	7.63	5.10	66.9	A (70)
Co (mg/kg)	12	0.46	0.30	64.8	
Ni (mg/kg)	12	3.62	2.26	62.6	A (25)
Cu (mg/kg)	12	21.87	1.32	6.1	A (70)
Zn (mg/kg)	12	45.20	8.31	18.4	A (200)
As (mg/kg)	5	1.17	0.06	4.8	
Se (mg/kg)	9	0.65	0.31	46.7	

[a] N: total number of data, coming from (references, number of data): Fandiño et al., 2014 (n = 3), Vázquez et al., 2015 (n = 7), OMA, 2018 (n = 4); Vázquez et al., 2020 (n = 2). Samples came from FP, SA, FS&STA, FHS&FPT, TSE&FCS and FES composting areas.

[b] In parentheses is the limit for class A (mg / kg) indicated in the Spanish standard (BOE, 2013).

was 2.9 ± 0.3% (Table 7). The C/N ratio was low (mean value of 14.0 ± 2.5), being indicative of good retention of the nitrogen content. The C/N was lower than the maximum indicated in the Spanish standard for the use of compost as a commercial organic amendment (BOE, 2013). In addition, the low C/N ratio is compatible with the advanced stabilization indicated by the *Rottegrade* classes, being suggested as a maturity index (Bernal et al., 2009).

The low C/N ratio and high N content show that the composting process favoured the conservation of nutrients leading to a product with a high fertilizer value. The nutrient content (N, P and K) was in the range of values previously reported for composts from food waste (Sangamithirai et al., 2015; Wei et al., 2015; Storino et al., 2016b; Vázquez et al., 2017). Phosphorus content was at the top of the range found in other industrial composts as reported by Wei et al. (2015) and was similar to P content in home compost in the region (Vázquez et al., 2017). Comparing to the same home composting source, K and Mg content was lower while Ca content was higher. On the other hand, final composts had a higher nutrient content than that reported by Sangamithirai et al. (2015) for various combinations of waste generated on campus, including some types of canteen waste such as fruit waste, spent coffee grounds, spent tea leaves and vegetable waste, but with a large proportion of yard waste. The treatment of the entire stream of food waste in the composting process, including dish leftovers and meat and fish scraps, is considered the main factor that led to a higher nutrient content of the final compounds (Storino et al., 2016b; Vázquez et al., 2017).

Contamination with HM was low in all samples. Only Cd content was slightly above the limit of Class A compost for agricultural use in Spain. This was due to 2 out of 12 samples, corresponding to samples with low bulking material to waste ratio and prolonged stabilization periods. This is because Cd is present in food waste and concentrates as the composting process evolves (Vázquez et al., 2020). In general, chemical composition is compatible with European Commission organic agriculture guidelines (Vázquez et al., 2015). These results are in agreement with the findings of Anastasiou et al. (2014) who reported that heavy metal pollution in general is not a risk in urban agriculture initiatives. Martínez-Blanco et al. (2010) also reported low HM content in composts produced at home scale.

3.5. Compost sanitization

Throughout 2018, 2019, a total of 23 samples were analysed for their content in *Salmonella* and *E. coli* (Table 8). *Salmonella* was not found in any of the samples. In contrast, *E. coli* ranged from 0 to 54,876 colony forming units (cfu)/g, with a mean value of 12,736 ± 17,445 cfu/g. Although the reduction of *E. coli* over time was observed on several occasions, re-growth was also observed on two occasions (i.e., in samples from the same batch). Only 8 out of 23 samples (35%) met the commercial compost threshold set in Spanish standards (BOE, 2013). At least 4 of the samples containing low or very low *E. coli* came from intensive and prolonged vermicomposting with earthworm (self--colonization). Vermicomposting, previously considered by other authors for on-campus food waste treatment (Babich and Sylvia, 2010; Perroy et al., 2012; Setyowati et al., 2018), seems to be a good alternative to achieve high sanitization of pre-composted food waste.

Salmonella and *E. coli* are the most common indicators for assessing the presence of pathogens in compost (Arias et al., 2021). Regulations on industrial composting in many countries require specific temperature profiles as the main method to reduce pathogen content. For example, Galician regulations for sewage sludge composting in turning piles require a minimum 55 °C during a period exceeding 4 h between turning episodes combined with at least three turning episodes that meet this criterion (DOG, 2012). Most UDC campus composting systems met this

Table 8
Counts of *E. coli* and *Salmonella* in UDC compost samples.

Composting area	n [a]	*E. coli* (mean and standard deviation: cfu/g)	Observations [b,c]
FHS&&FPT	3	28,552 ± 26,782	Reduction over operation time
FEB	3	21,332 ± 18,103	No correlation with operation time
FS&STA	3	24,815 ± 26,061	No correlation with operation time
FES	1	6522± nd	–
TSE&FCS	3	2008 ± 1729	Reduction over operation time
SA (maturation big bag)	3	2636 ± 1507	No data available on stabilization time
SA (maturation heap)	3	16,039 ± 15,192	Both reduction over operation time and re-growth
FS&STA and SA (+vermicomposting)	4	67 ± 133	Samples obtained after 3 month or more of earthworm colonization following stabilization
Total	23	12,736 ± 17,445	8 out of 23 samples below the threshold of 1000 cfu/g
Classification considering the maturation time			
Less than 2 months of maturation	13	13,594 ± 16,293	1 out of 13 samples below the threshold of 1000 cfu/g
Over 2 months of maturation	10	11,621 ± 19,685	7 out of 10 samples below the threshold of 1000 cfu/g

[a] Number of samples.

[b] *Salmonella* was absent in 25 g for all compost samples.

[c] Spanish threshold for commercial compost are (BOE, 2013): 1) *Salmonella:* absent in 25 g of final compost, 2) *E. coli*: colony forming units (cfu) < 1000 cfu/g.

criterion, but *E. coli* was usually above the Spanish threshold for commercial compost. Although this is not a legal issue, because no pathogen limits are set for local, small-scale, non-commercial composts, it is always of interest to improve the hygienic quality of compost used in urban agriculture.

However, the effect of temperature on compost sanitization does not follow a simple and unambiguous pattern (Soobhany et al., 2017). While Bernal et al. (2009) referred to a bottom limit of 55 °C to eliminate pathogenic microorganisms from compost, other authors reported sanitation effects at any thermophilic temperature (i.e. above 40 °C) and that sanitization can be effective in the range of 40–50 °C, depending of the duration of the thermophilic period (Ros et al., 2006; Arias et al., 2021). In fact, Arias et al. (2021) reported a significant correlation between *E. coli* content and the number of days at temperatures above 40 °C. On the other hand, Bustamante et al. (2008) reported that temperatures in the range of 50 and 60 °C do not necessarily imply complete sanitization of the final compost because some factors such as moisture content, nutrient availability, or competitive microbiota may determine the ability of *E. coli* or *Salmonella* to grow. Indeed, several authors reported re-growth of *E. coli* during the post-thermophilic maturation phase of composting (Bustamante et al., 2008; McCarthy et al., 2011; Adegoke et al., 2016). Partial sanitization and pathogens regrowth can be due to several factors such as the recontamination during compost turning or the existence of heat resistant mutants (Soobhany et al., 2017). The lack of efficient mixing and turning frequency that avoid extreme dryness or low temperature in parts of the material can be the main causes for incomplete sanitization.

In addition to temperature, operating time is considered an important factor in achieving compost sanitization, as indicated by Barrena et al. (2014) for home and community composting. In our study, the maturation time *per se* did not guarantee to reach a low *E. coli* content, as shown in Table 8. This may be due to the fact that the maturation bins were accessible for monitoring and control operations, and cases of punctual addition of fresh waste by users were observed. Because composting areas are generally accessible to the public, there have also been cases of small amounts of waste deposited by individuals. To help solve this problem, maturation composters were kept more strictly closed during the last year. However, this measure appeared to be insufficient to reach the *E. coli* threshold in the final compost samples. This is because the size of the areas and the volume of composters were designed to meet the requirements for only the stabilization of organic matter (3–4 months of process, Vázquez et al., 2020) and prolonged vermicomposting is only possible in some of the composting areas. Although these areas with advanced sanitation performance are currently producing a sufficient amount of compost for UDC vegetable gardens, a common vermicomposting system is currently being considered as a better solution to further process the already stabilized compost coming from the different areas. Soobhany et al. (2017) stated that the integrated composting-vermicomposting process is a promising sanitation technique in comparison to composting processes, although further experimental studies are need.

The presence of E. coli in the final compost is a limitation of the present study, being an open topic that requires further research. Since compost sanitization is primarily related to thermophilic temperatures and only 50% of the observed variation in thermophilic temperature was explained by measured variables (specifically by loading rate), well-controlled specific experiments would also be needed to treat this problem.

3.6. Compost use at the UDC urban vegetable garden

Once considered stable, the compost obtained was delivered in bulk to the vegetable gardens of the UDC campus, without drying, screening or purification, on request. It contained a thick fraction of 24.0 ± 6.8% greater than 10 mm in size (n = 4; data not shown). This fraction included bones, shells, and other coarse particles coming mainly from the bulking material used.

The use of compost in UDC vegetable gardens was assessed through a user survey in 2019 (OMA, 2020a). The main results are shown in Table 9. These responses should be evaluated in the frame of reference of the more general characteristics of the orchard. The majority of users (81%) strongly or strongly agreed on the importance of maintaining strict organic farming criteria in UDC vegetable gardens. Also a majority of current users (85%) and former users (94%) considered that the size of the plots is sufficient, and the rest consider it scarce. The available cultivations tools was rated as sufficient and adequate by 83% of users. The program offered agronomic and crop training, which was frequently attended by 35% of current users while 12% never attended, and the rest did it occasionally. The assessment of the training was good or very good by 69% of users. Plots are open and accessible to the public, and product theft has affected much or quite 35% of current users, a figure that was only 6% for old users. In terms of overall satisfaction, the vegetable garden service received an overall score of 3.5 on a 4-point scale.

The compost produced at the UDC composting areas was the base of the fertilization of UDC vegetable gardens, as approximately 88% of farmers used only or frequently the UDC compost. The supply was insufficient during the first years of the orchard, but currently only about two thirds of the production is consumed in the orchard. With regard to the quality of the compost supplied, it was qualified as good or very good by 65% of the current users. However, half of the users state that sifting the compost to remove bones, shells and other thick particles would be quite or very important, this being the reason for part of the

Table 9
Evaluation by users of the compost supplied to the UDC vegetable gardens.

Asked questions	Answer option	Answers (%) [a]	
		Current users	Former users (2013–2018)
Use of UDC compost as fertilizer or other fertilizer than UDC compost	Only UDC compost	65.4	56.2
	Occasionally other fertilizer	23.1	18.8
	Frequently other fertilizer	11.5	25.0
The amount of compost supplied was	Very or quite sufficient	92.3	56.3
	Insufficient	7.7	43.8
Quality of the UDC compost supplied	Good or very good	65.4	87.5
	Regular	30.8	31.3
	Bad	3.8	6.3
Importance of sifting the compost to remove bones, shells and other thick particles	Very important	7.7	37.5
	Quite important	42.3	18.8
	Little or no importance	50.0	43.8
The information on the compost quality was [b]	Enough	53.8	50.0
	Scarce	46.2	50.0

[a] Total answers: current users (26), former users from 2013 to 2018 (16). [b] The information included the origin of the compost and composting raw materials and the chemical characteristics (i.e. organic matter, nutrient and heavy metals content).

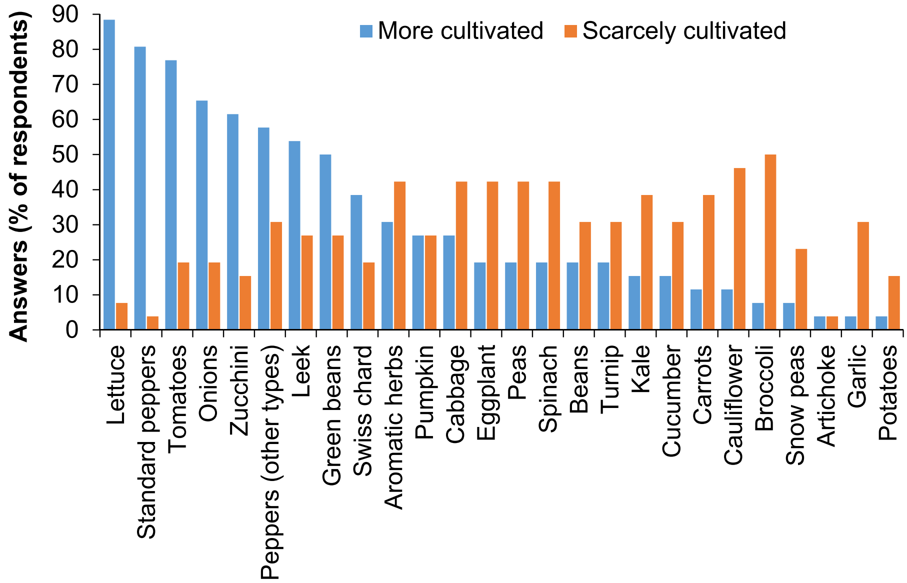

Fig. 5. Frequency of cultivation of different crop species by UDC vegetable garden users.

users qualify the quality of regular.

The satisfaction of the vegetable garden users with compost as the main and even the only source of fertilizer can be explained by the high nutrient content of the compost (Table 7), its well-balanced presence, along with advanced stabilization. White and Brown (2010) indicated that crop production is often limited by low phytoavailability of essential mineral elements or the presence of excessive concentrations of potentially toxic mineral elements, especially high salinity. Considering the three main macronutrients, these authors indicated levels of leaf sufficiency of 15–40 (N), 2–5 (P) and 5–40 (K) g/kg, while the toxicity thresholds were set at 10 (P) and 50 (K) g/kg. Thus, the mean NPK concentrations indicated in Table 7 were at the optimal levels (29.2 and 14.4 g/kg for N and K, respectively), only slightly exceeded by the relative value of P (6.3 g/kg).

Heyman et al. (2019) reported that all compost modifications improved soil health, even with very high amendment rates, of 33% by volume in degraded soils. These authors indicated that the optimal compost will generally have a C: N ratio of 10–20, content in P <1.0% and a soluble salt content below 3500 μS/cm, characteristics similar to those of the present Case Study. However, the addition of excess compost could cause soil contamination, particularly by excess phosphorus addition (Small et al., 2019). This issue and the monitoring of the phytosanitary status of crops is a topic of interest, but still pending study.

Although information about the compost quality is available on the UDC web site and given to the users when they became involved in the cultivation of the orchard by the first time, or when required, this information do not include until now the microbiological characteristics as compliance with pathogen content thresholds is not required by current rules. Indeed, microbiological data were not available until the last year. In spite of this, only 50% of users state to be satisfied with the information available, this being another factor to be improved in the future.

The combination of local composting of university canteen organic waste and campus gardening green waste with on-campus urban farming provided a robust service to the university community that is being well received by students and staff. Fig. 5 shows that eight vegetables were frequently grown by more than half of the users, but the crop diversity extends to more than 25 species. Other cultivated plants not included in Fig. 5 were strawberries (very frequently), flowers, beet, curly endive, romanesco, physalis, celery, lombard cabbage, watermelon, arugula, basil, sunflower, lamb's lettuce and soybean pods, as stated in the users survey.

4. Conclusions and future prospects

The local composting program on the UDC campus developed since 2011 included static and dynamic composting technologies for composting kitchen and food waste from various university canteens, as well as other gardening waste. Fish and meat scraps were also included to treat all the bio-waste from the university canteens on the UDC campus. The aim was to prevent the generation of waste and produce high-quality soil amendment and organic fertilizers for urban agriculture and gardening on campus. It also contributed to the dissemination and promotion of traditional and organic local agricultural practices. At the end of 2019, there were 9 composting areas in operation on the UDC campuses, treating approximately 80% of the canteen bio-waste generated. The program is a successful example of how to combine organic waste management and sustainable food production in the urban environment.

The rate of waste loading at each static composting system varied in the range of 6.3–16.6 kg/working day with an effective used capacity ranging from 36 to 70%. For each batch composting run, thermophilic temperatures varied from 44.5 to 59.0 °C on average over time periods ranging from 38 to 157 days. The loading rate was the only measured variable that explains the thermophilic temperature variation, contributing to more than 50% of the observed variation. On the other hand, process temperature correlated at a significant level with *Rottegrade* temperature gradient ($R^2 = 0.648$, $p = 0.000$), supporting that frequent temperature measurement is considered the best monitoring parameter and can be used as a criterion to decide when a compost batch is sufficiently stabilized for agricultural use.

The low C/N ratio (14.0 ± 2.5) and high N (2.9 ± 0.3%) content shows that the composting process favoured the conservation of nutrients leading to a product with a high fertilizer value. Contamination with heavy metals was low in all samples. Only Cd content in 2 out of 12 samples was slightly above the limit of Class A compost for agricultural use in Spain. Final compost was always free of *Salmonella*. However, thermophilic temperature and long maturation time *per se* did not guarantee to reach a low *E. coli* content. Prolonged vermicomposting with earthworm due to self-colonization favoured *E. coli* removal, suggesting that a common vermicomposting system would be a good solution to further process the already stabilized compost coming from the different areas.

About 48 t of organic waste from UDC canteens were composted in 2019. Most of the compost obtained was used in the vegetable garden of UDC at Elviña campus, in operation since 2013, while small amounts of compost are intended for other applications. The main results of this project were the prevention of 48 tons of waste every year, which did not require collection and transport, neither disposal nor incineration. This is being done in an economically sustainable way, as decentralized composting costs have been lower than the average costs of municipal solid waste treatment in the region. Static composting systems had lower overall costs than that of the dynamic composter. Besides, the very low investment costs of the static composting areas largely compensate the higher manpower costs, which in turn result in local job creation and makes possible the cooperation for labour reintegration of unemployed people.

The dissemination of composting practice to society was another important outcome of the project in the current local situation, including external visits and training for learning and control of composting processes. Composting areas have also been used as pilot and experimental sites for research and teaching. The replacement of chemical fertilizers in vegetable gardens and a closer knowledge of food production systems and direct contact with nature were additional advantages of combining on site composting and compost use by the university community. In practice, the compost produced at the UDC composting areas was the base of the fertilization of UDC vegetable gardens, as approximately 88% of farmers used only or frequently the UDC compost. The quality of the compost supplied was qualified as good or very good by 65% of the current users.

The composting program has grown continuously over the past few years and is intended to reach all 15 UDC canteens in the near future. Another line of future application would be the extension of on-site composting to the organic fraction collected from other local waste collectors than canteen collectors. In recent years, the separation of organic waste at source has extended to waste generated in classrooms, administrative rooms and general spaces of the centres, generating a new stream of organic waste that is sent to the municipal waste treatment facility off campus. The current quality goal of this flow is a minimum organic content of 85% that is being achieved in some cases. However, this quality is not considered sufficient for decentralized composting, for which a minimum of 95% of own materials has been set. On the other hand, this stream represents a lower amount than canteen bio-waste, but is generated at a much higher number of points, which makes it difficult to guarantee good quality. As the quality of waste separation at source improves, the option for on-site composting of this stream is also being considered. So far, this practice has only been started experimentally in a single centre on UDC campuses.

CRediT authorship contribution statement

Verónica Torrijos: Data curation, Investigation, Project administration, Visualization, Writing – original draft. **Domingo Calvo Dopico:** Formal analysis, Funding acquisition, Resources, Supervision, Writing – review & editing. **Manuel Soto:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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