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Implementing community composting in primary schools: first experiences at Universitat Autònoma de Barcelona, Spain †

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Abstract: Composting is one of the most extended alternatives to landfill disposal to reduce the environmental impacts of organic waste management, such as the emission of greenhouse gases (GHGs). A community composting system consisting in four 1 m^3 modules was installed in a selected primary school in Bellaterra (Spain) and monitored through daily analysis of the main process parameters (temperature, moisture content and interstitial oxygen) and weekly analysis of gaseous emissions (CH_4, N_2O and VOCs). The composting process was successful and gaseous emissions were maintained under desirable values, which can be used to support and promote this kind of initiatives.

Keywords: community composting; biowaste; compost; resource; valorization

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1. Introduction

Waste management is one of the main challenges of modern society, and its importance is expected to increase as the world's population keeps growing. The organic fraction of municipal solid waste (OFMSW) is especially sensitive, as its mismanagement results in serious environmental impacts such as global warming due to greenhouse gases emissions (GHG) [1]. Some decades ago, the final destination of organic waste was the disposal in controlled/uncontrolled landfills and the incineration with/without energy recovery, and it is still the case in many places [2]. In recent years, biological processes such as composting and anaerobic digestion have appeared as a much more sustainable alternative for organic waste management. These strategies offer a possibility to obtain value-added products from residues, including energy and other valuable bioproducts like compost [3], which can help closing the organic matter (OM) cycle and moving towards a more circular economy.

EU member states are obligated by the Landfill Directive (1999/31/EC) and the Waste Framework Directive (2008/98/EC) to reduce the amount of biodegradable municipal solid waste (MSW) sent to landfills and to recycle organic fractions using more environmentally friendly technologies [4, 5]. The European Commission (EC) adopted the "Circular Economy Package" to lower limits for municipal waste going to landfills and set a target for recycling 65 % of municipal waste by 2035 [6]. Recently, European regulations have stated that biowaste must be source-separated and collected for its proper treatment and valorisation for resource recovery [7]. In Spain, new legislation requires municipalities to totally separate domestic biowaste in origin by the end of 2023 [8]. These policies, together with the rising prices and obstacles set to landfill disposal, will increase the demand for biological treatment processes.

Composting is a widely known biological process in which OM is decomposed mainly by microorganisms under aerobic conditions producing compost, which can be used as fertilizer [9]. Currently composting is mostly applied through centralized systems that treat the organic wastes of several municipalities at an industrial scale. The reasons behind this approach are that 1) industrial composting is more efficient, 2) different odorous compounds such as ammonia, hydrogen sulphide or a wide range of volatile organic compounds (VOCs) are produced during the composting process, which can be partially or totally treated in those industrial plants and 3) ordinary citizens might be unable to select the suitable waste and properly operate the process [10].

However, in the last years there has been a rise in small-scale composting initiatives in diverse communities (villages, neighbourhoods, apartment buildings, schools, hospitals, hotels, prisons, etc.) [11-13]. In these decentralized composting systems, the location where waste is generated and treated is close to where the compost is used, which minimizes material transportation and, therefore, reduces process costs, GHG emissions, road wear, traffic and noise generation [14]. Then, the utilization of the compost produced not only improves the soil quality, but also avoids the environmental impacts associated to the production of mineral fertilizers [15].

Decentralized waste management systems have a high potential to involve users and promote environmental education. Specifically, community composting systems have an even higher potential, as the process is relatively simple and can be understood by all social groups [9]. In decentralized composting systems, waste generators become the people in charge of the process and the recipients of the final product, what increases their awareness on the impacts involved in MSW management and their own waste generation and tends to reduce this amount [16]. The waste separation at source also improves, as it is critical to the success of the initiative, which in turn improves the quality of the compost obtained [17].

The main drawbacks of house and community composting are the problems to obtain stable mature compost and the unpleasant odours produced, which can be usually dampened by adding a suitable fraction of bulking agent to the raw material [3, 18]. Therefore, the quality of the compost and the gaseous emissions related to environmental impact and unpleasant odours are the key points for the successful application of community-scale composting systems.

In the context of promoting the advantages of decentralized composting and ensuring the quality and efficiency of the process and the final product, the "CARE: Citizen Arenas for Resource Use and Waste Management" project aims to bring the composting science to children at primary schools, raising their awareness on the environmental impacts that their own biowastes can generate if they are not properly managed, and to give them the opportunity to learn the benefits that compost represents to the environment. With that purpose, a community composting system has been installed in a selected school in Bellaterra (Cerdanyola del Vallès, Spain), where organic kitchen waste is transformed into compost, which can later be used in the school's green spaces. During the process, typical parameters such as material temperature, interstitial O_2 or humidity, as well as gaseous emissions, are monitored continuously to ensure the proper functioning of the community composting system.

2. Materials and Methods

2.1. Characteristics of the feedstock

The biowaste fed to the composting system is the organic fraction of waste generated at the school, which comes mainly from the meals prepared at the restaurant. Everyday approximately 400 meals are served, accounting for 50–60 kg OFMSW/day on average. Shredded pruning waste supplied by the gardening services at Universitat Autònoma de Barcelona is used as bulking agent. The residue and the bulking agent are mixed in a 1:1–1:1.25 volumetric ratio to adjust the porosity of the raw mixture and promote the air flow through it, which is one of the key parameters to ensure the efficiency of the process and the quality of the resulting compost. This translates into a daily volumetric load of around 100 L of mixture to the composting system.

2.2. Community composting system

The community composting system installed in the school consists in four composting modules with a volume of 1 m^3, and a storage compartment to keep the bulking agent (Figure 1). The system configuration allows continuous operation of the process, as each module is devoted to a specific phase of the composting process. Specifically, module 1 (feeding) receives the daily loads and is where the process begins, and the temperature starts rising reaching the thermophilic range. When module 1 is full, the material is moved to module 2, where the thermophilic phase continues. The material transfer helps to properly mix and oxygenate the material and to liberate module 1 to continue with the feeding. When module 1 is full again, the material from module 2 is moved to module 3 or 4 (maturation), where it is kept until it is fully stable and ready to use as fertilizer; the material from module 1 is moved to module 2, and so on.

Figure 1. Community composting system installed at the selected primary school.

2.3. Composting and compost analytical procedures

There were four classes of 3rd and 4th grade involved in the project, with a total of 80 students aged 8–10 years and 3 teachers. Through a series of formation and information sessions, the children and the teachers were introduced to composting terms, process parameters and operation. Thereafter, there were joint practical sessions for preparing the biowaste (weighting the biowaste and the bulking agent, mixing, sorting impurities and loading module 1), measuring and understanding the key parameters (temperature, interstitial O_2, and moisture content) and observing the process development (checking the module fill level, mixing the material, adding water or bulking agent to adjust the moisture content, noticing odours, etc.).

2.3.1. Routine analytical methods

Solid samples obtained along the operation were characterized in terms of moisture content, dry matter, OM, pH and electrical conductivity according to standard procedures [19].

For a qualitative control of moisture content, the "fist test" or "squeeze test" was performed, which is based on taking a handful of mixture and squeezing it. If the material drips liquid is too wet and bulking material must be added, while if it totally disintegrates is too dry and it must be watered. If the material remains aggregated without leaching, the moisture content is appropriate.

2.3.2. Temperature and interstitial oxygen

Temperature was measured daily using three different temperature probes simultaneously, placing one in the centre of the composter (more active and warmer zone), another one in an intermediate zone and the last one next to the composter wall (theoretically less active and colder zone). The action was repeated for all modules with material inside, even though in this case there was only one active module. The ambient temperature was also recorded.

Interstitial O_2 was measured in the same locations as the temperature by means of an O_2 probe equipped with a manual air pump connected to an O_2 sensor (Sensotran, Spain).

2.4. Gaseous emissions sampling and analytical procedures

A semi-spherical stainless steel flux chamber (0.443 m of base diameter, 0.154 m^2 of base area and 0.045 m^3 of volume) provided by Scentroid (IDES Canada Inc., Whitchurch-Stouffville, ON, Canada) was used to perform emissions sampling [21]. Nalophan® bags were used to store gas samples, which were obtained before and after mixing the material inside the corresponding composting module. The gaseous samples were obtained once per week, corresponding to days 15th, 23rd, 32nd, 37th, 44th and 49th of running.

CH_4 and N_2O analysis were performed using an Agilent 6890 N Gas Chromatograph (GC) and an Agilent 8860 GC, respectively (Agilent Technologies, Inc., Santa Clara, CA, USA). For CH_4 analysis, the Agilent 6890 GC was equipped with a flame ionization detector (FID), whereas for N_2O analysis, the Agilent 8860 GC was equipped with an electron capture detector (ECD). Both GCs were equipped with a HP-PLOT Q semi-capillary column (30 m × 0.53 mm × 40.0 μm, Agilent Technologies, Inc.) with N_2 as carrier gas at 13,79 kPa pressure coupled to a post-column particle trap (2 m, nº 5181-3352, Agilent Technologies, Inc.). The injection volume used for each sample was 250 and 500 μL and the total time of analysis was 4 min and 6 min for CH_4 and N_2O, respectively.

To perform VOC analysis, a MiniRAE 3000 portable analyser was used (RAE Systems, San José, CA, USA), which is equipped with a 10.6 eV PID lamp with a detection range from 0 to 15000 ppm_{veq} isobutylene [21].

3. Results and discussion

3.1. Composting performance

The daily material loads accounted on average for 65 kg mass, accounting both for the organic waste (OFMSW) and the bulking agent (VF). Considering the feeding ratio in the school and that the material was loaded 3 to 4 days per week, a total of 3 weeks were needed to fill module 1, reaching an accumulated mass of 450 kg. Due to the school's summer holidays, only one round of compost will be produced, but the material was transferred to module 2 once the first module was full to promote the mixing. The accumulated mass shown in Figure 2 represents the fresh material loaded into the composting system. The subsequent volume reduction due to degradation and water loss has not been considered, but by the end of the period depicted in Figure 2, the remaining material had 60 % of the initial volume.

The moisture content, although not shown, was maintained within a range of 40–60 %, which is recommended to facilitate the activity of the microbial degrading populations and to avoid the generation of leachates throughout the process.

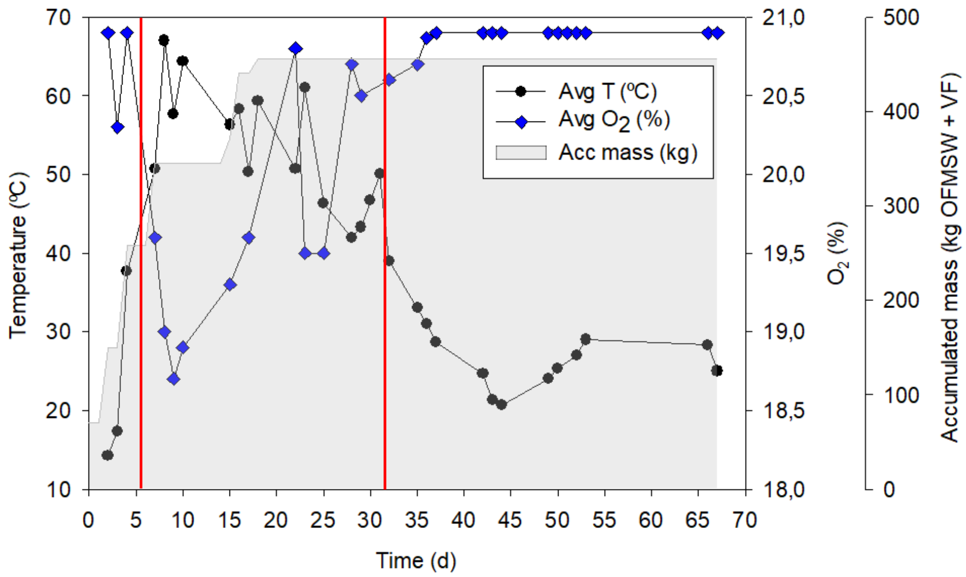

Figure 2. Accumulated material mass, considering the organic and vegetal fractions (OFMSW + VF) and main process parameters (average temperature and interstitial O_2) measured during the composting process. The vertical lines represent the different phases of the composting process (mesophilic, thermophilic and maturation).

Temperature is the key parameter ruling the composting performance. The curve observed from the composting system established in the school shows the typical phases of the composing process: a first mesophilic phase from ambient temperature up to 45 °C, followed by a thermophilic phase up to 70 °C, where maximum OM biodegradation occurs, to end up with a cooling and maturation period (below 45 °C), where material is finally stabilised. It is considered that the thermophilic phase should last for at least 14 days to ensure the material sanitisation and that, after the peak, the temperature must descend back to ambient values to consider the material stable and optimally mature [9]. Both conditions were accomplished in the system, which guarantees the quality of the composting process and the compost produced.

Interstitial O_2 gives valuable information about the biological activity. There is an inverse relation between temperature and interstitial O_2, as high temperatures entail high biological activity, which leads to an increase in O_2 consumption and a decrease in its concentration. A concentration of 10 % O_2 is considered the limit value to make sure that microorganisms have enough O_2 to degrade the OM aerobically; below that value, anaerobic degradation processes may take place, resulting in problems related to material rotting, unpleasant odours, etc. [9]. Interstitial O_2 was maintained over 18,5 % throughout the process, thus avoiding anaerobic degradation and ensuring aerobic conditions throughout the process.

3.2. Emission of GHGs and VOCs

Composting of organic wastes in centralized/decentralized facilities are a green alternative to reduce the environmental impacts of landfill deposition, but still poses some problems regarding the emissions of GHGs including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) [22], and compounds responsible for odour pollution like volatile organic compounds (VOCs) [23]. During the composting process operation, gaseous emission samples were obtained weekly to monitor the associated emission of CH_4, N_2O and total VOCs, as shown in Figure 3.

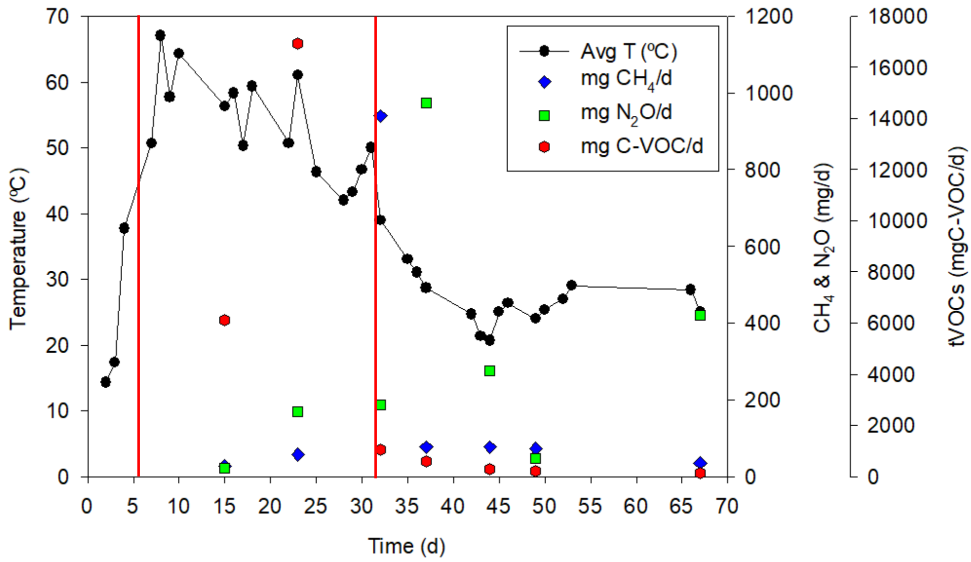

Figure 3. Temperature curve and gaseous emission rates (CH_4, N_2O and tVOCs) measured during the composting process. The vertical lines represent the different phases of the composting process (mesophilic, thermophilic and maturation).

The average CH_4 concentration measured was around 2.4 ppm_v except for a 39.7 ppm_v peak observed at the end of the thermophilic phase, coinciding with a period of 10 days with no mixing, what may lead to the formation of some anaerobic spots within the material and the subsequent punctual emission. In terms of CH_4 emission rate, the observed average was 183.7 mg/d. N_2O emissions were low from the beginning of the operation through the thermophilic phase -around 2.0 ppm_v- until the material's temperature went down below 45 °C, when a peak of N_2O was observed -14.5 ppm_v- and its emission followed a regular increase. At this mesophilic temperature conditions together with a possible limitation in carbon sources, denitrifying bacteria tend to reduce available NO_3^- forming N_2O as an intermediate, provoking its subsequent emission [24-27]. Regarding N_2O emission rates, the observed average was 299 mg/d. Considering the Global Warming Potential on a 100-year frame of CH_4 and N_2O (27 and 263 times higher than that for CO_2, respectively) [28], the process average GHG emission rate was 86.8 g CO_2-eq/d. Finally, VOCs were found to be emitted mainly during the thermophilic phase, where the most easily biodegradable OM is consumed and volatiles are much more easily formed and emitted [21]. The highest total VOC concentration observed was 255 ppm_v, whereas VOCs average concentration was 53.9 ppm_v. Therefore, it is important to notice that community composting systems must be managed properly to avoid undesirable gaseous emissions to ensure not only the comfort of the people nearby the system, but also the environmental sustainability of the process.

4. Conclusions

The composting process presented here has been successfully operated, regarding the loading and transfer of the material and the main process parameters analysed. The temperature curve shows that the treated material has gone through all the expected phases of a composting process and that it is therefore properly sanitized and matured. Interstitial O_2 decreased during the temperature peak as a result of the intense microbial activity but remained way over 10 % throughout the process, thus avoiding anaerobic degradation processes. Emissions of GHGs (CH_4 and N_2O) and odour pollutants (VOCs) were generally maintained under desirable limits, except for sporadic peaks. The correct management of the process is key to ensure the successful implementation of community composting systems like the one installed in the school, while avoiding any significant detrimental effects on the environment from the process.

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