Selective Collection
Of The Organic Waste In Tourist Areas

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# Guidelines on the definition of low cost, low tech high quality biowaste management models- the SCOW model.

(Task 4.3-2)

WP4. ANALYSIS OF MANAGEMENT MODELS RELATED TO PROJECT OBJECTIVE


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| 4.3-2. Guidelines on the definition of low cost, low tech high quality biowaste management models- SCOW model. | |
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| **WP** | 4. Definition of the general management model |
| **Coordinator** | Beneficiary |
| **Sub-Activity** | 4.3 Definition of the general model and possible variations (bio-waste producers; different types of collection, treatments and plants, capacities; co-management; monitoring, etc. |
| **Description of the tasks (FAF)** | - Definition of common elements of the model. Management phases: producers, collection, treatment, compost use.<br>- Definition of technical options for each phase of waste management model: Typology of biowaste to be collected (meat, fish, raw or vegetable leftovers, etc.), collection vehicles, typology of treatment and plant, plant capacity range(minimum- maximum), process determinants (aeration, water inflow, turn over, structuring material addition, etc.).<br>- Evaluation parameters for the determination of variables: weather, proximity of inhabited areas, quantity of biowaste generated, flows subject to co-management, compost use capacity, etc.<br>- Definition of monitoring protocols.<br>- Proposal of result indicators: economic, managing, environmental, social. |
| **Action Plan Period** | June 2014 planned. Final delivery January 2015. |
| **Name of the Output** | **4.3-2 Guidelines on the definition of low cost, low tech high quality biowaste management models- SCOW model.** |
| **Date of the delivery** | First draft: Sept. 2014; Second draft: Dec 2014; Final: January 2015. |
| **PP involved** | Beneficiary and Technical Expert (Envipark for Monitoring Chapter) |
| **Description of the Output** | Creation of a report regarding the general key options, elements and parameters to take into consideration ithe process of implementing a low -cost, low -tech,high quality Biowaste management model in relation to the configuration and systems for collection and the treatment modalities and technologies. The document defines the specificities of the SCOW model. It has also included a chapter about the monitoring and indicators, as well as marketing of the compost. |
| **Objectives of the Output** | -To create a public outputs by means of a guidelines defining low cost-low tech-high quality Biowaste management models and SCOW model.<br>-To provide the general public with information and instruments to define equivalent or similar models for their territories. |
| **Remarks** | This report is created using the contents of following internal outputs: 4.3-1 Definition of the SCOW general model and possible variations, 4.2-2 Key options and elements to define a Biowaste management model related to project objectives; and public outputs: 4.2-1 Successful decentralised composting models Database. |

| | |
|---|---|
| **Communication/ Capitalization actions** | -Available on SCOW website for all the public and for project members.<br>-Distribution of the document and informative note to all the PP.<br>-Distribution of the 4.3-2 output link and informative note to associates and other entities according to the SCOW Capitalization Plan. |

# 1.- Introduction

*Source: Bio-waste composting strategies: Management options for 6 composting schemes. First draft, September 2013, ACR+.*

## The organic matter in the urban wastes

Analyzing waste streams is not a straightforward and easy task since reliable data on municipal waste are clearly not as available as previously thought.

The regional composition of biowaste in the municipal or household waste fraction varies according to a range of factors, including geographical location, meteorological season, urban or rural characteristics of the region, type of settlements, standard of living, food and drink habits. In European countries, between 22% and 49% of municipal solid waste consists of food and green waste. In some Mediterranean regions this proportion is much larger and consists of percentages of fermentable waste (up to 70%) because of a relatively large use of vegetables and fruit in the daily diet, tourism that generates extra waste from meals and a lower presence of packaging waste due to a less wealthy economy.

The average bio-waste portion in the MSW for selected geographical regions varies from 37% (EU-15), to 47% (Balkan, Turkey and EU-13), and up to 59% in the MENA region. However, when looking at absolute data, the countries of EU-15, due to the higher overall MSW generation, produce the most bio-waste. EU-15 citizens generate on average 200 $kg \cdot cap^{-1} \cdot y^{-1}$ followed by MENA citizens generating 167 $kg \cdot cap^{-1} \cdot y^{-1}$ and finally 155 $kg \cdot cap^{-1} \cdot y^{-1}$ for EU-13 and Balkan citizens. In this sense it can be said that the potential for bio-waste composting strategies is high for the three geographical regions.

Additional information on bio-waste streams can be found in different research studies carried out by universities, public authorities, institutions, and finally in the different case studies presented in this technical report.

## Biowaste sub streams: food and green waste

Biowaste is composed of two major sub streams: food waste (also called food scraps) and green waste.

The quantities of food waste generated depend on the standard of living, food preparation and consumption patterns, and the number and age of persons living in the households. The values range between 30 and 90 $kg \cdot cap^{-1} \cdot y^{-1}$. Calculations made on behalf of the EU study based, among other sources, on Eurostat and national data assume a default value of 90 $kg \cdot cap^{-1} \cdot y^{-1}$ as the average municipal food waste potential in EU-15. Another study, based on data collected from US EPA, DEFRA, WRAP and Perkan, provides figures of 212 to 298 kg of household food waste per year.

In contrast to the food waste potential, the literature reports that the weight of green waste greatly varies. Values from 20 $kg \cdot cap^{-1} \cdot y^{-1}$ to more than 700 $kg \cdot cap^{-1} \cdot y^{-1}$ have been reported. This variation between countries and within countries between regions can be explained by differences in rainfall, temperature, type of natural vegetation, garden area (related to type of building) and length of growing season.

## Household versus municipal food and green waste

Data on the ratio household versus assimilated food and green waste provide interesting information for all composting strategies and more particularly for composting strategies by institutional and commercial entities. Based on an Irish and US EPA study, ACR+ assume in its document a ratio of 50%/50% of household against assimilated food waste and a ratio of 80%/20% of household against assimilated green waste.

Other general references, according to various European studies, say that the weight representing commercial residues inside the municipal wastes moves in a range of between 15 and 30%, depending on the type of municipality and basically the type and amount of economic activity that is present. This would mean that in rural or semi-rural areas, surely this percentage is around 15%, while in purely urban areas will be between 20 and 30%, depending on geographic location, demographic and socioeconomic characteristics.

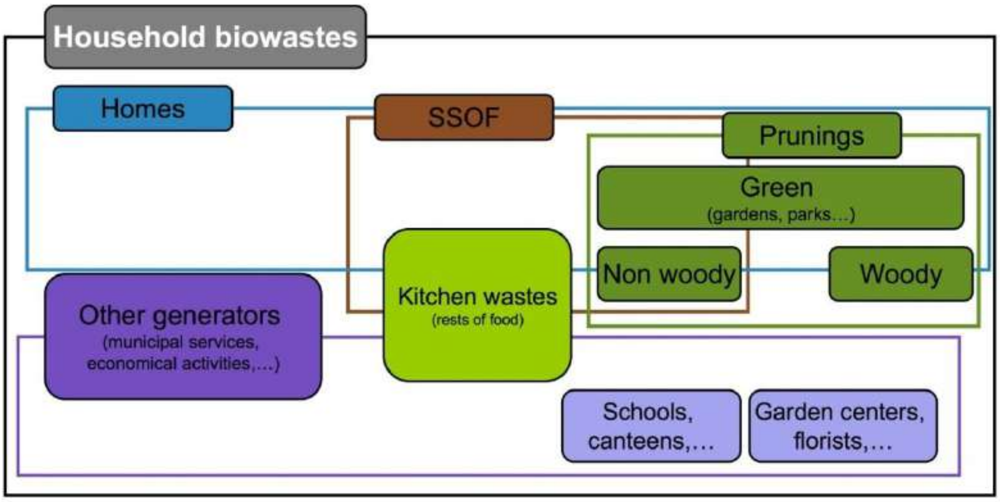



**Figure 1.** Classification of biowastes according to typology and generation fields. SSOF: Source Separate Organic Fraction (Source: Spanish Environmental Ministry, 2013).

# 2.- Definition of the separation at source

## 1.1. Types of biowastes and conditions for the source separation

In the SCOW project there are considered three possible flows of biowaste depending of its source or its origin:

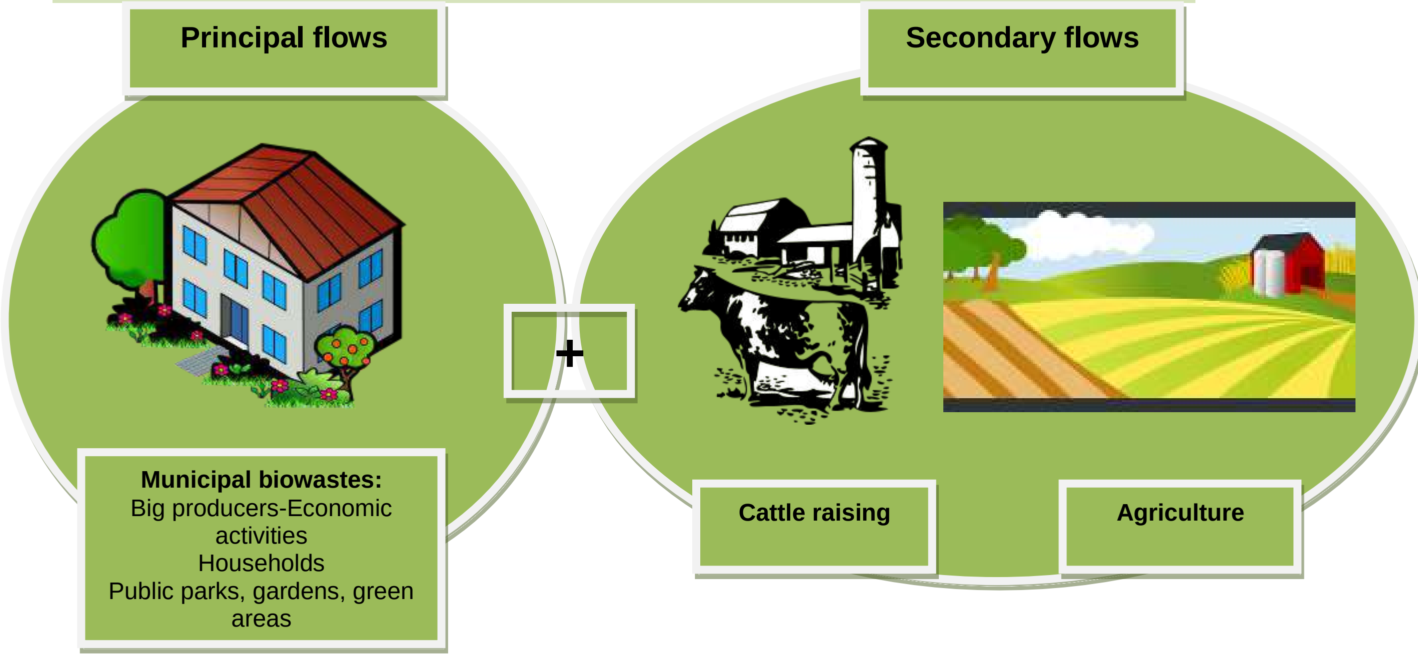



**Figure 2.** Origins of the biowastes that can be composted in the SCOW project

According to the aim of the project, the main involved producers have to be the commercial activities, especially those related to tourism (hotels, pensions, campsites, restaurants, bars, etc.). In any case, a household can be included if there is sufficient capacity in the facility and the final collection service is coherent and optimum. Additionally, there is the possibility to introduce a co-management of other secondary flows coming from agriculture and cattle raising, but always in the framework of having overcapacity after treating the target urban biowaste streams of the project.

The classification of these biowaste streams according to LER Code of the EU is the following:

| LER code | Description | Observations |
|---|---|---|
| 20 01 08 | Kitchen and food waste | From private households and from central kitchens and catering services with animal residues |
| 20 01 25 | Cooking oil and fats, grease trap residues of vegetable | |
| 20 01 38 | Wood, tree and bush cuttings (different than 20 01 37) | Code 20 01 37 refers to wood containing dangerous substances |
| 20 03 02 | Waste from markets | Only if they are biodegradable and are equivalent to the waste code 20 01 08 and 20 01 25 |
| 20 03 03 | Street cleaning wastes | Only if they are biodegradable |

**Table 1.-** Classification of biodegradable organic waste according to the current Coding LER.

Regarding the municipal wastes, in the design of this biowaste management model, all types of Biowaste generated in the kitchen, from food manipulation or conservation and leftovers from meals (-cooked and raw-) will be accepted. They could be accompanied with non wood vegetable waste (of small size) generated mainly in households (gardens, plants growing, etc.). See the following list of accepted materials. All of these materials should be accepted and composted in small scale facilities[1].

1 In some countries of North and Central Europe (Germany, Austria, Netherlands, Nordic countries) the type of biowaste collected separately is limited to vegetable waste from parks, gardens and fruit and vegetables wastes. This type of collection is known as VFG (vegetable, fruit and garden) or like GFT (Groente, Fruit and Tuinafval). But it is recommended to treat all the types of biowaste not limiting the materials in order to capture the maximum quantity of this fraction.

## LIST OF COMPOSTABLE BIOWASTE MATERIALS

**Food waste / food preparation waste**

*peel and rejected parts of fruit and vegetables*
*bones and waste meat*
*fish bones and waste, shellfish and mollusc shells*
*egg shells and nut shells*
*food waste and food in poor condition*
*leftover bread*
*coffee grounds and tea waste*

**Waste paper**

*dirty kitchen paper*
*dirty paper napkins*
*paper handkerchiefs*

**Small-sized plant waste**

*dried up bunches of flowers, dry flowers and leaves*
*weeds, grass cuttings, small branches from pruning, fallen leaves*

**Compostable materials**

*compostable bags*
*other compostable materials*

**Other materials**

*Cork material*
*sawdust*
*natural wood chips and shavings*
*domestic animal excrement without absorbent sand or litter*
*toothpicks and ice-cream spatulas, chopsticks or kebab sticks, etc*


**Figure 3.** List of compostable biowaste materials that can be treated in the facility.

- **Municipal**: conformed by some subcategories depending on the activity that generates the biowaste.
  - **Households:** mainly composed by food waste (raw and cooked), kitchen paper, (Figure 3) of the activity that generates the biowaste. Collection can be mainly door-to-door or in a container/bin, which would influence the frequency of collection as well as the quality (See chapter 2 about collection). The consideration of "quality" for this category will be related to:
    - Content of non-organic materials/kind separation at source:
      The biowaste separated at source and delivered by the users of the model have to have a good quality with a limited percentage of impurities. To obtain this level of improper materials, apart from the communication activities, is essential to use compostable bag liners. Non demanded materials like plastics, metals, batteries, hygienic or body care wastes,… have to be bellow 2% (mass) of the total weight of the biowaste collected (with a maximum limit of 5%).
    - Bagging of the biowaste/other elements: the combination of bag compostable and perforated bins as elements of collection at homes also has a positive effect on the following biowaste management in the treatment facility. The fact that the compostable bags are breathable, allowing the passage of air, induces a reduction of the mass of the biowaste up to 5% in 3 - 4 days[2]. However, to obtain those maximum effects, it is essential to combine the use of biodegradable bags with perforated or aerated cube/caddie also known as an "aerated system". This container of an approximate volume of 10 litres (usually between 7l and 20l depending on the number of inhabitants per household), has perforated walls to allow the passage of air through the bag and the biowaste accumulated there.
      In the framework of a model based on small scale composting facilities the compostable bags are compulsory.

[2] Puyuelo, B.; Colón, J.; Martín, P. & Sánchez, A. 2013. Comparison of compostable bags and aerated bins with conventional storage systems to collect the organic fraction of municipal solid waste from homes. A Catalonia case study. Waste Management 33, 1381–1389

The compostable bags must comply under the following standards:

- Consisting of certified compostable materials (including paper).
- Having the adequate capacity according to the caddy dimensions.
- Resistant enough to support weight of disposed waste during all the storage and waste delivery process.
- Avoiding the leakage of leachates (liquid production) and promote perspiration to prevent the generation of leachates and odours.
- In some systems like door to door collection, will require transparent bags in order to examine their contents, or homologated if there is a payment by generation system per bag.

  It is recommended that the authorities make compulsory and promote the use of certified compostable bags, according to the European standard:

  EN 13432 standard: "Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging."

  More info:

  http://www.okcompost.be/data/pdf-document/Doc-09e-a-Requirements-of-norm-EN-13432.pdf

  http://www.biobagusa.com/certificates.htm

  The use of compostable bags has to be promoted by means of communication campaigns, free distribution or applying grant mechanisms to offer lower prices than the market, distribution points in shops, introducing an obligation for it use, etc. [3]

- Age of the biowaste/collection system: Low collection frequencies creates a cycle of uncontrolled biological degradation in housel-

[3] Many municipalities carry out bulk purchases of bags that are sold at cost price in local establishments or can be picked up by the citizens at the city hall or other municipal entities.

hold waste. When this occurs the composting facility will have to be prepared to confront episodes of bad odors, excess of leachates at the reception and other problems. The biowaste received at the facility must be as “fresh” as possible.

- Reservation of necessary space inside households (kitchens) to locate the source separation caddies or receptacles, as well as in the building (or other community areas) for collective containers or bins (waste delivery rooms) if the collection is door-to-door.

- **Commercial generators:** This category not only includes supermarkets, food stores, universities, schools or hospitals but also all the tourist activities: hotels, restaurants, B&B´s, clubs and/or residential areas are also considered. The main characteristics of biowaste composition is essentially food leftovers (cooked, precooked and raw like fruit peels, coffee rests, bread,…) which can be collected into large size bags or directly into bins or containers.

  Commercial activities can be called to carry out declarations of waste generation to allow the authorities to develop a proper dimensioning of the service.

  It is recommendable to apply door-to-door systems to collect biowaste generated by these activities (see chapter 2 about collection), especially for those producers with large amounts of biowaste.

  The consideration of “quality” for this category will be also related to:

  - Content of non-organic materials separated at source: as most of biowaste is generated in kitchens, restaurants, cafeterias, food stores, etc. Any kind of no-compostable should be avoided: container, bottles, glasses, dust. The presence of those materials must be bellow 2% (mass) of the total weight of biowaste collected (with a limited percentage of impurities of 5%).
  - Age of the biowaste in collection system: Tourist activities demand a daily, high frequency collection to avoid sanitary problems and because the high rate of production in peak season. The problem could appear if the biowaste collected has to be stored for a period

of time before being taken to the composting facility. In some cases, containers or bags are stored in cold rooms until the time in which the biowaste is collected (particularly in the case of the largest producers or when the collection frequency is limited). The main objective is to guarantee that the biowaste received at the facility is as “fresh” as possible.

- Bagging of the biowaste/other elements: to facilitate the collection tasks of the biowaste in the areas where is generated (mainly kitchens, restaurants, cafeterias), big bags/liners are often used (also for cleaning reasons). Those receptacles are also useful for the delivery and collection tasks, but can become  a serious issue for composting facilities unless bags are made of certified compostable materials (EN 13432 for the EU) (plastic bags must always be avoided). . If they are not, the receptacles must be taken out after empting their content. Under no circumstances may plastic bags can be accepted in a low tech composting facility.

  There is the possibility of not using any kind of bag and introduce biowaste directly intobins. In the case of not using any bin liners, the frequency of receptacle cleaning should be appropriate to avoid hygienic problems.

- Reservation of necessary space for biowaste collection in the economic activities[4]. They should make a reservation of space in their premises to set up the necessary containers or bins (specifically in the kitchens or places where food is manipulated). There is also the option to transfer the separate biowaste from the kitchen bins to other larger containers located outside of the building (personal containers or general street containers shared with other producers).

[4] Health authorities often require economic activities generating biowaste to extreme sanitary precautions using suitable containers or buckets, industrial bags, no manual mechanisms for container opening (like pedals). For kitchen  establishments are also required to place the bins under the working desk, usually of stainless steel, which are accessed through an integrated hole its surface.

The collection bins usually are of 20-40 L for small generators and from 120 to 360L for larger generators, even these last ones can require containers of bigger capacities (including four wheel containers).

- **Public parks, gardens, green areas:** In the urban environments vegetable or green wastes are also generated in public parks and gardens, as well as in residential areas, houses with gardens, some hotels, clubs,… These wastes can be classified in two groups attending to their source and how they would be degraded under composting conditions: pruning or grass. Branches from trees and bushes (lignified materials) should be shredded after being cut and can be used as complementary or bulking materials to compost biowastes with high moisture levels and/or with high nitrogen content. The cut grass must be considered a nitrogenous biowaste, which will be easily degraded under uncontrolled conditions because of its content in macronutrients and its moisture. If it is not treated properly it is a potential source of problems, mainly bad odours.

The wood materials of the vegetal fraction must be collected separately from the kitchen biowaste. There are different systems to carry out this capture such as demand services, drop-off in specific point with big containers, delivery in the recycling center, etc. For non wood materials of the vegetable fraction (grass, leaves, etc.) delivered in important quantities it have to be considered their collection system and route, depending on the dimensioning of the other biowaste capture mechanisms (see chapter 2).

If wooden materials are going to be used as bulking material in composting, the "quality" of the pruning should comply with:

- Content of non-organic materials: the presence of non-adequate materials in this biowaste is uncommon, but precaution should be taken in account during the tasks of collecting and shredding to avoid plastic bags or other materials that can be found in the parks and gardens.

- Particle size: depending on the dimensions of the composting heap, windrows or in-vessel systems, the shredded pruning should have an adequate particle size to be used as a bulking material.
- Moisture content: the bulking material has another function as a regulator of the excess of moisture in the mixture of biowastes. The moisture of the shredded pruning should be low, under 40% (600 $g \cdot kg^{-1}$ of total solids), so it can absorb some water content of the other biowastes.

The SCOW project's objectives look to promote a co-management of municipal biowaste with other organic flows from rural areas, like manures or other vegetable wastes. The complementarities of the different biowastes can lend many advantages to the biological processes by improving its efficiency (economical and material assessments), producing higher quality compost and even contributing to the economic activity of the area and/or of the farms

The co-composting of these flows with the municipal biowastes should only be utilized if the capacity of the composting facility is enough to treat both household and commercial bio waste (the priority), or if the quality and characteristics of the compost produced were adequate in composition.

These are some other biowastes that could be co-composted with the municipal ones:

- **Cattle raising**: This normally is the main source of organic matter in many countries, that would become a problematic waste to manage when the cattle density in some areas or regions is high. The direct application of manure as a soil and plant fertilizer has been the most common use of manures and slurries for generations Currently the present intensive stockbreeding generates high quantities of these biowastes that cannot be recycled by the environment without producing contaminates (excess of nutrients, pathogens,). However, many advantages are shown when they are managed through biological treatments like anaerobic digestion, composting and/or vermicomposting:

- a minimum content of non-organic materials,
- most of the organic matter is labile and can be easily degraded,
- the texture is homogeneous,
- it can be treated in situ
- the moisture content is usually adequate.

There is another characteristic that could be considered as an advantage if the biowastes are treated appropriately: the relatively high levels of nitrogen (mainly from urea, proteins and amino acids). This nitrogen can be a source of nutrients for the crops. Ideal nitrogen production can be achieved under the right conditions with correct C/N ratio, temperature and pH levels.

The "quality" of these biowastes is comprised of:

- Content of non-organic materials: As it was told manures and slurries are very homogenous and almost do not have non-organic materials in them unless the collection, storage and transportation (if there is) is not properly carried out. The percentage of impurities should be under 1% of the total mass of biowaste.
- Age of the biowaste: The physical and chemical characteristics of these biowastes guarantee that they are biologically degraded under natural conditions. If that degradation happens uncontrolled it easily create anaerobic fermentation, generating methane (a gas with a higher greenhouse effect than $CO_2$) and odorous gaseous substances (mercaptans, volatile fatty acids, aldehydes and nitrogenous). These environmental negative effects could be avoided if the manure is managed immediately post collection from the farms. It is important to consider that when biological degradation occurs under uncontrolled conditions, the generated metabolites produced would degrade the quality of the final product to be used as a fertilizer/amendment. When old manure is composted, it must be mixed with other biowastes and treated by a more complex through processin order to correct the quality of

the organic matter composition and to be able to obtain and apply a suitable compost fertilizer.

- <u>Presence of straw or other vegetable wastes</u>: It is not uncommon that some agricultural wastes like straw, sawdust, shredded bushes are used to cover the floor of a cattle barn. When the manure is collected, it is mixed with these materials and will act as a complementary or bulking material in composting. Not only does it mean that the natural degradation (which happens during the time before entering to the composting facility) is under better conditions, but also less proportion of bulking material is needed to manage those manures correctly. Then it will be a benefit not only for the biological process and the quality of the final compost, but also a saving of bulking that can be hard to find in the quantities required in some regions and countries.

- <u>Heavy metals content</u>: the use of some chemical compounds in the feeds to make the animals fattening faster are directly related to the presence of important concentrations of copper (Cu) and zinc (Zn) in the slurries, mainly in pigs. The composting of these biowastes increases the concentration of these heavy metals in the final compost and renders it unsuitable to be considered legal compost.

- **<u>Agriculture</u>**: This source of biowaste is quite similar to the green wastes that are generated in parks and gardens, but with distinct differences. Firstly it is important to consider that there are production peaks throughout the year, depending on the kind of crop and cultivated vegetables, the production time is inconsistent. Crops can derivate in biowaste like prunings (to be considered as bulking material in composting) or more like grass or other more easily degradable materials. There exisits an residual part of the harvest produced when food is deteriorated or not complying with the standards so it is not put in the markets. Farmers will also get rid of excess of production to maintain market pricing. In that case, it is a managed biowaste with a high content of water and can easily degrade. This high degree of biodegration can present problems if the compost is not treated appropriately by following the same protocols as for household biowaste treatment.

The “quality” of these biowastes consists of:

- Content of non-organic materials: As for any other biowaste it is important to pay attention to all collection tasks, storage, and transportation to avoid the presence of improper materials. The percentage of non-organic materials should be under 1% of the total mass of biowaste.
- Age of the biowaste: For the same reasons explained for the other biowastes, but in this case there are two extreme examples. The surpluses of harvest, especially fruits, should be managed and treated immediately to avoid negative environmental impacts and that these formalities may be used to benefit the biodegradative process. The case of pruning and lignified materials (like straw or plants of other cereals) is completely different due to its degradation being much slower. This enables these materials to be stored after drying and be used as bulking material for composting other biowastes.
- Particle size: the same reasons given in the case of the pruning from parks and gardens.
- Presence of pesticides and other phytosanitary products: These products are normally used in intensive agriculture to prevent or fight pests and illness of the crops. Most of them are thermolabile and will be degraded under intensive conditions of composting, but their presence must be taken into account when managing the compost process. Composting protocols must utilize higher temperatures at longer durations of time will, will be needed to ensure the adequate degradation of these chemical compounds.

  The absence of these products is always highly recommended and agricultural biowastes from ecological farming should be prioritized when composting.

## 1.2. Animal byproducts

On 3rd October 2002, the EU adopted Regulation EC 1774/2002 on animal by-products not intended for human consumption. That regulation entails strict standards regarding animal and public health applicable to the collection, transport, storage, handling, processing and use or disposal of animal by-products. These rules are applicable throughout the EU since May 1st, 2003.

These by-products are those materials that are generated in primary livestock production and processing of food ingredients of animal origin industries, that for commercial or health reasons, do not enter into the food system and therefore need to be managed properly.

There are multiple fates of these products: those who do not represent any kind of risk, once subjected to very severe treatment in specialized companies, may be intended for the manufacture of organic fertilizers, technical products, or in very specific cases, used as food for pet animals. Which entails risks for human health and the environment. This waste must be separated and identified unequivocally, subjected to treatments of transformation to remove health hazards and then subsequently dispose through incineration or co-incineration.

Category 2 material (art. 13.e. Regulation 1069/2009) can be composted or transformed into biogas:

*(i) following processing by pressure sterilisation and permanent marking of the resulting material; or*

*(ii) in the case of manure, digestive tract and its content, milk, milk-based products, colostrum, eggs and egg products which the competent authority does not consider to present a risk for the spread of any serious transmissible disease, following or without prior processing.*

Category 3 material will not require previous treatments or other controls.

This legislation and the transposition in each country must be taken into account if any Animal by-product flow is included in the biowaste management system created in the framework of SCOW project.

# 3-Design of the collection systems

*Source: the contents of this chapter are an adaptation of some parts of the Biowaste Management Guide of the Spanish Environmental Ministry, 2012 (created by BCNecologia; the concerning parts of the guide also counts on the participation of F. Giró).*

## 2.1. Basic aspects to consider

- **Determine the types of waste that can be incorporated into the new collection.**

It has to be defined the **widest possible spectrum of waste required to be managed as source separate Biowaste.** Limiting the types of Biowaste considered suitable (only Vegetable Waste[5], or only raw but not cooked materials[6]) reduces the benefits and potential advantages and does not avoid the need to properly manage the rest of Biowaste remaining in the Residual Fraction.

- **Understand the singular characteristics of Biowaste to properly plan its management**.

The characteristics of Biowaste, and especially its high density and humidity and the generation rate and monthly fluctuations, are of great importance to design the management as they influence relevant aspects such as the capacity of the receptacles (bins, containers) that temporarily store the waste, the collection frequency, the capacity and features of the collection vehicles (non compactor vehicles, usually with low capacity)[7], as well as the treatment plants sizing.

[5] In some countries of northern and central Europe (Germany, Austria, Netherlands, Nordic countries, etc.) the typology of Biowaste demanded is limited to vegetable wastes of parks, gardens and waste of fruit and vegetables, and known as VFG -vegetable, fruit and garden - or as GFT -Groente, Fruit & Tuinafval.
[6] On few occasions the collection is limited to the crude organic waste, rejecting the waste cooked, alluding to the presence of fat or to a higher salt content of this organic waste. Although it is true that the cooked food waste presents a higher content of fats and oils and is characterized by a greater conductivity due to the use of kitchen salt, it does not involve any limitation for its composting or anaerobic digestion and, therefore, that is not a sufficient reason to justify the exclusion of such residues.
[7] Its high density and low compactness involves that the pickup have to be done through not compactor vehicles and normally with low capacity, which could mean savings in the economic investment, operation and maintenance (vehicles with compaction device but in off mode can be also used). The vehicles should be provided with gaskets to ensure that there is no loss of leachates.

**Obtain low level of unsolicited materials for the separate collection of the Biowaste**.

**A goal of values of less than 2% of impurities,** expressed by weight, but always with a recommended threshold of 5%. If the level of improper materials is sufficiently low, the obtaining of high-quality compost and a good functioning of facilities are ensured. For this purpose, the use of compostable bags is highly recommended for citizens and commercial establishments, even mandatory to utilize.

**Differentiate whenever possible leftover food from the green wastes.**

It is recommended that, whenever possible, **decouple the management of the vegetal residues, especially the pruning, from the Biowaste derived from leftovers**, due to the patterns of generation of each material tend to be different, thus pruning is necessary as a bulking material in the composting processes to modify decomposition of surrounding waste. If it is not possible to implement home composting management (which facilitates and cheapens Biowaste management) for the vegetal fraction, or there is a demand of structuring material, specific collection systems can be introduced for green fraction.

**Reservation of necessary storage space and use of vented caddies**

**Reservation of necessary space** inside households (kitchens) to locate the source separation caddies or receptacles, as well as in the building (or other community areas) for the collective container or bins (waste delivery rooms) if the collection is door-to-door (an accessible entrance for the collection service is recommended). The economical activities should also make a reservation of space in their locals to set up the necessary containers or bins (specifically in the kitchens or places where food is manipulated).

**Usage of vented caddies/receptacles** (with the appropriate capacity) for the source separated Biowaste at the point of generation, **combined with compostable bags** that make the storage of Biowaste more comfortable (avoiding odors, lixiviates, etc.) (Puyuelo et al, 2013).


**Figure 4.** Vented caddy and compostable bags (Source: BCNecología, 2011)

## 2.2. Key elements of the collection design [8]

### Intrinsic Constraints

**Additive versus integrated implementation.**

The implementation of the separate collection of any waste fraction of municipal competition, especially for Biowaste, should be done as far as possible from an **integrated logic**. This means to integrate the new separate collection in the configuration of the other flow services, **rethinking the other wastes collections** according to, in the present case, of how they are conditioned or affected by the organic fraction (especially for the Residual Fraction).

**Field, scope, recipients, and implementation date.**

In the framework of municipal waste, the **recipients** are basically: **households and commercial activities** (and other activities like public entities, association, etc). There

[8] Because of its breathability and water vapor permeability, the use of the compostable bags with aerated caddies or small bins involves a reduction of the amount of water in the Biowaste (liquid perspiration in form of water vapor during the storage in the container). This mechanism avoids the appearance and accumulation of leachates and the generation of odors and reduces the weight of the waste that must be transported (more capacity available in the vehicle) and treated in treatment plants (reduction of the management costs and necessary treatment capabilities). All this translates into a clear environmental and economic benefit.

is the possibility of collecting the Biowaste simultaneously or independently or only focusing the collection on one of these origins.

In **areas with high concentration of singular producers**, the implementation of door to door collection with specific routes for big produces should be assessed. If necessary with variable frequency for each generator in accordance with its waste production and a timetable adapted its functioning.

With regard to the **introduction date of Biowaste collection,** normally it seems advisable to avoid summer, since the population living in the municipality may be on vacation and the weather conditions (high temperatures, high relative humidity, etc.) may cause some inconvenience to the Biowaste collection if the service is not consolidated and does not have a normal operation. Except in tourist areas or zones with high presence of second homes where it is interesting to carry out campaigns when the seasonal population is present.

Anyway, the type of municipality and population should be considered to select the **best time to start the implementation,** with the maximum of resident population present that can participate in campaigns and when other local events cannot overshadow the new collection[9].

### Frequency of collection and cleaning, collection capacity, calendar collection, schedules and collection time.

Biowaste requires a high frequency of collection as its nature makes difficult to maintain the material inside homes or on the streets **more than 3-4 days in Mediterranean countries** and especially during summer[10]. For this reason, some municipalities modulate the collection frequency throughout the year, increasing the frequency from mid-May to mid-September. Other factors that can influence the frequency of collection are altitude[11], urban configuration or the type of collection system[12].

[9] It is advised that the implantation takes place during a sufficiently stable political situation and moved away from election periods, in order to avoid the political conditions could have a negative impact.

[10] This assertion would be valid for the majority of countries of the Mediterranean basin, in other latitude regions like central or northern Europe, with lower temperatures, the collection is much more spaced, even with a frequency of 15 days.

[11] Even within the same country, mountainous areas, with lower environmental temperatures, affect the biodegradation process of the organic waste that will be slowed down, so that the appearance of odours is usually exceptional, which allows a reduction of the collection frequency, often compensating the higher collection costs in areas with high population scattered and located far from the treatment centers.

[12] There is the possibility to use vehicles compartmentalized to collect simultaneously two or three fractions but it should be taken into consideration which fractions are chosen and if the frequency and plant transport distances are adequate to optimize the service.

Additionally, **areas of high tourist influx (or second residences) and economic activities density require greater attention** and a service adapted to the needs of the existent typology of biowaste producers and to the seasonal variations, with higher collection frequencies in some periods of the year (or weekends).

The most common number of weekly services according to the type of collection system [13] is the following:

| | With container | Door to Door |
|---|---|---|
| Biowaste | 3-7 times / week | (2) 3-4 times / week |
| Residual fraction | 3-7 times / week | 1-2 times / week (even fortnightly) |

**Door-to-door system** requires the establishment of a **weekly timetable for the collection,** which determinates the days to deliver and collect each of the different fractions. On some occasions, in the case of large municipalities, different calendars for the several neighborhoods or districts can be established. See some examples in the 2.3 chapter.

In regard to the **pick-up time, there are basically three possibilities:**

- Nighttime Collection (the specific horary interval may vary in each county).
- Daytime Collection (the specific horary interval may vary in each county).
- Special timetables for the singular or big producers adapted to the functioning of the activities.

In parallel, it is also important to consider the frequency of cleaning of the containers that could be graduated in intensity in periods with higher temperatures. It has to be considered both the external cleanings (for aesthetic reasons) and, above all, the internal cleanings (for hygienic-sanitary reasons). During the winter the cleaning of the containers takes place monthly and in the summer often increases to fortnightly.

If the Biowaste is deposited directly in the container or caddy without any type of bag or if bags are broken, the service or the owner of the recipient (depending on the distribution of that responsibility, which is transferred to the users in door to door schemes) has to be sure the container regularly meets the necessary safety measures.

[13] For pneumatic systems the collection frequency is usually daily, depending on the number of emptyings in each drain program established for each group mailbox or on the use of filling sensor system to automatically activate the suction in a section of the network. For subterranean containers the number of services could be lower than for surface ones if they have higher capacity and also because odor problems seems to decrease.

### Modalities of collection service provision and service management.

The provision of the service can be developed basically using three different modalities: **direct management** (local authority), **indirect management** (private company concessionaire) and **joint management.** Each one of them has advantages and disadvantages. There is also the possibility of management by a supra-municipal entity, applying economies of scale if needed, especially for small municipalities.

The management of Biowaste must be done in terms of and **economic, social and environmental efficiency and viability.** The appropriate definition of the contracts and services, its monitoring and control and the definition and application of indicators allow the establishment of an adequate and of **quality service with good results, as well as the development of an objectively, continuous and comparative assessment of the achieved results.**

The final objectives of this new definition of the contracts and services are the following: reach a joint responsibility of all the involved stakeholders, especially involving the contractor; maximize coordination council-contractor, obtain a maximum responsibility and self-sufficiency of the collection company (results, quality and incidences), have more flexible service adapted to changes, and finally, get an excellent level of the service and results.

### Complementation with other instruments apart from the technical ones.

The concept of management of municipal competition waste, especially in the case of Biowaste, **goes beyond the technical tools** (design and development of the collection) and treatment infrastructures. Therefore it is necessary to address and deploy other complementary instruments to ensure a proper separate collection and plants management, such as **instruments of environmental education and communication, economical and fiscal, and control and monitoring of the model.** All these instruments, essential to achieve successful management systems, have to be designed to form a puzzle where all the pieces are linked and which allows synergies to lead all the involved agents towards the desired scenario and outcomes.

## Extrinsic constraints

**Demographic, socioeconomic and urban factors.**

In order to choose and dimension the collection service it is **essential to know the characteristics of the target population and zone:**

- Number of inhabitants - by facto and law-,
- Familial aggregation,
- Number of households (primary residences) and associated population.
- Number of second residences and associated population. Patterns of usage.
- Number of buildings and number of households per building (identification of the buildings that could need community bins for DtD schemes).
- Location of the households and the second residences. Number and type of housing (vertical or horizontal typology of building).
- Presence of urbanizations, isolated houses, etc.
- Socio-economic parameters like incomes[14], employment rate, level of education, labor mobility, etc.
  - Commercial activities or other type of activities considered as singular or big producers - private or public – that need the provision of municipal collection:
    - Number of establishments and typology of economic sector.
    - Dimensions or capacity for hotel, B&B, campsites, etc. and restaurants, bars, etc.
    - Pattern of influx associated to tourism. Seasonality and population flows that have an important impact in the design of the service and also requires its variation along de year.
    - Location of establishments.
- Mobility aspects related to the characteristics of the streets: driveway and wax width and car parks, slopes, turns, directions, etc. Distance to the treatment facilities.
- Existent collection systems, available material and personal means.

[14] There is a clear relationship between the level of income, the patterns of consumption and waste generation.

It is also advisable to know the **environmental variables, especially geographical:** centrality and positioning of the municipality in relation to other municipalities from a particular geographical area, distances to the treatment facilities[15] of the different waste streams; which are necessary to consider the possibility of establishing certain synergies [16] or not.

## 2.3. Types of collection systems

Due to the characteristics and importance of Biowaste within the management model, its collection can be performed using different systems, always fulfilling specific requirements to ensure an efficient operation and good results (regarding quality and quantity).

It should be noted that **it is not true that each system must be exclusively associated to a particular urban configuration. Anyway, it is possible that in the same municipality different collection schemes coexist in distinct areas.**

In a synthetic way it can be found basically the following collection systems:

### Door-to-door systems

This is a system widely used in Europe which consists **of the delivery of waste (residential or commercial, selective or mixed) by the generator at each door, portal**, inner courtyard or other accessible areas of the building or housing in accordance with a predetermined calendar (normally weekly) that indicates which fraction/s are demanded each day. The waste may be delivered by means of bags, buckets/caddies with small dimensions or bins/containers (as well as in bulk, in boxes or bales) depending on the type and amount of waste generated and the storage time. The operator of the service carries out the pick-up service door-to-door, so it is feasible to apply a minimum control and follow-up, both the user's participation and the quality of the residue

[15] If the facilities incorporate several waste management options (for example, landfill and biological treatment plant or MBT with two lines) can be interesting a simultaneously collection of Residual Fraction and Biowaste in order to optimize the time and cost of the collection.

[16] The synergies can be set at two levels: depending on whether the collection is individualized (single municipality) or joint (more than one municipality sharing the services), and depending on whether there is a mono-recollection (most common), or a simultaneously collected for more than one fraction (typically for 2 or even 3 fractions in the same route).

delivered. Obviously, **this system is much closer to the citizens, although it involves certain obligation** to perform a separation at source for all the fractions, not doing so may complicate the collection process.

Through a door-to-door model is possible to develop the collection of **all the waste fractions of domestic and/or commercial origin, or the collection of some selected fractions, which contain both** Biowaste and Residual fraction, maintaining the previous system (usually containers) for the rest of flows[17].

The implementation of door-to-door systems **allows the service to identify each producer.** This identification process enables the application of more equitable service taxes, like the payment systems by waste generation (for example, payment per bag or bin).

The implementation of the door-to-door collection can be **easier in areas with low population density[18] but it is also possible in large cities** [19] and in high density areas. Higher populated areas will require special adaptations to these contexts (in many cases through community collection in bins or containers for multi-family housing).

The **selective collection results** in the municipalities that have implemented door-to-door systems, in general, **are much higher than the rest of the systems**, with regard to both the amount collected as well as the quality of the separation (in general they are between 60% and 80% of separate collection), so this goes in favor of the Biowaste collection necessities.

[17] The glass-packaging is the single fraction that is often maintained in containers system. In many cases emergency containers in strategic points of the municipality are introduced to facilitate the delivery of waste in specific cases when it is not possible the use of the DtD service.

[18] In areas with extreme dispersion (or isolated houses) this system would not be the most feasible, being the container collection in transit points and the home composting the most efficient solutions.

[19] There are several experiences of door-to-door collection in big cities. In Europe can be found many references especially in Italy where this system is having a proliferation up in recent years: Salerno with 150,000 inhabitants, Turin with 1,000,000 inhabitants -60% population-, Naples with 1,000,000 inhabitants -100% population, which is scheduled at the end of the 2012-, Milan with 1,200,000 inhabitants -30% in the present and expected 100% population in the early 2014-

(a) Biowaste and paper-cardboard DtD Collection in the municipality of Verdú-Catalonia (1,200 inhabitants).

(b) Light packaging DtD collection on a street with terraced houses in Verdú-Catalonia (1,200 inhabitants).

(c) Commercial biowaste DtD collection with specific bins for big producers for a fruit/vegetable store in Barcelona -Catalonia

(d) Biowaste DtD Collection in the municipality of Hernani-Basque Country (19,300 inhabitants).

(e) Biowaste of very high quality collection in compostable bag or in bulk from Hernani-Basque Country (19,300 inhabitants).

(f) Emergency Area in the municipality of Seva-Catalonia (3,400 inhabitants) complementing the DtD service.


(g) Biowaste DtD Collection in the municipality of Canet de Mar-Catalonia (14,183 inhabitants)

(h) Biowaste DtD Collection in the municipality of Canet de Mar-Catalonia (14,183 inhabitants)

(i) Commercial biowaste DtD Collection in the municipality of Barcelona-Catalonia

**Figure 5.** Selective Collection by door-to-door systems (Source: Giró and BCNecologia, 2009-2012)

The following points describe the elements to consider in the design and implementation of DtD systems that should be adapted to the specific needs and context of each territory:

- Determining the **producers and the related fractions that will be collected by DtD** apart from the Biowaste: which domestic and/or commercial producers and which kind of selective flows that at least should be

Biowaste and Residual fraction. In any case, the best option is to collect by DtD the five main fractions to achieve the highest results[20].

- Determining the **weekly timetable for the collection** of the biowaste and the other fractions of the DtD scheme, which defines the days to deliver and collect each of the different fractions[21]. To establish this timetable should be taken into account the following elements: inhabitants patters of waste production and delivery during the week, second residences and tourisms influx contributions (specially at the weekends), special needs of the economical activities (additional days of collection), possible frequency increasing in summer or periods of tourism presence, optimize the materials and personnel means during the week and for all the flows, possibility to collect several fractions in the same day (including the use of compartmented vehicles), nighttime or daytime services according to the traffic constrains, more expensive cost of service for weekend, etc.



[20] The glass-packaging is the single fraction that is often maintained in containers system.

[21] On some occasions, in the case of large municipalities, different calendars for the several neighborhoods or districts can be established.


**Figure 6.** Examples of calendar collection door-to-door in the municipality of (Source: F. Giró- Municipality of Verdú, Municipality of Sant Antoni de Vilamajor (Catalonia) and Municipality of Esporles 2012 (Mallorca), Municipality of Ornago (Italy)).

- All households must be provided with **small caddies for the separation at source of the biowaste (better aerated and with compostable bags as was mentioned).** The receptacles for the kitchen can be the same as the ones that users place in front of their doors, but there is also the possibility to distribute additional caddies (no aerated) especially for waste delivery (usually of 20l) of the single-family homes. Each delivery receptacle needs the identification of the owner/household (by means of a mark, sticker, transponder chip or tag -metallic sticker with bar code-, the last two ones in case of using an identification system on the collection vehicles). The biowaste can be provided in bulk (it is advisable to use kitchen paper) or in compostable bags (certified).[22]


**Figure 7.** Receptacles and other complementary materials for single-family homes in DtD (Source: Spora, 2014)

22 Other fractions can be delivered by means of caddies or bags (any kind of plastic bag or homologated one), specially paper can be provided in bulk and glass usually using caddie because of the possibility of brokenness. The DtD schemes can require to complement the collection of the residual fraction with extra services for separate delivery of nappies (normally in a specific receptacle on the vehicles of other flow routes).

- For **multi-family dwellings,** there exist different options to store and deliver biowaste after it has been separated within each home. By means of collective **two-wheel containers or bins** (installed capacity: average of 10-20l per family in the building) that can be storage in community spaces or waste storage rooms (internal o external) and placed at the point of collection on the street by doormen, designed neighbors or specific building cleaning companies (and collected back once they are emptied). If accessible storage areas/rooms are established, the same collection operators can enter and transport the bins. To avoid the management of the community bins, there are other solutions such as the delivery of the single caddies on the floor grouped in a specific place (if the quantity and urban configuration permit it) or the installation of hangers (also identified with the owner) on facades or sticks on the public way.





Pict. a: Barcode sticker attached to waste bin    Pict. b: Transponder chip and its location on a waste bin

**Figure 8.** Receptacles and other complementary elements for multi-family buildings in DtD (Source: Spora, 2014)

- For **commercial activities** and other singular or large
- producers, the DtD system requires the usage of single bins or caddies (or even for wheels containers) of different volumes depending on their waste generation (with or without composting bags) as was mentioned. In the same way presented for the household, these receptacles have to include any of the above listed types of identification systems. The producers place the receptacles on the street at the established point and timetable and take them inside again when they are emptied.
- In many cases, **emergency containers** at strategic points of the municipality are introduced to facilitate the delivery of waste in particular situations when the DtD service is unavailable. The tendency is to implement the minimum quantity of these points to avoid the possible misuse and many people accessing them. For this reason, many of these areas are equipped with identification system to permit the entrance, or the same recycling centers (with staff control) carry out this kind of service.

Commercial biowaste DtD Collection in the municipality of Barcelona-Catalonia

Emergency Area in the municipality of Seva-Catalonia (3,400 inhabitants) complementing the DtD service.

**Figure 9.** DtD commercial collection and emergency areas (Source: Giró and BCNecologia, 2009-2012)

- **Operators collect the receptacles** (or the bags that go inside them), throw the biowaste into the vehicle, and then place them in the point of departure. During this process **checking if the biowaste** contained is the demanded fraction and the separation at source is done properly is essential (low quantity of impurities). If these two requirements are not accomplished, the operators leave the biowaste at the point of delivery and **add a warning** (usually by a sticker) for the producer that includes advices to improve the performance. The vehicles equipped with **incidences buttons/panel** to record all of the problems registered during the route, are a very useful mechanism to control the functioning and user participation.
- The **vehicles** for biowaste collection **do not have to be compactors,** and depending on the collected amounts can be of small dimensions. To facilitate the emptying of the caddies or thrown of bags, many times the truck carry hooked a receptacle where to first dump the biowaste and then download its content into the truck box or is provided with lateral doors/overtures to facilitated the bags introduction. On the streets that are not accessible by the vehicle, the **operators go walking** to collect the biowaste usually with the help of a wheeled receptacle or carrycot. Additionally, in this case there is also a **point of wastes deposition** a little farther from the house doors can be establish to permit the arrival of the vehicle or the workers. It is important to establish a transfer system, especially when small trucks are used and facilities are far away, to reduce the transportation needs optimizing the service.

  The trucks must also incorporate a receptacle or specific mechanism to collect nappies and sanitary textiles as normally this residual fraction is allowed to be delivered almost all or all days of the week.

## Delivery systems

This is the most widely used system and is based on the **delivery of the waste (residential or commercial, selective or mixed) by the generator to any of the systems available for the reception on the street -segregated or not-,** usually containers or bins on the surface or underground. It can be differentiated between "Areas of sidewalk" (when the location of the containers is relatively nearby[23]) and "Areas of contribution" (when the location of the containers is quite more distant[24]).

### a) Containers on the surface

The collection through **containers on the surface located on the sidewalk or the street pavement,** as its name indicates, consists of the collocation of containers of different types, volumes and characteristics depending on the demanded waste and other urban characteristics (lateral load, rear load, top -igloo, bilateral- load, etc.). The containers are **collected periodically in accordance with the frequencies of drain,** which are defined conforming to the characteristics of the generation of each type of waste and the capacity installed.

Usually, Biowaste tends to be collected in two-wheel containers (90, 120, 240 or 360 litres); although there are some areas with four-wheel containers (400, 660 or 770 litres) with dimensioned overcover, but in some cases, containers of bigger size are implemented. The most common setup is the collocation of Biowaste and Residual fraction in the same point (areas of sidewalk) and, glass, paper and cardboard and lightweight packaging on other farther delivery points (areas of contribution). Other increasing option is to implement complete batteries for the five main factions together.

For this type of system, different configurations may be applied to develop the collection, but the **essential idea is to put the delivery of selective fractions on an equal footing of distance and comfort (especially Biowaste) in relation with Residual fraction.**

[23] The containers are located approximately 50 meters from the producers. This system is commonly used for Residual Fraction and Biowaste, in some cases also includes lightweight packaging.

[24] Conformed by containers usually for selective collection (glass, paper-cardboard, lightweight packaging), with a radius of coverage of between 100 and 300 meters, which means more effort for users to reach the points.

Regularly the collections of Biowaste in containers are carried out by not compactors collection vehicles with rear, lateral, or bilateral load depending on the type of container used[25].

One of the **critical points that presents the collection through open containers on the public highway,** is the quality of the Biowaste. The presence of impurities, or by the presence of woody green waste (such as branches, trunks, etc.) influences the level of quality of biowaste composition. To avoid these problems, in addition to the correct setup of the groups of containers and to develop appropriate communication campaigns, there are **different solutions that have shown good results:**

- **Use input holes dimensioned or small overcaps** (and if it is necessary the delivery of commercial large bags, combined with big cover including key for commercial users): to hinder the delivery of other fraction bags/other materials that are generally bigger.
- **Use of biodegradable bags**: promoting bags in communication campaigns, free distribution or applying grant mechanisms to offer lower prices than the market, promoting distribution points in shops, introducing an obligation for it use, etc. [26]
- **Use a variant of the containers system, consisting of the implementation of locked containers** and facilitation of an access key/card to those citizens who voluntarily participate in the collection. The quality of the delivered material is generally high, but through low participation; consequently the collected quantity is not very prominent.

(a) Containers for Biowaste and Residual fraction (bilateral load collection) in Barcelona (1,500,000 inhabitants).

(b) Containers for Biowaste, Residual waste glass, paper-cardboard and lightweight packaging (side load collection) in Barcelona.

(c) Bins for Biowaste (240 liters, rear load collection) and Residual waste (side load collection) in Mollet del Vallès-Catalonia (52,400 inhabitants).

[25] The vehicle use to be for mono-material pick up, but also there is the possibility of bi-material, in which case it would be a bi-compartmented vehicle, designed to carry out simultaneous uploads and clearly differentiated from the two fractions (with different receptacles).

[26] Many municipalities carry out bulk purchases of bags that are sold at cost price in local establishments or can be picked up by the citizens at the city hall or other municipal entities.


(d) Containers for Biowaste (770L rear load collection) with sized small over-cover in Mataró-Catalonia (124,084 inhabitants).

(e) Bins for Biowaste (240 liters, rear load collection) and Residual waste (side load collection) in Prat de Llobregat-Catalonia (63,505 inhabitants).

(f) Container for Biowaste (1,100 liters, rear load collection) and Residual waste in Galicia.

(g) Locked containers for Biowaste with access key in Donosti-Basque County (183,190 inhabitants).

**Figure 10.** Selective Collection by containers on the street (Source: Giró and BCNecologia, 2009-2012)

The following points describe the elements to consider in the design and implementation of containers systems that should be adapted to the specific needs and context of each territory:

- Determining the most **appropriate types, volumes and characteristics of the containers** depending on the generation and urban characteristics (lateral load, rear load, bilateral- load, etc) and the type of cover or dimensioned overcover to guarantee the quality of the biowaste (remember that in case this system is combined with low tech facilities the impurities should be limited to 2%, this constrain can be challenging when open road containers are used).
- Determining **the containers location on the streets** according to the inhabitants and economical activity density, always facilitating the access and reducing the distance for the uses.

- Establishing the most **suitable collection frequencies,** conforming to the containers installed capacity and the patterns of generation (taking also into consideration the needs in the summer). Taking into account the possible reduction of the frequency for Residual waste in case the capture of recyclables and biowaste is inadequate.
- Selecting the most appropriate and efficient vehicles using non compactors equipment depending on the generation, the type of containers used and the urban configuration[27.] This should be considered the need of a transfer system.
- The collection of the commercial biowaste can be carried out in the same street container for households, but in the case of big producers there is the possibility to implement specific door-to-door collection services that could be developed independently of the household container route or in the same circuit, always thinking about designing an optimized model.

### b) Containers underground

**Buried separate collection containers consist of placing the containers in the underground and the only parts on the surface are the delivery box** through which the waste is deposited and the cover to be opened to raise the inner receptacle. The installation of underground containers involves performing civil works in public road.
**This system could be applied to collect Biowastes but it should be taken into consideration the following weaknesses** related to the Biowaste management needs: usually large capacity receptacles and spaced pick up frequencies, longer time to load and unload the containers, more distance of the collection points to the users, frequent problems with blocked delivery boxes and residues left on their side, not flexible modality once it is implanted, more cost of investment and maintenance, etc.
For all the above mentioned, this model is not recommended when a low tech facility is part of the management model.

[27] The vehicle usually is for mono-material pick up, but also there is the possibility of bi-material, in which case it would be a bi-compartmented vehicle, designed to carry out simultaneous uploads and clearly differentiated from the two fractions (with different receptacles).

**Figure 11.-** Selective Collection by underground containers (Source: Giró and BCNecologia, 2012)

| | | |
|---|---|---|
| (a) Underground containers system with hydraulic elevation platforms. | (b)Underground containers island with hidraylic cover opening and collection of the inner receptacle. | (c) Collection of buried container with integrated delivery box. |

**Figure 11.** Selective Collection by underground containers (Source: Giró and BCNecologia, 2012)

## Pneumatic systems

**Pneumatic collection system consists of a series of drop boxes connected via underground conduits to a suction point.** The collection cycle begins when residues are deposited in the drop boxes, which can be found both inside the households (in a minority of cases) and at community areas inside the buildings or outdoor in public areas (in the majority of occasions, whether on streets, island interiors or facades). There are two different modalities: **mobile systems** (small networks with suction points to connect a collection vehicle) and **static system** (larger network with suction and storage central where waste is periodically transported from each drop box to subsequently be transferred with vehicles to the treatment plant).

**This system could be applied to collect Biowastes but it should be taken into consideration the following weaknesses** related to the Biowaste management needs: limitation for the use of compostable bags, existent experiences show that the selective collection is not high neither in quantity nor in quality, important energy consumption and consequently emissions at the point of electricity production, not flexible system once it is implanted, blocked delivery boxes and residues left on their side because of its design, etc.

| (a)Mobile pneumatic system | (b)Delivery boxes of a pneumatic network | (c)Suction and storage central |
|---|---|---|

**Figure 12.** Selective Collection by pneumatic systems (Source: Giró and BCNecologia, 2012)

For all the above mentioned, this model is not recommended when a low tech facility is part of the management model.

## Vegetable fraction collection

**It is recommended, as previous remarked, whenever possible, to separate the vegetable fraction management, especially for the woody materials, from Bio-waste** circuit because the patterns of generation and treatment tend to be different for both of them as it was mentioned above[28].

As well, for this type of green waste, both generated in the private sphere and by municipal services, there are several and interesting options, always with the basic premise that the best solution is to promote whenever possible self-management.

- **Home composting** of green wastes exclusively: individual or collective.
- **Self-crushing of pruning** (own, shared or municipal machine) **and use it as own bulking material for home composting** (individual or community), or as **vegetal padded** (also called mulch; own use by households or municipal services).
- **Composting of municipal green wastes** through on-site composting modules, open piles or windrows or accumulation in open spaces (sometimes by uncontrolled process).

[28] If the vegetable fraction (especially the pruning) does not present a differentiated management from the Biowaste, it can cause problems of absorption in containers and vehicles, overflows of containers and related review services, requirement of bulky materials pre-selection and greater wear of equipment in the plants. There are also other forms of improper management, like practices of burning or delivery to incinerators and landfills, with the environmental impacts generated in these processes.

**When those mechanisms are not feasible or woody fraction is needed to cover the demand of bulking material**[29] for home composting or for those models with separate Biowaste collection and treatment in biological facilities, the residue can be collected using different systems and properly treated[30]:

- **Door-to-door collection** (through on demand services and, in the door-to-door models, on the same collection days for Biowaste or specific stipulated days). In many occasions homologated sacks are used for the collection which also permits the control of volume contributed to the system. On demand services could be made jointly with on demand collection for bulky fraction.
- **Concerted points without container** (usually in bundles) on stipulated days (in many cases it is advisable to deposit it on the side of containers areas or at specifically enabled points). The possible misuse of this system should be considered.
- **High-capacity containers** located at strategic points (either permanently or coinciding with the pruning periods, especially for the bulky green materials). The possible misuse of this system should be considered.[31]
- **Recycling center/clean points** (where there are high-volume containers for its storage).

Its high density and low compactness involves that the pickup have to be done through not compactor vehicles and normally with low capacity, which could mean a savings in the economic investment, operation and maintenance (can be used vehicles with compaction device but in off mode). Vehicles must also be equipped with gaskets to ensure that there is no loss of leachates.

[29] Or other demands of mulch impossible to cover by the pruning generated in the same place.
[30] Woody materials have to be previously shredded in situ -preferred to optimize transport and costs- and then distributed to the users or biological treatment facilities as bulking material. The non woody fraction should also be sent to green waste or/and Biowaste treatment facilities.
[31] There is a significant risk for the container to be filled with other bulky wastes.

(a)VF collection in large dimensions container in Sant Quirze del Vallès-Catalonia.

(b)Problems with the delivery of FV in the containers for Biowaste.

(c)Collection of vegetable waste in a container located in a Recycling center

(d)Door-to-door collection of FV with big homologated sacks.

(e)Pruning of trees followed by crushing machine and loaded onto a truck in London,

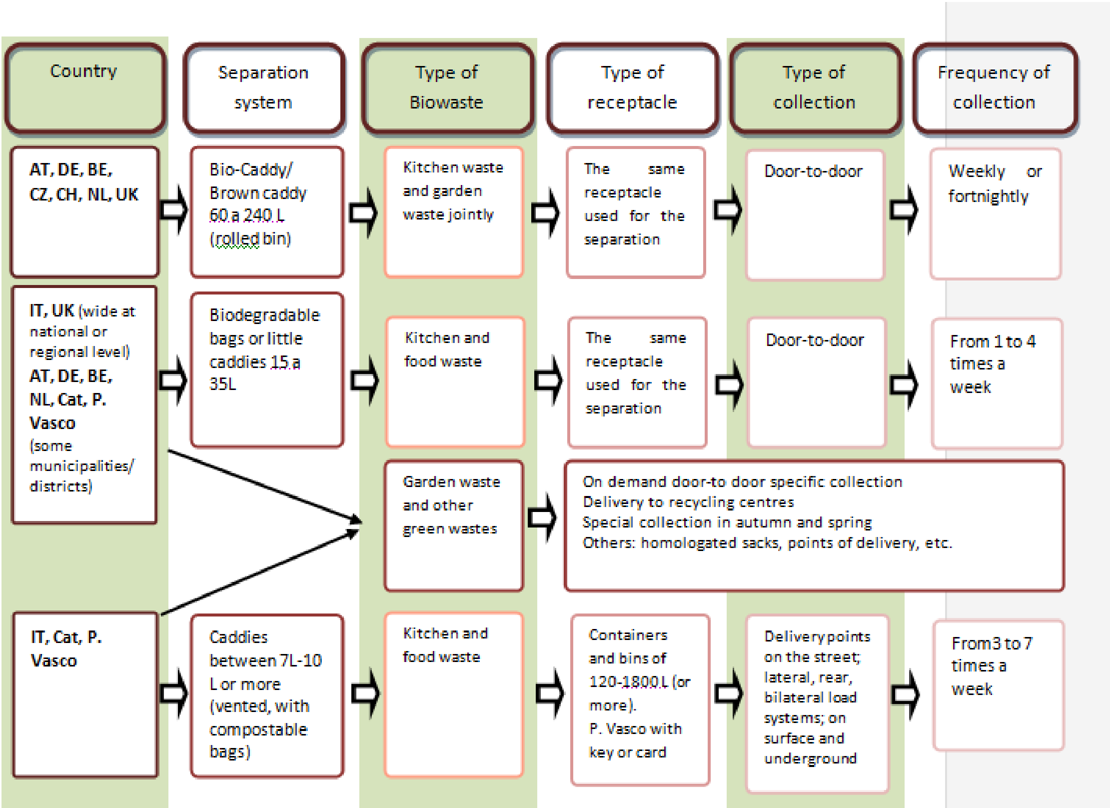
(f)Use of the crushed FV as mulch in the gardens of Barcelona.

(g)FV collection in a public park of the municipality of Arenys de Munt, later on, it is shredded and composted, and the compost for park's own usage.

(h)Home composting in a private house with orchard and garden.

**Figure 13.** Selective Collection of the vegetal fraction (Source: Giró and BCNecologia, 2012)

## Examples of different collection schemes in EU




Cat=Catalonia (ES), P. Vasco=Basque Country (ES)

**Figure 14.** Main characteristics of the collection systems in different EU countries (Source: Adaptation from Amlinger, 2012)

## 2.4.Other general elements of the design of the pick-up service

A **good design of the technical tools of the collection system is the base for obtaining good results,** especially for the Biowaste due to its characteristics and the objective of reaching a good quality material.

- **Usability:** the collection system (especially for the collection in containers and delivery boxes) should be comfortable and designed for all types of public (dimensions and height of the opening, kind of overture, security systems, etc.).
- **Clarity of information** (identifiability): the colours, shape and labels of the container/bins/caddies or bags/liners are very important for the users to easily identify each demanded fraction.
- **Ease of collection:** the implanted system must have a minimum or optimal time of collection to reduce the costs of the service and to avoid traffic problems, especially if the circuit is diurnal.
- **Flexibility to adapt to the continuous changes of the city**: the used vehicles must be able to collect different types of containers and volumes, especially in the case of co-existence of different systems or variations. The chosen type of collection system must be the most appropriate according to the characteristics of each urban configuration. Static systems should be avoided whenever possible because of their observed limitations for future changing requirements.
- **Impact of the collection system on the public space and population:** measures have to be taken to minimize these types of impacts: smells, noise, visual impact, dirtiness, impact on the mobility, opportunity cost of public space, etc.
- **Image of the service**: the image perceived by the users must be positive in order to encourage participation in the separate collection (in terms of containers and trucks proper cleaning and maintenance, provided information, staff behavior and appearance, avoiding overflows, appropriate destination of the waste, solution of containers location incidences, etc.).

## 2.5. Logistics of the collection and service optimization

The logistical aspects associated with the collection and transportation of the waste are very important and **greatly affect the cost and impacts of waste management.** A logical definition of the collection and the optimization mechanisms of the service are essential for obtaining good management results, also in environmental and economic terms. Some of the elements that should be taken into consideration are the following:

- **Usage of compostable bags with aerated caddies** or small bins involves a reduction of the amount of water in the Biowaste (there is liquid perspiration in form of water vapor during the storage in the container[32]). This mechanism avoids the appearance and accumulation of leachates and odors, as well as reduces the weight of the waste that must be transported (more capacity available in the vehicle) and treated in facilities (reducing the management costs and necessary treatment capacities). That is translated into a clear environmental and economic benefit[33].
- **Usage of bi-compartmentalized trucks** (vertical or horizontal division) for simultaneous collection with another fraction (or even tri- compartmentalized).
- **Implementation of shared circuits for the household and commercial wastes** (in case they are optimal and feasible, including the modality where the establishments have their individual containers or bins).
- **Optimization of the routes and frequencies depending on the real needs of each area**. The new Biowaste service should be designed not additively, but integrated (especially rethinking the Residual fraction collection). It is essential to study the itineraries to minimize the routes and number of trips to the facilities and carry out comparatives of the energy and emissions balances.

[32] As it allows the passage of air induces a reduction of the mass of the Biowaste, because it favours the start of the degradative process to give the appropriate conditions (air and moisture) and transpiration bag favours thee vaporation of water, producing a total of up to 5% mass loss in 3 - 4 days (Puyuelo et al, 2013).

[33] The value of the weight reduction achieved basically depends on the typology of Biowaste, the frequency of waste delivery (receptacle emptying), the geometry of the perforated caddy, if it is covered or not, its location (inside a cabinet, above the kitchen tile, on the balcony, etc.), the temperature and humidity, as well as the air stream inside or outside the house (which the container is subjected to). There is evidence that a collection frequency of three times a week (approximately every 56 h), typical for door to door systems, implies an average weight loss of 4.3%. For containers systems, if an average delivery frequency of every 36h is assumed, the weight loss would be located at 3.3%. Source: Association of Municipalities Catalans per a selective Recollida porta a porta, 2010. Impactes de l'ús of bossa gestió compostable in the FORM.

- **Usage of trucks with appropriate capacities for the collected quantities and less-polluting fuels** (biodiesel, natural gas, hybrid or electric vehicles, etc.).
- **Introduction of transfer systems**[34] between trucks[35] or by means of transfer stations[36], to minimize de transport costs to the treatment facilities.
- **Replacement of the conventional collection vehicles by horse-drawn (or other pack animals) equipment,** as more economic and ecological option, especially for the door-to-door collection[37].
- **In cases of population dispersion, Biowaste collection service can be substitute by home composting systems,** individual or community modalities.

(a)Collection truck with three separate compartments inside, lateral load.


(b)Mono-material collection truck of 7 m3, used for door-to-door collection of several selective fractions (including Biowaste) and the Residual fraction.

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[34] It is advisable above 30 km and essential for more than 50 km of distance. It is strongly recommended not to submit the Biowaste to compaction. Given its high density, the compaction would not reduce the volume and would generate, unnecessarily, a large amount of leachates.

[35] Direct Transfer: a "satellite" vehicle for collecting downloads its content inside of another vehicle of rear load and higher capacity.

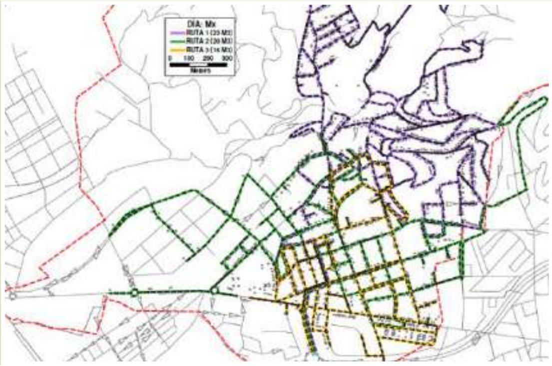
[36] Different modalities: a) Transfer Point: a rear load vehicle discharges, in a pier, directly to an open container or box of 20 to 30 $m^3$. b) Transfer Area: waste download directly to the ground and a shovel loads the residue in an open container or box of 20 to 30 $m^3$. c) Transfer Plant: unloading of the vehicle directly to transfer hopper which feeds a compactor container.

[37] A few years ago, through continuing increase in the price of fuel, more than sixty companies and municipalities in the south of France started to use this system. According to the association Equiterra [www.equiterra.fr], a French association that promotes the use of the energy of the horses in the territory, both urban and rural, the replacement of a waste pick-up trucks by a vehicles pulled by horse (horse-drawn) can reduce CO2 emissions by 35 %, with a cost of investment and maintenance (food in place of fossil fuel) lower than motorized vehicles and with a longer lifetime (15 years compared to the usual 8 years of vehicles). In addition, horses do not pollute and cause noise, which still makes them more attractive options.

(c)Collection truck with two separate compartments inside, lateral and rear load.

(d)Bi-compartmentalized truck for Biowaste (30 % of capacity) and Residual Fraction (70 % of capacity), rear view

(f)Horse-drawn vehicles to collect door-to-door.



(g)Analysis and optimization of the circuits of door-to-door collection through the program Transcad(R).

**Figure 15.** Vehicles for waste collection and route optimisation study (Source: Giró and BCNecologia, 2012)

## 2.6 Other instruments for Biowaste management

The concept of management of municipal competition waste, especially in the case of Biowaste, **goes beyond the technical tools** (design and development of the collection) and treatment infrastructures. Therefore it is necessary to **address and deploy other complementary instruments to ensure a proper separate collection and plants management**, such as instruments of environmental **education and communication, economical and fiscal, and control and monitoring of the model.** All these instruments, essential to achieve successful management systems, have to be designed to form a puzzle **where all the pieces are linked** and which allows synergies to lead all the involved agents towards the desired scenario and outcomes.

## Education and communication instruments

Developing **communication channels and participation and information activities** (like campaigns, conferences, expositions, advertisement, communication material edition, etc.), will allow citizens and other agents involved in the management to know the best practices to be applied, how to develop them, why to apply them, as well as the result of their actions finally promoting their behaviour change.

There are **other communication actions that must be continuous** from the beginning of the service such as containers and vehicles labeling, periodic publication of the results, attendance service for incidents and doubts, among others.

## Economic and fiscal instruments

a) **Taxes on final treatment**: taxes on landfill and incineration expensive in relative terms these treatments, with the consequent promotion of prevention and recycling. Generation of financial resources will be used to fund waste policies, both in prevention and collection and treatment of certain fractions (for instance, by means of directional grants or tax return system for concrete positive management results or activities like quantity of collected Biowaste, level of impurities, use of compostable bags, home composting programs, etc).

b) **Collection and management taxes:** these are the most important instruments at local level. The environmental interest of taxes is because they can potentially encourage taxpayers to change their behaviours (for instance, to separate or composting waste at homes) if they are properly designed.

   For incentives focused on Biowaste separation, residual fraction should be taxed using by generation payment systems like the payment per collected weight or volume (knowing the production of each taxpayer usually by means of door-to-door collection -payment per bag or bin or trucks with weight devices for receptacles- or containers with identification systems -identification cards for the users-).

   Additionally, regarding local collections taxes, there is the possibility to include bonuses for concrete positive activities, such as home composting, material contribution to the recycling points, etc. or even penalties in case the user is not following the rules of the door-to-door schemes when collection staff identifies a waste delivery with impurities or incorrect fraction.

c) **Bonus- penalization systems**: consist of penalizing municipalities or agents with lower waste management results compared to the average, while bonus those with management results over the mid-range.

d) **Variable fee entrance according to the quality of Biowaste**: introducing a variable entrance fee for composting plants depending on the quality of the incoming waste, according to the percentage of impurities.

e) **Permits for disposal or incineration**: this proposal is inspired by the UK system of Landfill Allowances Trading Scheme (LATS) and consists of the allocation to Local Authorities of annual permits for the landfill of certain amounts of biodegradable wastes (if they do not use a part of their permitted range they could trade with it).

f) **Grants awarding:** mechanism available for governments to promote concrete positive or desirable activities and results, for example to implement or improve Biowaste separate collection, proper management of vegetable fraction or home composting.

## Management and monitoring of the collection contracts and services

**The management of Biowaste must be done in terms of economic, social and environmental efficiency and viability.** The appropriate **definition of the contracts and services, its monitoring and control** and the definition and application of indicators allow the establishment of an adequate and of quality service with good results, as well as the development of an objectively, continuous and comparative assessment of the achieved results.

The final objectives of this new definition of the contracts and services are the following: **reaching a joint responsibility of all the involved stakeholders,** specially involving the contractor; maximizing coordination council-contractor, obtaining a maximum responsibility and self-sufficiency of the collection company (results, quality and incidences), having more flexible service adapted to changes, and finally, getting an excellent level of the service and results.

To reach these objectives, it is necessary to include in the tenders and contract documents with the concessionaries, the elements listed below that must be implemented during the contract validity period:

- **Specific objectives to be achieved** (in this case, separate collection, impurities levels) **and clear definition of the services and quality in the public tender.**
- Creation of **systems of information management**, to improve coordination between the Council- collection company (new Information and Communication Technologies (ICT) can play an interesting role in this respect).
- Usage of **certified traceability** (routes and container network) and **weighing systems.**
- **Incorporation of control and monitoring systems** of the target service, for example, with an external control service[38].
- **Remuneration to the company in terms of really developed service and its quality**, and according to the fulfillment of objectives[39.] Clear remuneration request forms, including details of the services provided and any discount or extra service.
- Possibility to carry out **external audits** of the service.
- Development of **continuous improvement programs.**
- Development of periodic **population surveys** to assess the level of satisfaction and the expectations and needs. It can also be included other forms of citizen participation and evaluation.
- Incorporation of **citizen attendance service** ran by the collection company in collaboration with the Council.
- Design and conduction of staff and environmental educators **training plan**.

[38] The control and monitoring system is based on the monitoring of the collection team presence and configuration and the analysis of performance and service results (according to protocols of the service execution). Its purpose is to detect whether breaches have taken place, or whether to make improvements to the sizing and configuration of the service as part of a continuous improvement process. This control is accomplished mainly through site inspection, tracking systems or other specific reports requested to the service dealer.

[39] The payment by results means that the achievement of quantity and quality objectives (level of separate collection and impurities), of service perceptions of the population (measured through surveys, for example) and the fulfillment of the service development conditions (measured by monitoring and controlling, and compliance of schedules, routes, collection and cleaning frequency, service image, etc.), are linked to the payment of the contractor's profit percentage, so that non-compliance with these criteria may lead to a reduction of the income perceived, which encourages a quality service provision.

- Inclusion of specific annual **budget dedicated to environmental education and prevention.**

# 3.- Composting process

## 3.1. Basic ideas and concepts about composting

**Composting is the optimization of the natural process by which organic remains return to the soil closing the cycle of matter**. The knowledge of this process to obtain a humus or mulch allows that what it even takes months and years to happen in forests can be done in much less time keeping and improving its quality.

From the current point of view of the organic wastes management and its problematic we could considerer the composting like:

An exothermic aerobic biological process, susceptible to be applied to any biodegradable solid organic remain and from which are obtained intermediate products like $CO_2$, water vapour and other metabolites; and like final product an stabilized organic matter, free of pathogens and polluting elements, being beneficial its application to the soil.”

An often important aspect forgotten, is **that composting  is a biological process**. Although in the natural cycle of decomposition of organic matter are also involved macro and mesofauna, the responsible of the degradation process in composting are microorganisms: mainly fungi, bacteria and actinomycete. Due to conditions of the environment changing substantially over time, throughout each phase of decomposition may modify the activity of some microorganisms and also lend advantages to others. Each of these phases is well defined by physical and chemical conditions of the material, mainly by the temperature. **To achieve certain conditions, it is necessary to meet certain physical and chemical parameters of the initial organic waste**, as well as a follow-up, and to extent the **control of other parameters during the process**, assuring its efficiency.

## 3.2. Key parameters of the biological process

### The initial parameters

Looking for an eminently practical composting system focused on organic waste treatment from urban, agricultural or livestock origin; **the following aspects of the mixture of materials to compost should be taken into account**:

*The physical structure or matrix*

**In almost all of the cases it will be necessary to prepare the main organic waste to compost mixing them with a material that confers a structure or a porous matrix to the resulting mixture**.

To add the needed type of bulking material (considering also its "quality") and in the **proper proportion** is the key to the correct initiation and development of the process. It affects its initial speed, whether there is leaching of the material in the early stages, influences the generation of bad odors and determines the level of care and attention that has to be given to the material during the most critical phases of the composting process.

The reason is in the definition of “composting”. It is an aerobic process so it needs to move the air through all the organic mass, and that is why it has to be porous. The best visual analogy would be to imagine a sponge, formed by a matrix of micro-pores. Thus it must be the heap for composting which can be tight or compressed, but it returns to its initial form when the pressure ceases.

**Materials most commonly used as bulking are woods or shredded woody plant remains**, because besides this **porous structure that gives to the organic waste when mixed**, they should not be difficult to find in the majority of cases. There is also a capacity of collection and retention of water by the wood and it is a corrector of the relationship carbon/nitrogen and/or supply of nutrients. That bulking material has the possibility of recovery and reuse because it will not be completely degraded after the composting cycle.

**The amount of bulking that is necessary to add to organic waste to compost, is variable depending on the type of waste, the composting system, and the season of the year and the location of the facility**. The ratio of organic waste and initial bulking is usually expressed in terms of volumes, because that measuring system is easier and more reliable for an industrial composting facility.

In the case of animal manure and slurries, whose density and consistency are very similar, they can be composted correctly with an initial 1:1 mixing ratio (organic waste:bulking) in a dynamic composting system, but a 1:2 ratio is more recommendable. In winter and especially in open systems a 1:3 ratio is more favourable for the process, but it means a higher cost finding the amount of bulking which would be necessary and the occupation of larger areas in the facility.

The turnings or periodic agitation of the material contribute to fluff it, allowing it to recover the structure of the initial matrix. If the treatment system does not provide turnings or agitation of the material during the process it is necessary to increase the amount of bulking in the initial mixing to make greater its resistance to compaction. It also contributes to the efficiency of the process, getting a higher maturation degree of the organic matter in a shorter time than the static systems.

### *Moisture*

**It is a key factor in the whole process**, from the creation of the initial composting mixture up to the stage of maturation, with greater influence on the microbial activity than the temperature (Liang *et al*, 2003). The reason for this importance is that the biological degradation process occurs on the outside of cells, so **this medium moisture must be enough for all the biochemical processes**. There is a direct relationship between the levels of moisture and rate of activity of microorganisms (Liang *et al*., 2003), because there is a direct relationship between moisture content and the free space on the network of micro-pores, which is created with the mixture of organic wastes and bulking (Madejón *et al*, 2002). If there is an excess of water in the micro-pore there will be not or will be very little space for the exchange of gases, and it will be exhausted of oxygen very quickly. When this occurs, the process becomes anaerobic, and creates: odors, leaching, slowing degradation. If the content of water in the pore is insufficient, extracellular enzyme activity will be limited, the microorganisms will die or enter into forms of resistance and the process will stop until the conditions of the environment will be suitable again.

An initial excess of moisture would also allow for a large part of the metabolic heat generated in the initial stages to be invested into the evaporation of the excess of water, rather than being accumulated in the phases of temperature rising up to the thermophilic stage, thus slowing the process. Therefore it is a factor with a direct influence on the process, being an inhibitor by default and by excess, being more problematic at high rates of moisture (Finstein *et al*, 1986) (table 1).

We will obviously not always be able to measure the exact moisture from the mixture of organic waste, and therefore take actions on it to correct this parameter. Simpler methods range from direct observation of the material, obviously very determined by the experience of the operator; the known method of the "fist" where the material in the palm of the hand is compressed to estimate moisture; even the most reliable which is taking a representative sample and its analysis in laboratory.

The optimal moisture levels are between 50% and 60% (Jeris & Regan, 1973, Tiquia *et al*, 1996; Walker *et al*, 1999), but in industrial facilities, and depending on the type of organic waste and the environmental conditions, you can extend the range between 40 and 65%, although at these extremes is frequent to have an initial stress of the process (Madejón *et al*, 2002).

| Moisture (%) | Effects on the biological activity |
|---|---|
| < 30 | The biological process is stopped |
| 30 – 40 | Limited. There is degradative activity in the zones less dry |
| 40 – 50 | It can be considered normal |
| 50 – 60 | It is considered optimum for the biological activity |

| Moisture (%) | Effects on the biological activity |
|---|---|
| > 60 < 70 | High values that will limit the process. Risks of lack of oxygen |

**Table 1.** Relation between the moisture levels of the organic wastes and their effect on the biological activity of the composting process.

### *pH*

This **is a parameter of relative importance in the initial phase of the process**, and is associated with the origin and state of decomposition of the waste to composting. Although the optimal range of initial pH values is close to neutrality (6,5 – 7,5), in the bibliography can be found experiences of composting organic wastes of extreme values although in those cases is suffering a period of initial stress. The acidity of these wastes is mainly due to the presence of short-chain organic acids (Beck-Friis *et al*., 2001), whose concentration increases during the initial phase of composting (Nakasaki *et al*., 1993; Beck-Friis *et al*., 2003), occasionally due to the evolution of anaerobic processes. It is at this time when can be limiting or inhibitory to microbial activity, so we will consider this parameter in the list of the process control.

### *C/N rate*

Being the composting a biological process is a **nutrient relationship** established as the amounts of carbon and nitrogen available (that is not the total), **is essential for the development of micro-organisms** (Nakasaki *et al*, 1992). The carbon as main component of organic molecules and source of energy. The nitrogen as an element of the proteins and cells synthesis. On this basis, establishing which is the most appropriate relationship for the process comes into discussion. Firstly, it should be noted that this parameter is based on a chemical analysis of the total content of both elements in the material and a numerical calculation of their relationship. If the retrieved value does not indicate their state of availability to microorganisms, which can lead to a misinterpretation of the parameter (Puyuelo *et al*, 2011). It is also necessary to consider the difficulty posed in a composting facility to carry out a correction of the C/N relation from the organic waste materials that are available. The large availability of materials and the ease of use in laboratory tests in composting can move away from a practical implementation of the conclusions obtained.

The variety of the origin of the organic waste and its combination ensures that the resulting mixture has a correct ratio of nutrients. If the bulking material is woody vegetable-type already is a source of carbon,  it must be combined with an organic waste that provides nitrogen. From highest to lowest content in nitrogen we will sort organic waste such as manure from animals, food scraps, grass, green or fresh vegetable rests,...

## The process parameters

After conditioning the organic waste /s for composting, the degradaton process will start. Its evolution affects, and at the same time is defined, by certain parameters that are called "process parameters". **The monitoring of these parameters gives information of the state of the biological process**, and from the control of some of them depends that the optimal conditions for micro-organisms during the degradation process can be maintained, ensuring that the final obtained product is of the best possible quality.

### *Temperature*

Composting is an exothermic process that produces energy as heat by releasing the chemical energy contained in organic macromolecules links when they are broken by the action of microorganisms (Mato, 2005). Therefore, **temperature is the key factor that defines and names the phases of composting**. Alone it gives partial information about the development of the process, but it can induce errors if certain features of this parameter are not taken into account and the information provided is not compared with other parameters. In general, it determines the rate at which many of the biological processes take place and plays an important role in evolution, density, composition and succession of the communities of microorganisms during the composting process (Mustin, 1987; Liang *et al*, 2003).

Temperature defines the three sequential stages of composting (Figure 16).

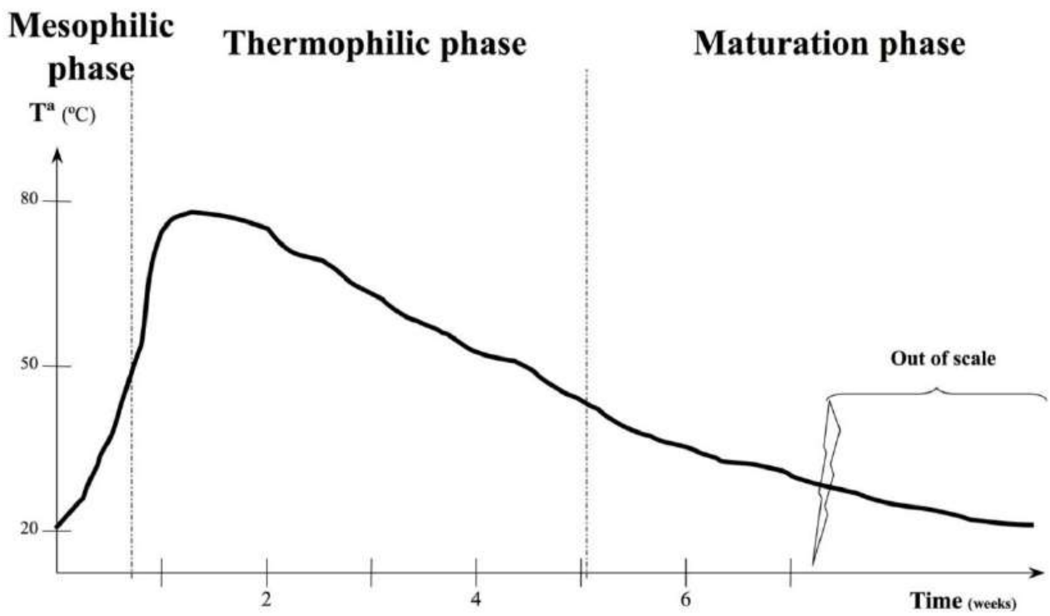



**Figure 16.** Evolution of the temperature during the composting process and the three phases of the process.

### *Oxygen*

Composting is an aerobic process, so it is obvious that **this factor will be the key at every moment to maintain the conditions of the environment suitable for successive populations of microorganisms**. Monitoring the oxygen content in the heap or windrow provides crucial information regarding the biological activity of the material, which, combined with the temperature measurement, enables a first immediate diagnosis on the evolution of the biological process. Sometimes it is appropriate to measure a third parameter, the production of $CO_2$, since it is a direct indicator of microbial activity. As oxygen levels are limiting factors for the biological process, its monitoring is the most used in industrial applications.

If the oxygen monitors are combined with the $CO_2$ it can confirm if the biological activity is being correct when both curves are the opposite, so the reduction of oxygen levels coincide with the increase of the production of $CO_2$.

## *Moisture*

During the composting process, it is normal that **moisture decreases due to the intense evaporation of water caused by the heat generated** (Walker *et al*, 1999; Madejón *et al*, 2002). The way to restore and maintain moisture levels suitable for the process is performing regular waterings of the material, with the leachate that could have been generated in the early stages, or with clean water during the maturation phase. Depending of many factors like the type of organic waste, the proportion of complementary/bulking material used in the mixture, the composting system, the weather conditions, etc… the evolution of the moisture on the material can be different and need more or less attention. Nevertheless, it is a parameter that must be monitored and controlled to prevent problems (Figure 17).

**Figure 17.** Different levels of moisture in materials that are being composted. Upper left, initial moisture close to 60%, that it is considered optimum. Right, biowaste in process with moisture higher than 70%, so it is generating leachates and it can be seen that the material is compacted. Bottom left, biowaste mixed with wood chips and with a very low moisture (below 40%) that limited the biological process.

*pH*

**The combination of certain factors in the transition between the mesophilic and the thermophilic phase can cause an inhibition of microorganisms**. On the threshold of the thermophilic stage there is a high biological degradative activity, a high consumption of oxygen that can become anaerobic if uncontrolled, and an accumulation of short chain fatty acids that tend to acidify the medium. This concentration will increase as more anaerobic processes take place. **As the thermophilic microfauna, (mainly bacteria) are sensitive to acidic pHs; their activity will be inhibited until the fatty acids degrade and the environment tends to neutralize or alkalinize pH values** (Nakasaki *et al*, 1993; Smårs *et al*, 2001; Smårs *et al*, 2002; Sundberg *et al*, 2004; Sundberg & Jönsson, 2008).

## 3.3. The phases of the composting process

### Mesophilic phase

That is the name of **the period of time between the establishment of the initial mixture of** organic waste **in a heap or windrow, where the temperature of the material will be very close to the environmental until it reaches 40 – 50ºC**. The type of organic waste, the mixing ratio with the bulking, the composting system (open or closed) and the season of the year conditions the duration of this phase. Degradation activity is focused on the organic fraction of the organic waste more labile and readily available. It will promote the rapid development and multiplication of the microorganisms, so its biological activity rate will be very high, significantly increasing the demand for oxygen.

As the temperature begins to exceed 40ºC, parts of the microorganisms mesophiles will die or become resistant, while the diversity of species of thermophilic or thermotolerant bacteria, fungi and persistence increases (Hassen *et al*, 2001).

## Thermophilic phase

There is not a particular value that indicates the beginning of this phase. It **is considered that once 50ºC is exceeded, the material has entered in the thermophilic phase of the process, but taking this statement as an absolute truth applicable to all cases can lead to serious errors in method application**. As it was already mentioned, the insulating capacity of the composting matrix is so high, that although microbial activity was inhibited or stopped at the end of the mesophilic phase, the temperature will continue to rise until thermophilic values. It could promote interpretation errors of the evolution of the process.

To maintain the degradative biological activity during this phase it is necessary to have a succession of mesophilic populations to the thermophilic, where other bacteria, fungi, and actinomycete are found (Figure 18). Among all of them the most abundant population is the bacteria of the genus *Bacillus spp* (Tang *et al*, 2004). **For a long time it was erroneously considered that at higher temperatures was a better decomposition** (Haug, 1980), when actually **the range of temperature more suitable for the largest variety of thermophilic microorganisms, based on the maximum rate of degradation, is located between 52 and 60ºC** (Hachiha *et al* 1992; Miller, 1992; Marrug *et al*, 1993). Temperatures in excess of 60ºC seriously affect the rate of degradation of organic matter due to the decrease in microbial activity (Hachiha *et al* 1992; Miller, 1992; Marrug *et al*, 1993). Above these temperatures it was detected the presence, in good quantities and with significant metabolic activity, of certain degradative bacteria (Beffa *et al*, 1996). If the temperature exceeds 82ºC the microbial community is severely limited (Nell & Wiechers, 1978; Finstein *et al*, 1986; Beffa *et al*, 1986; Fermor *et al*, 1989) and the number of active species is extremely reduced (Strom, 1985) (Figure 13 18).

Therefore it is important to consider that the more the temperature of the mass increases, the more the variability of species that can be developed and act on the organic matter of the biowaste is reduced.

**The temperatures that are reached in this phase and the time that it lasts it will depend on the rate of elimination or cleaning of pathogenic microorganisms that were present originally in the** organic waste (Hassen *et al*, 2001).

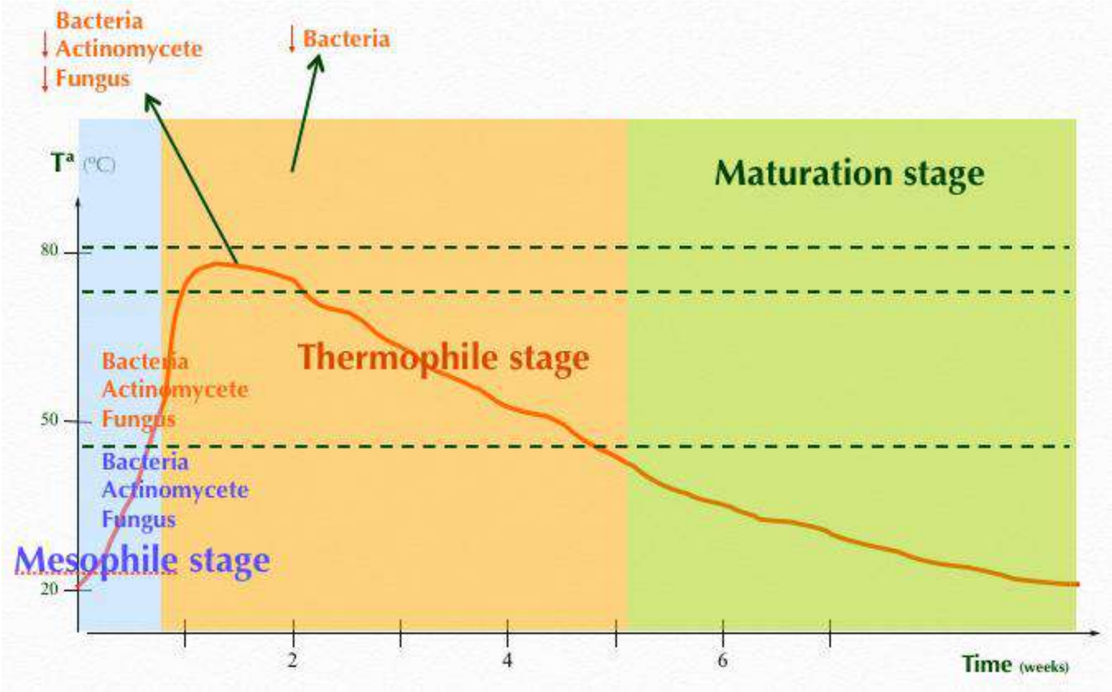



**Figure 18.** The three stages of composting process according to the temperature and its influence and relationship with the different groups of microorganisms.

As it can be assumed the biological activity during this phase is very high, because there is an important diversity of microbiota that can feed and degrade on the labile organic fraction and the more resistant to degradation. This means that **the oxygen demand will also be very high during this phase, so being a limiting factor of the process**. Also the heat generated will facilitate the loss of water by evaporation and this decrease of moisture content will adversely affect the microbial activity.

The end of the thermophilic phase marks the reduction of the temperature cooling down till values of the initial mesophilic phase, below 45ºC. The more labile organic matter already has been degraded to a large extent, and the one that is not so available is not enough to maintain the amount and variety of microbial populations that are in the material, reason why the rate of metabolic activity will be diminishing gradually and therefore the temperature, taking place a new ecological succession.

## Maturation phase

The maturation phase is a slow process where the quantity and diversity of microorganisms responsible are extraordinarily high. **In this phase the organic matter becomes to more stable forms, although its duration is usually measured in weeks, you cannot speak of humidification or mineralization, phenomena that at most will be emerging**. Therefore the duration of this phase is not defined already by directly measurable parameters and attends more to the required characteristics of the final compost, as well as to the space needs and the flows of materials in the industrial facility.

## 3.4. Risks and potential problems of composting adapted to the Mediterranean area

### The influence of the Mediterranean weather on the process parameters of composting

Thinking about the possibilities of applied the composting process to the management of organic waste and the construction of new composting facilities, there is always certain considerations that must be taken in account to the design:

- The **typology**, **characteristics and needs of the** organic wastes **to be treated**.
- The **zone where the facility is going to be build**: nearest population, industrial activities in the area, farming activities,…
- The **weather in the area**: winds, precipitations, temperatures,…

Obviously this third factor is different or has important differences between countries, regions, provinces and even localities.

The SCOW project projects  the composting facilities to be located in the Mediterranean basin, in five different countries that, even when they are almost in the same latitude, the weather conditions along the Mediterranean Sea have significant differences. Moreover the exact location of the composting facilities can vary from mountain areas (like the Pyrenees) to desert conditions like in Israel or Palestine, it also means big differences in the weather conditions that have to be considered to achieve an adequate design and work protocol according to the organic waste characteristics and the composting process under those circumstances.

But some **common points can be taken in account about the influence of the weather in the process parameters**:

- **Moisture**: It will be the most limiting factor in the process, mainly during the warmest months of the year. it can be assume that the environmental temperatures will be moderate to high, so the lost of moisture in the organic waste during the composting process will be also high. Another meteorological event such as wind, will have an important effect on the moisture content of the material, especially within open systems. Zones with a constant wind flow, will cause a fast desiccation of the material. Because of those phenomena should be considered certain aspects in the final design of the facility:
    - **Include elements and/or protocols of work to critically reduce the potemtial the loss of water**. Protocols may be the use of covers for the material in process, reduction of ratio of surface/volume of the windrows, heaps, etc… of organic waste, find the optimum frequency of turnings,… In the case of windy areas it should be even considered to arrange physical barriers (even green barriers with bushes or trees) to reduce the effect of the air. Plastic covers may be an option, but they could increase the temperature of the material if the sunlight hits them directly.
    - **Optimize the management of water in the facility, by collecting any leachates that can be produced during the first stages of the process**, reuse them, storage rainfalls to use for watering the material in process, try to find liquid organic waste in the surroundings of the area to introduce them during the waterings of the material, modify the relation of bulking and biowaste during the months of winter and summer…
    - **Include in the design of the facility a watering system for introduce water to the material**. The most efficient system is combined the turnings of the windrows with the waterings.
- **Temperature**: There will not be expected very low temperatures during the winter months so there will not be problems for the process. If the moisture is controlled the temperature will be also in the adequate values.

- **Oxygen**: If the work protocol in the facility is focused on the reduction of the losses of moisture, it must be considered that the porosity of the mixture of organic waste has to be guaranteed. When the proportion of bulking material is reduced the capacity of the windrow to self-oxygenate will be also reduced, especially during the first stages of process. It is prudent to consider the changes within the work protocol, introducing more or less turnings of the material to keep the porous matrix.

## Potential problems in the Mediterranean area

Due to the unique circumstances of the Mediterranean basin, the **management of bulking agents can present many challenges within certain areas**. Usually the bulking materials are wood chips or pruning scraps that were shredded and have a particle the size of 30 to 70 mm; depending if they are going to be used in home composting or in a composting facility. However the quantity of wood that can be obtained from pruning will be very different due to external factors such as: parks or green areas in the zone, local authorities, and the type of vegetation, etc...

Nevertheless, there can be found other sources in the agriculture, or even with some industrial wastes that are biodegradable. It must be remembered that the bulking - complementary material must accomplish three roles:

- **Regulate the moisture of the materials**. Most of the organic wastes use to have a very high contain of water (70% - 80%) so it has to be reduced to achieve the optimum levels for composting. The bulking material will capture the excess of moisture and will returns it gradually to the process.
- **Correct the Carbon/Nitrogen balance**, providing oxidisable carbon to balance a potential excess of nitrogen from proteins in the organic waste. It will improve the biological process and reduce the losses of nitrogen by volatilization.
- **Give a physical structure to the mixture of materials**. That matrix of micro-pores that is created when the organic waste is mixed with the bulking agent will allow the air to pass through the whole volume of material that is going to be composted. It will prevent any anaerobic phenomena and will be a key factor in the efficiency of the biological process.

When it is not possible to have the quantities and/or qualities of bulking material required for the composting of the organic waste it has to be assumed that there will be problems with the biological process: a low efficiency, environmental affections and low quality product. Under those circumstances the design of the facility regarding its composting system, the process time and the work protocol, must be reconsidered.

- Depending on the initial moisture of the organic waste there are high probabilities of generate high quantities of leachates that must be collected and treated to avoid problems of bad odours, insects and pathogens.
- The organic waste will probably have compacting problems that will generate anaerobic areas inside the material where bad odours will be generated and the degradation of the organic matter will happen under different circumstances from the composting process (mainly by the lack of oxygen and the development of anaerobic bacteria), because of that the final product will not have the best quality. The frequency of turnings and movements of the material to maintain it as porous as possible must be revised, as well as the dimensions (mainly the height) of the windrows, heaps, etc. of organic waste.
- Maybe there can be found other materials like sawdust, that even when they do not have the tree main characteristics of a bulking material, they have one or two (disposable carbon and/or low moisture).

## 3.5. Composting systems and technologies “low cost” – small facilities

This point is focused on the industrial applications of composting that are where **the lack of knowledge about the process is one of the key factors in the success or failure of the facility**. We will not talk about the home composting. There are many successful experiences around the world where they usually recover the old agricultural techniques to produce compost already explained.

Sophistication and evolution of the composting methods of *Beltsville* and *Rutgers*, along with the development of specific machinery for the process, such as the turners, enabled the creation of a larger range of composting systems. They are classified in relation to two aspects or characteristics: the isolation level with respect to the outside; and if there are turnings or mixings of the material during the process. It is an artificial form of classification like many others, but attends the need to be able to compare and to put into groups the different composting models that can be found nowadays (table 2).

Thus its classification is based on the isolation from the outside and/or the control of emissions divides them in:

- **Open systems**, where the process is realized at the open air (although facilities under cover can be easily found in areas with high rainfall).
- **Mid-open systems**, where the process is realized in closed premises that have some system to capture and send the gases to a depuration system, generally a biofilter.
- **Closed systems**, where the process is realized in hermetic enclosures, put under an exhaustive control of parameters, and with conduction of all the gases to a cleaning and depuration system.

Other division is made depending on if the mass to compost is going to be removed or turned by some mechanic device that blended the material. So the outer shells of the mass get to the inside and the inner shells to the outside. Based on these two groups are created:

- **Static systems,** where once the windrow is made it is not moved until the end of the process, or until the dwell time in an area of the facility is over.
- **Dynamic systems**, where turnings or movements of the material are realized.

It is important to clarify that there is not a composting system better than another. Depending on the kind of organic waste to be treated, on the situation of the facility, on the environment characteristics of the area, and some other questions, it would be a better composting system than others if what is wanted is to obtain good quality compost. But in every case it will be the knowledge of the process and of the necessities of the waste that will determinate the success of the facility at the end.

| SYSTEMS | Open | Semiopen | Closed |
|---|---|---|---|
| **Static** | • Heaps<br>• Windrows (with/without forced aeration)<br>• Plateaus (with/without forced aeration) | • Windrows with semi-permeable cover (with/without forced aeration) | • Home/communal com-posters<br>• Containers<br>• Tunnels or compo-tunnels |
| **Dynamic** | • Turning windrows<br>• Plateaus | • Trenchs<br>• Windrows/Plateaus in closed building | • Dynamic tunnels (hori-zontals or verticals)<br>• Drums |

**Table 2.** Classification of the composting systems

### 3.5.1. Open systems

These are the most primitive ones but not the less efficient. Usually they are use to be low cost systems and simple technology, applicable mainly in small or medium size communities of zones where there land is available, mostly rural or semi-rural areas. The weather conditions of the area can be decisive, limiting much of this influence with simple covers without walls, which would imply a justified increase of the costs of the installation. In some cases, looking for a cheaper solution, only the maturation area or part of it is covered, with the purpose of avoiding excessive moisture of the material in phases next to the final sifting. The form of accumulation of the material in this type of facilities is varied (windrows, table heaps, piles, etc…), as well as the ways of processing it.

In this system we can find two varieties: dynamic and static windrows. In the case of dynamic windrows the only way to control temperature is the combination of turnings and waterings, or by manipulating windrow size.

#### Static piles or windrows

It was Sir Albert Howard who at the 1930's implemented the traditional composting me-thods with piles of long windrows of green and animal wastes. Since here they became the classic composting system and have been the base of forthcoming developments. Once prepared the matrix, with or without mixing bulking materials depending on the nature of the organic waste, it is arranged in elongated windrows with a section with a triangular form (approximately).

The shape and relationship height-width of the windrow will depend on the static angle of the material to treat. If it is a material that intertwined well and has structure, we can give more height to the windrow with a specific base, but if the material lacks structure, the triangle of the windrow section will be very low for the same base width.

For the choice of the size of the windrow, we have to look at the proportion of easily degradable materials present in the residue (labile or volatile matter) and its structure. The first will set the rate of oxygen consumption once the process is in march and the second will mark us the capacity for replenishment of oxygen through the pores of the material in decomposition. At first, if we have a material with good structure and a medium or low degradability we can arranged a large windrow without fear of occurring anaerobic phenomena, if it happened the other way around, we will be obliged to arranged windrows of lower height. The first method is difficult and requires great care and experience. In general there is an (widespread) error of considering that a turning will reduce the temperature, when the reality is exactly the opposite during the fermentation stage (except during the minutes immediately after the turning). Only combined with irrigation can succeed.

The second method is based on range heat emission from the windrow modifying the free surface of the same. For example, if a windrow is too hot, we can make it stay at lower temperature simply by arranging it longer and with a lower section and vice versa, varying the surface/volume ratio.
The typical heights of the windrows tend to oscillate between 1 and 3 m, with widths on the base of between 1,5 and 8 m. But it must be also considered, as the most important factor to regulate the size of the windrows, its porosity, directly linked to the proportion of bulking used in the mixture.

Years later, in the Universities of Beltsville and Rutgers (USA), there were developed two different methods to control the composting process in static windrows (Figure 19). The introduction of forced aerated ventilation to guarantee the levels of oxygen (*Belstville* system) and to control the temperature and guarantee the levels of oxygen (*Rutgers* system) inside the windrows, marked the way to combine the use of technology to monitor the biological process and the extreme importance of control some parameters to get the maximum efficiency of the biological degradation (Figure 19).

In the annex I there is more information about these two methods and the strategy of process control.

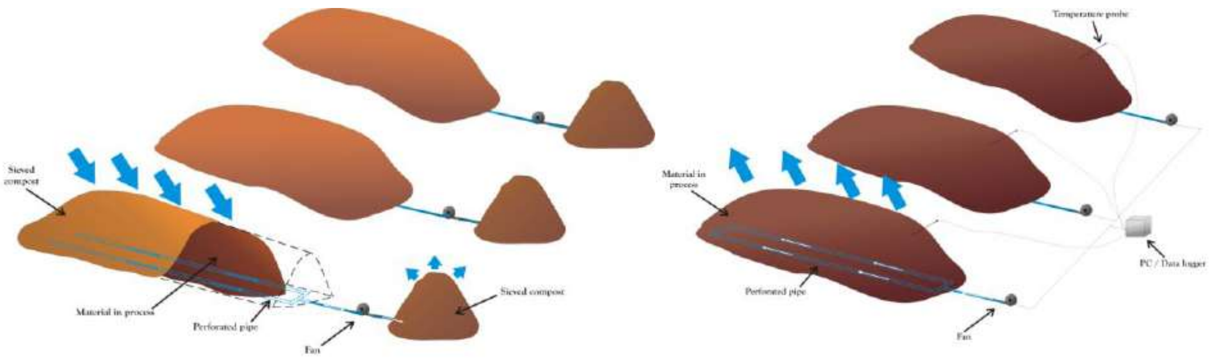



**Figure 19.** Left, scheme of the *Belstville* system where the air pass through the windrow by suction of a centrifugal fan. Right, scheme of the *Rutgers* system where the air is blow inside the windrow by the fan and its cycle of on/off is regulated by the temperature of the windrow (Annex I).

## Dynamic or turned windrows

The dynamic windrows have the advantage of achieving a **higher homogenization of the material, a mechanical diminish of the particle mean size that contributes to obtain a higher volume diminish and, finally, a higher material hygenization because all the material passes through thermophilic phases after some turnings**. Unfortunately, they presented a challenge for controlling the temperature, due to possible problems of deficient oxygenation in deep layers if the porous structure is not the adequate one (it could not be guaranteed by the turnings (Manzano *et al*, 1998)) and the expensive price of the turners. There are high-efficiency turner machines, usable when the installation dimensions require it and the budget permits it, although with a greater effort and lesser perfection windrows also they can be turned with a shovel loader or even better, if it is done using a spreader trailer.

The turning machines available on the market mark size limits of the windrows (Figure 20), or the maximum height that can be achieved with a shovel. But the usual windrows sizes are in the same values of those in the static systems.

***Control of the process***

**The turnings, with or without watering the windrows, are used to control the process**. As it was previously commented, there is a limitation in this control system for temperature, due to the rising after the turning within the first stages of composting. **The only parameters that can be controlled by this method are: moisture content and the porosity (the capacity for self-oxygenation) of the windrow, to maintain the optimal conditions for the biological process. Temperature has to be controlled by the size and dimensions of the windrow and if possible, through waterings.**

**Figure 20.** Left, static windrows with forced aeration by the *Rutgers* system. Right, dynamic windrows being turned by a turned machine.

## Composting in plateaus or big heaps

It is a windrow variant from a triangular section to another trapezoidal one that allows a big width base similar to a lateral union of too many windrows. **The main advantage is a better surface use (higher number of $m^3$ by $m^2$ of occupied surface) and a higher retention capacity of generated heat by the microbiota metabolism**, which reinforces the system capacity to have the possibility to be employed as open system in extreme environments, from cold and moisture ones to hot and desert ones, because it also allows a higher material moisture retention.

**Their main related disadvantages are that the turnings are more difficult and they need a very specific type of turners (Figure 21) or must be done with a loader**; its ability to self-oxygenation is usually poor, so forced aeration is needed in the first phase of the composting process, when the more easily degradable materials are being degraded and there is a high oxygen demand.

**Figure 21.** Left, type of lateral turner machine to realize the turnings of the composting plateaus. Right, a forced aerated system for static composting plateus.

This ventilation is obtained, as in windrows, through a false floor or perforated pipes with holes connected to fans that insufflated or suck air through the mass of the mixed materials (Figure 16). The maximum height that is given to the plateau must not exceed 3 meters (Mato, 2005), although there are cases of plateaus of up to 6 meters high (Cookson, 1995), in which networks of pipes have been introduced at different heights to allow self-aeration.

It is a very suitable system for the treatment of slow degradation organic wastebiowaste or for the recovery of soils polluted by organic wastes, such as hydrocarbons (Benazon *et al*., 1995) or sewage sludge (Mato *et al.*, 2006). In these cases the residence time lasts for months with few actions apply to the material, minimizing and even canceling the turnings.

A variant of the plateaus, called "mattress", is formed outdoors in superimposed layers, usually remains of gardening and pruning, using a machine that grinds them and compact them *in situ*. This system tends to take a long period of time, after which the material is turning and screening. In any case, it is very common to use windrows or plateaus, static or dynamic, force aerated or not, as a final stage (maturation) of materials that have passed their decomposition phase in more sophisticated systems.

### 3.5.2.- Other systems and technologies “low cost”

Controlled Microbiologically Composting (CMC)

**It is a method difficult to clasify, because it is realized in turned windrows, but it normally uses a semipermeable canvas to maintain the windrow conditions** (Figure 22). It is a method developed and property of the family Lübke whom is the responsible of the information transmission and knowledge about the system so its implementation and diffusion have been limited. The best of this method is that is affected by the knowledge of the process, the waste and its necessities, that are which occupy the first place over the technology.

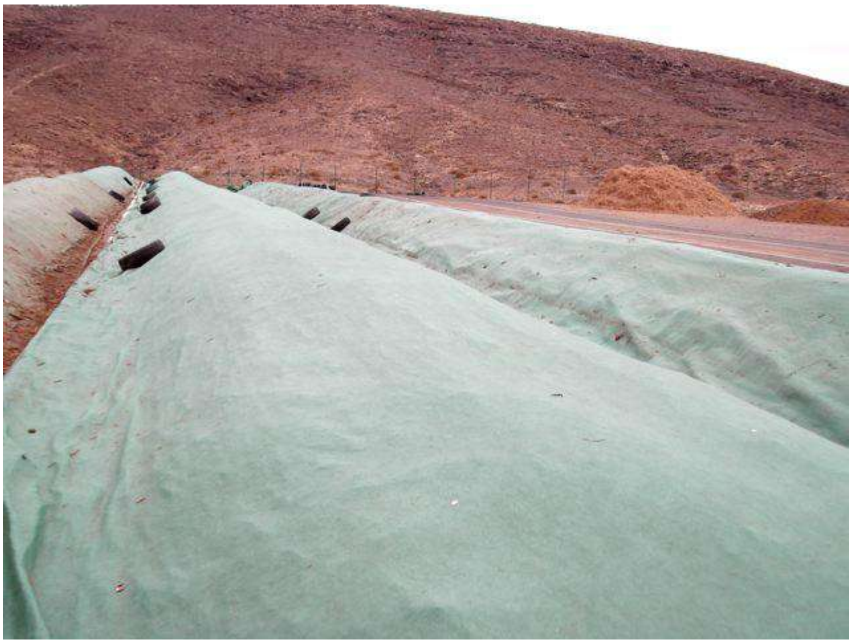


**Figure 22.** A composting site with the CMC method. The canvas used to cover the windrows can be observed.

## Low dedication composting method (LDC)

Although it is a method more directed to home composting or self composting, it is interesting to show it after the previous methods explained before for its simplicity and its low maintenance. The professor Tomás Alcoverro Pedrola from the Agrarian Research Canaries Institute, master composter, has developed it and is named Low Dedication Composting (LDC) ("*Compostaje de Baja Dedicación"*).

The method consists in **building windrows or piles of organic material to compost homogeneously mixed with an enough proportion of structural material, being careful for obtaining a final mixture with the precise moisture**. After that, it is **covered with a simple opposite lawn canvas for four weeks are left and the first turn is given and it is dipped, covering it again** (Figure 23). After the next four weeks, the operation is repeated.

The windrow must be situated on a shady zone and protected from wind.

**Figure 23.** First turning of a windrow with the LDC method.

## 3.5.3.- The dynamic and closed composting systems

### Automatic composters

The main challenge presented whichcan make  people or small communities do not try to manage the organic wastes that they produce by composting, is the lack of know-ledge about the biological process and that it takes some dedication and efforts to guarantee its efficiency and the quality of the final product.

Under these circumstances there is a market for some kind of equipments for compost-ing household biowastes at different scales, **from communal composting to mini-facilities (3 to 150 tons of biowaste per year), which are automatic.** Essentially the user introduces his biowastes in the machine and after a time obtains a final product that can be more or less similar to compost produced by more "traditional" methods, at less in appearance.

**The more common form of these equipments is a cylinder with some kind of rot-ative device inside that periodically removes the material and**, in some cases, makes it advance from one side of the cylinder to the opposite site. Some of them also have a forced aerated system to extract the wet air from inside the composter and in-troduce new fresh (and not so wet) air from the outside (Figure 24).


**Figure 24.** Different models of dynamic closed composters for household biowastes (Jora, Kollvick, BigHanna, Rocket, Campusteiro). All of them have a common structure (cylinder with agitation system). The differences are in the process control, the regulation of the retention time, the regulation of leachates, and the stability of the final product.

The management strategy of these composters is to use the heat of the process and the high frequency of the turnings to have a fast lose of moisture. The turnings also contribute to keep the material porous or, at least to prevent compaction of the organic waste. Nevertheless, depending on the composter model and the characteristics of the organic waste regarding its moisture**, it is usual the need to add a complementary material, with a very high total solids content, to prevent the generation and accumulation of leachates** that would be a problem in these closed systems. This material uses to be wood chips (with a small particle size), wood pellets or even sawdust. Depending on the composter model and the total solids content of the material, the mixture relationship with the biowaste (volume) can be from 2:1 to 1:1 (biowaste:complementary material).

The retention time inside these composters it is not very long, from a few days to an average time of two or three weeks. Most of the composters have instrumentation to measure the temperature and the environmental moisture of the air inside the cylinder, but there is no direct measurement of the material in process.

After that time it is obtained a final product that is hardly mature or completely stabilized because, even when in some cases the biological process is really intense, the transformation of the organic matter needs more time to form the complex molecules of the humic substances as well as the developing of a high diversity of microorganisms that will be useful and enrichment for the soil. These characteristics of high quality compost cannot be reached in that short period of time and with the process conditions inside those composting equipments.

There are not independent researches about the efficiency and the quality and characteristics of the final product obtained (Figure 25), and most of the information about these systems comes from the makers and, in some cases, from technical reports of some users who found problems using them.

**Apart from these uncertainties and the high investment costs of these composting systems and the advanced maintenance that the equipment could required, their use could be justified under certain conditions of need of management *in situ* of the** (household or equivalent) biowastes generated by a big generator (hotel, restaurant, market,…) or communities. There is also another difficulty or problem to take into account with the big generators: the plastic bags that are used to collect the biowaste. Some of the composters designed for the treatment of the biowaste generated by communities **specify that paper bags must be used to deposit the rests in the machine. Big producers cannot do that,** so they will need very specific compostable bags or to introduce the biowaste without any bag. This and the fact that the door to load the biowaste has limited dimensions, mean that the material has to be introduced by smaller parts during a certain period of time.

The main effect or benefit of the system should be considered under the scope **of getting some reduction of mass and volume and obtain a homogeneous product that would not cause environmental impacts, so it can be easily transported to another place where can complete the composting process.** Obviously, if there is enough space and the operator has the knowledge and requirements, the maturation can be realized also *in situ*.

**Figure 25.** Appearance of the final products obtained from these composting systems. It can be observed the excess of moisture (left) or the presence of organic materials that had not been degraded (right).

## 3.6.- The bulking or complementary material

It is one of the keys to the proper management of a composting facility**: provide the precise amount of a bulking material suitable for the organic waste to composting.** As it was previously explained this material is responsible for the regulation of most of the initial parameters of the process like the moisture, the physical structure or porosity and the C/N rate, but to achieve that the bulking material must have some characteristics like:

- Slow degradation under the environmental conditions of the composting process.
- Capacity of captures and retains the excess of moisture from the organic waste.
- Resistant to compression and with a particle size that allows the formation of a porous matrix.
- A high C/N rate so can compensate the balance of macronutrients (nitrogen) in the mixture with the organic waste to be composted.
- It cannot have any substance that could inhibit the biodegradative process of the microorganisms (varnish, glues,…) or contaminate the final compost.

The most common source of bulking that includes all the characteristics listed **is the wood, although there are some researches about the use of non-organic materials (mostly plastics) like** bulking (Plana *et al*, 2006). The wood can came from different origins or sources, from pruning to old pallets, but in any case it must be pretreated before using it as bulking. This pretreatment is mainly focused on reducing the particle size to the optimal dimensions for the composting process, so the wood materials are grinded with machines of different sizes and capacities, depending on the type of wood material that is going to be used as bulking.

**Figure 26.** Aspect of bulking material from pruning of public parks and gardens.

**Materials commonly used as bulking**

- The woody remains, where we would consider branches and trunks from pruning of trees and some bushes. Given its composition and characteristics it needs to be grinded using specific machinery. Once it has been grinded it can be used as a bulking to mix with other organic wastes of higher density and thickness, allowing that the resulting mixture to have a porous matrix that permits the pass of air through the mass. This gives to the bulking an important value to achieve the ideal parameters of the biological process, being a must in a composting facility. This source of bulking is seasonal, so it is generated during certain months of the year (October to February in most of Europe, but this period can be different in other latitudes and countries). Grinding should be done always at the same place where the pruning, to increase the efficiency of the transport of the material to the composting facility.

  The origin of these materials can be the remains of urban and forest pruning by municipal services, as well as it could be the generated by big producers, like agriculture, forestry, residential areas, campsites, maintenance of roads, private gardening services, etc…(Figure 27).

It is important to consider that after the final screening (in the composting process) it will be recovered a large percentage of this material if the initial particle size was the appropriate. So this material can be re-circulated and re-used as a bulking material in the order of 70-75% of the initial mass.

**Figure 27.** Material from pruning of public parks (left) and private gardens (right), where the users leave their green wastes to be shredded and used as bulking material in communal composting.

- The woody wastes from industrial activities. These can be broken or old pallets, pieces of wood or even sawdust (Figure 28). All these materials have to be free of any contaminating substance or that could produce inhibition of the microorganisms. Most of them have to be also pre-treated to achieve the adequate particle size for the composting process. The management of these wastes can even be an economic income for the composting facility, but under the environmental regulations not all the woody materials from industrial activities can be used as bulking in composting facilities. So it is important that each region analyzes the possible sources of these woody wastes and if they can manage and use them for composting other organic wastes.

**Figure 28.** Other materials that can also be a source of bulking material in composting facilities.

# 4. SCOW model for composting facilities

Considering the characteristics of the main organic wastes to be treated by composting, the facility associated to this kind of management must combine different factors:

- Flexibility: it should be able to treat different kinds of organic wastes (from households, farming,…) and quantities due to the possible variation during the year specially in tourist areas.
- Efficiency: to produce the higher quality compost that could be possible with the less cost.
- Simple management/tech: to combine flexibility and efficiency the composting system should be simple, so it could be easily adapted to the conditions, characteristics and needs of the organic waste to be composted. Technology and equipments have to be selected according to the needs of the composting system and the organic waste. Doing that low-tech equipments and machinery can be used, combining functions and tasks inside the facility. The simplicity of the facility allows different kind of managers to make the process works properly, including the local farmers or other agents from waste sector.
- The climatology of the area: because it will also affect to the composting system and the protocol of work in the facility. Keep and manage adequately the moisture of the mixed materials is a key factor to prevent problems and gain efficiency of the biological process.

## 4.1. System

The proposed system is the turning windrows with covers to have a better regulation of the composting process (Figure 29). The periodically turnings of the material will maintain the porosity, the homogeneity of the mixture, will adapt the particle size of the materials to the development of the process and will allow to regulate the moisture of the mixture.

Dynamic or turning windrows offer the advantages of getting a greater homogenization of material, a mechanical reduction of the average size of particle that contributes to a greater decrease in volume and, finally, a greater guarantee of sanitation of the material to get the entire material pass by thermophilic phase after all the turners. On the contrary it presents a great difficulty to have a direct control of its temperature, possible problems of poor oxygenation in deep layers if the structure is not appropriate and relatively high costs of turner machines.

Depending of certain conditions of the area and the nature and characteristics of the main organic waste to be treated, there can be included another variations to the model.

**Figure 29.** Examples of composting facilities with turned windrows.

## *Size of the windrows*

The size must allow the air to circulate through the inside of the windrow, akin to the process within a chimney. The heated air from the inner parts of the windrows ascends and exits by the top of the windrow, while the colder air from the outside gets inside the windrow by the sides. Obviously the porosity and density of the mixed materials must allow the circulation of air.

The relation between height and width also affects to the capacity of retention of the heat produced by the aerobic biodegradation activity. It allows that the temperature of the windrow increases and reaches thermophilic temperatures, but it also permits that the production of energy (heat) exceeds its dissipation to the environment by convection phenomena fundamentally, and to a lesser extent by conduction.

The dimensions of the windrows should be:

- Height: between 1,5 and 1,6 meters (or less), to avoid compacting of the bottom part of the windrow.
- Width: between 3 and 3,5 meters, around twice the height of the windrow to facilitate the pass of air to the inner parts of the windrows.
- Length: it depends on the capacity of the facility and the daily inputs of organic wastes that are received. Here it should be considered also the factors of manageable and traceability, so it is recommended that a new windrow be constituted every one or two weeks (depending on the capacity of the facility) (Table 3).

In table 3 are examples of the windrows size for different treatment capacities of composting facilities, and considering that a new windrow is made every week.

| | 500 t·year$^{-1}$ | 800 t·year$^{-1}$ | 1000 t·year$^{-1}$ |
|---|---|---|---|
| **Ratio bulk: organic waste (vol:vol)** | 2:1 | 2:1 | 2:1 |
| **Height (m)** | 1,5 | 1,5 | 1,5 |
| **Width (m)** | 3,5 | 3,5 | 3,5 |
| **Length (m)** | 12 | 19 | 24 |

**Table 3.** Dimensions of the windrows in a composting facility with different treatment capacities of organic waste and a bulking: organic waste mixture ratio of 2:1 (volume), and where a new windrow is made every week.

## 4.2. Complementary / Bulking material

Considering that the main fraction of the biowaste to be composted in the facility comes from urban (households and tourism activities) the complementary/bulking material is a key factor to:

- Regulate the excess of moisture of the mixture and prevent the generation of leachates.
- Provide carbon to balance the C/N ratio, which will prevent the losses of ammonia during the process and will enrich the characteristics of the final compost.
- Give a higher surface to the development of the microorganisms.
- Provide an adequate porosity to the mixture of materials and create a web of micropores for where the air could circulate and reach the inner parts of the windrow.

The best material to be used as bulking is wood chips or shredded branches. Its particle size should be between 5 to 2 cm.

Considering the normal characteristics of the household biowastes, its high moisture content (about 75%), and the usual content in nitrogen, the best volumetric proportion to mix bulking with biowaste is 2:1 (bulking:biowaste – vol:vol). If the bulking material has the required properties (mainly low moisture and an adequate particle size) the mixture of both materials will have an initial moisture around 60% and a good porosity to guarantee the aerobic conditions of the biological process. Lower proportions of bulking can be used if it is necessary, but the process conditions will not be optimal.

## 4.3. Areas or spaces in the facility

Although each facility has a different distribution of spaces depending on the form of the disposable surface, there are common tasks for all the facilities that should be realized in independent places. The distribution of these areas should be made considering the circuit of stages that the composting process is going to have and trying to make it circular. Doing this it could be possible to economize movements of materials and occupied a lesser surface.

### Reception and mixture area

The urban biowaste (households and big producers) should arrive to the facility according to the collection frequency exposed in the corresponding section. The different steps that should be realized are:

***Reception***

Every truck that arrives to the facility must be noted and identified. The load has to be measure by its weigh (if there is a scale) or volume (volume of the truck's box must be previously determinate). Origin or route of the truck must be also known.

***Unload of trucks***

The reception and unload of the trucks or convoys will be realized directly in the composting area, in the zone defined to constitute new windrows. A layer of bulking material has to be extended on the ground and the truck will unload its charge on it Figure 30). The wood captures any leachates that the organic waste could have generated, avoiding them to spread.

**Figure 30.** Sequence of formation of windrows with different biowastes. Upper line: left, layer of bulking material extended; center, unload of biowaste (swine manure) on the layer of bulking; right, covering the biowaste with another layer of bulking before the pass of the turner machine. Bottom line: left, covering household biowaste with bulking; center, aspect of the windrow before to be turned; right, turning the windrow to mix bulking and biowaste.

***Formation of the windrow***

Another layer of bulking material has to be added to cover the biowaste (Figure 31) and the turning machine can now pass mixing the materials and constituting the new wind-row. The next day the operation has to be repeated from one of the extremes of the windrow.

If the materials cannot be mixed immediately the windrow must be covered with bulking material.

***Other options***

If the facility does not have a turning machine a mixer is needed. This equipment could be recycled from a feeder for cattle (Figure 31), or a trailer for spread manure on crop fields (Figure 31). In this case there has to be an area for reception and mixing of the organic waste. The reception area should have a slope of not less than 3% and a pe-rimeter leachate collection. Unload of the organic waste must be realized on a bulking layer that was previously disposed on the ground. Another layer of bulking has to be disposed covering the organic waste and then it has to be taken with the front loader and introduced in the feeder or mixer equipment. From it the front loader takes the mixture and places it in the decomposition area, conforming a new windrow or completing it, with the adequate dimensions.


**Figure 31.** Other options of machinery for mixing and turning the materials. Left, feeder for cattle adapted to work like a mixer for biowaste and bulking; right, a trailer to spread manure used to mix the biowaste and the bulking material (it can also be used like turner machine).

If a manure spreader trailer is used for mixing, after it has been loaded it can be moved to the decomposition area to unload, mixing the materials and conforming the windrow at the same time.  The first load put in the trailer must be always bulking material, then a load of the same volume of organic waste, and finally another load of bulking. If the trailer is big enough to admit more weight, the sequence will be repeated. It is also very important to distribute the load homogenously in the trailer.

| Reception and mixture area | Commentaries |
|---|---|
| **Timing / frequency** | Every time that new **organic waste** is received in the facility |
| **Machinery** | Front loader / turner or mixer |
| **Type of ground** | Concrete floor or pavement. It can be do in the same area of the decomposition stage for the windrows |
| **Area ($m^2$)** | According to the average quantity of **organic waste** received. If the same area of the decomposition stage for the windrows is used there is no need of a specific area for reception and mixture |
| **Electricity supply** | Only in the case of a mixer with an electric engine it has to be considered an electrical connection |

**Table 4.** Aspects to considerer about the reception and mixture area.

## Areas of the composting

In this basic model the areas that any composting facility should have to be able to achieve the goals of flexibility and efficiency are described. It is possible to make different combinations, depending on other external factors as it is mentioned in the following text.

The Figure 32 shows a scheme of the different areas for the model of the facility described in the text.

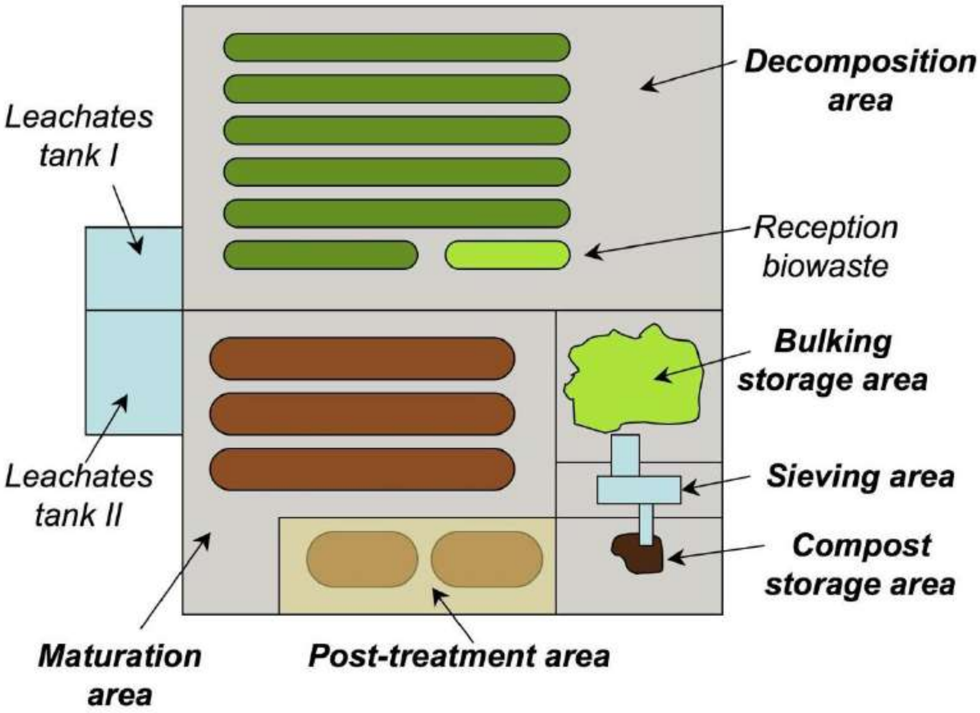



**Figure 32.** Scheme of the composting facility under the basic model description.

## Decomposition area

This is the zone where the more intensive and delicate stage of the composting process is going to take place. It must be accessible for the machinery and to realize adequately all the operations and tasks needed.

***Windrows characteristics***

The ground should have a slope between 2 – 4%. It prevents that any leachates and rainwater could be retained in the area and could ferment anaerobically producing bad odours.

The surface has to be calculated to be able to have <u>four to six weeks of retention time</u> for this phase of the process. The space between windrows must be considered depending of the kind of machinery for turning that the facility would have:

- A self-propelled turner allows occupying a lesser surface because windrows can be almost side with side. A separation of about 0,5 meters between the laterals of the windrows can be enough (Figure 33).

**Figure 33.** Composting windrows operated by a self-propelled turner.

- A towed turner (by a tractor) needs between the windrows a space width enough to allow the pass of the tractor. In this case, to optimize and minimize the surface of this area, this free space can be provided each two windrows (Figure 34). The turning of the windrows will be realized in different directions for each windrow because the turner is always at the same side of the tractor.

**Figure 34.** Composting windrows operated by a towed turned. It can be observed the distance between the groups of two windrows.

- If there is not turner and the turnings of the windrow are realized with a front loader or with a manure spreader convoy, the windrows can be closer between them, like in the case of using a self-propelled turner. In this case the turnings will be realized with a lesser frequency, and every turning will be also a movement of the windrow.

In all these possibilities the space needed for manoeuvre the vehicles and machineries must be also considered in the design.
The turning frequency should be at least twice a week (more information about this aspect in the work protocol).

***Watering***

This area will also need to have connections for the watering of the windrows during the turnings. The frequency of watering will depend on the kind of the organic wastes and their proportions, as well as of the evolution of the process and the climatology.
Most of the turners have a watering system integrated that only needs to be connected to a hose. The type of connector normally used is a “Barcelona” model.
If the tuner does not have this watering system, it can be easily made with a perforated plastic pipe (Figure 35).

**Figure 35.** “Self-made” watering system for a towed turner. Left, it can be seen the perforated pipe linked to the rear part of the turner and with the length and form of the arch. Right, a hose is connected to the pipe during the turning and watering of the windrows.

### *Windrows cover*

The windrows have to be covered with semi-permeable blankets or canvas (Figure 36). These will protect the material from an excessive loss of water, will maintain all the volume of the windrow in darkness allowing that all of it could be biologically degraded by microorganisms, and will reduce bad odours if the process becomes anaerobic fo any unexpected reason.

**Figure 36.** Different examples of covers or canvas for composting windrows. Upper left, Gore®Cover canvas; upper right, TopTex™ canvas; bottom line, anti-grass covers used in professional gardening.

There are different brands for composting covers, being the most popular the Gore(Cover[40], Incabo[41] and TopTex™[42]. Nevertheless, there is the possibility to use a non-commercial cover that, although it is not specifically designed for composting, can be perfectly applied for this function. The anti-grass covers used in professional gardening will protect the windrows for the sunshine and precipitations will prevent an excessive loss of moisture and will lightly reduce some odour emissions that could happen. And their cost is much cheaper than any of the others specific composting covers (Table 5).

| | Gore(Cover | Incabo | TopTex™ | Anti-grass cover |
|---|---|---|---|---|
| **Price (€·m$^{-2}$)** | 55* | 30 | 3 | 0,7 |
| **Advantages** | - Only $O_2$, $CO_2$, vapour $H_2O$ and a small percentage of $NH_3$ can pass through the material.<br>- Resistant | - Lighter than the Gore(Cover<br>- Resistant | - Cheaper<br>- Protect the windrow from sunshine and excessive drying | - Very cheap<br>- Protect the windrow from sunshine and excessive drying<br>- Light and easy to handle<br>- It can be easily find in professional gardening stores. |
| **Disadvantages** | - Very heavy, difficult to move without mechanical elements | - Not so efficient to the pass of certain molecules like Gore(Cover | - Very heavy when it gets wet<br>- Not so resistant like the previous covers<br>- Not completely waterproof<br>- Not so efficient to the pass of certain molecules like Gore(Cover or Incabo | - Fragile to mechanical tensions<br>- Is not completely waterproof<br>- Not so efficient to the pass of certain molecules like Gore(Cover or Incabo |

** In the past years the Gore(Cover patent has expired, so there are other manufacturers in the world, different than Gore, that offers the same type of covers at a lower price.*

**Table 5.** Comparative of average prices and characteristics of the different brands and options of composting covers.

[40] http://www.gore.com/en_xx/products/fabrics/swt/index.html
[41] http://www.incabo.com/en/technical-applications/fr-composply-compost-covers.html
[42] http://www.tencate.com/emea/geosynthetics/applications/industrial-fabrics/agriculture-horticulture/compost-covers.aspx

| Decomposition area | Commentaries |
|---|---|
| **Duration (time)** | Decomposition stage should last between 4 and 6 weeks |
| **Machinery** | Front loader / turner (self-propelled, towed (with tractor) or manure spreader) |
| **Turning frequency** | At least twice a week |
| **Type of ground** | Concrete floor or pavement. It can be do in the same area of the decomposition stage for the windrows. Slope between 2 – 4%. |
| **Area ($m^2$)** | According to the average quantity of organic waste received. For self-propelled turner:<br>- 500 $t \cdot year^{-1} \approx 545\ m^2$<br>- 800 $t \cdot year^{-1} \approx 680\ m^2$<br>- 1000 $t \cdot year^{-1} \approx 775\ m^2$ |
| **Electricity supply** | Only related to the pumps for watering the windrows |

**Table 6.** Aspects to considerer about the decomposition area.

## Maturation area

The next phase of the composting process is realized in a separated area. The main reasons for this are to:

- This stage of the process is not so intensive (biologically speaking) so the management of the materials/process can be simpler than compared with the decomposition or fermentation stage.
- To prevent recontamination of the material that is in this phase and that during the fermentation phase have been hygienized of pathogens. It should not be in contact with any solid or liquid from the decomposition area.
- If the biological process has been realized properly the volume of the windrows would be significantly reduced (around 50% or more). Because of that the distribution and dimensions of the windrows or heaps in this stage can be changed to optimize the space occupation. Two windrows may be joined

in one or all the maturation stage can be realized in large table heaps. In the case of table heaps their dimensions can be adapted to the disposable space in the area. Only its height cannot excess the 2,5 meters.

- The turning frequency in this phase can be reduced because the composting process it is not so intensive. Depending of the climatology, the capacity of watering the material and its age, turnings can be realized every two weeks, or longer in the last weeks of the process.
- During this phase of the process it would be necessary to water the material with clean water (but it does not have to be drinkable) to maintain the moisture and complete the degradation process.

The duration of this stage will depend also on the kind or nature of the organic wastes and the stability of the compost that it is wanted to obtain. It will also be influenced by how intense the process was in the decomposition stage. However a period of time of about eight weeks should be considered for this stage.

Depending of the climatology conditions of the area it could be useful to reduce the surface/volume ratio of the windrows or heaps to keep the moisture of the material (if there is a high evaporation rate), the heat produced by the biological process or to protect most of the material from an excess of rain (or snow if that is the case). If that strategy is adopted it could be not necessary to cover the material with blankets or canvas.

| Maturation area | Commentaries |
|---|---|
| **Duration (time)** | About 8 weeks, but it can be changed depending of different factors |
| **Machinery** | Front loader / turner (self-propelled, towed (with tractor) or manure spreader) |
| **Turning frequency** | Every two weeks or less |
| **Type of ground** | Concrete floor or pavement. Slope between 2 – 4%. |
| **Area ($m^2$)** | According to the average quantity of organic waste received. Using a table heap for maturation of the material<br>- 500 $t \cdot year^{-1} \approx 300\ m^2$<br>- 800 $t \cdot year^{-1} \approx 415\ m^2$<br>- 1000 $t \cdot year^{-1} \approx 480\ m^2$ |
| **Electricity supply** | Only related to the pumps for watering the windrows or table heaps |

**Table 6.-** Aspects to considerer about the maturation area.

## Post-treatment area

In this last stage, the main objective is to prepare the material to be sieved, the process of losing enough moisture and then breaking any aggregates that may exist. If the composting process is managed correctly during the previous stages, sieving may not be necessary, but sieving always useful for increase storage capacity of the material. This zone may or may not be necessary depending on the level of demand of compost and if it would be possible to regulate the production. If the customers or consumers of the compost do not want it sieved this area can be also avoided. Nevertheless, in the design of the model of the composting facility it is better to consider a post-treatment area, because it gives more flexibility to the work protocol and to the yearly capacity to absorb peaks of organic wastes to be treated.

The timing of material going through this stage is around three weeks. If the area is not sheltered, the material may be disposed in covered windrows of the same height and width (same as decomposition stage), and must be periodically turned to increase moisture loss. This turning frequency will be determined depending on the environmental conditions (heat, precipitations…) and the evolution of the material moisture. If material is sheltered then the material may be disposed in heaps to increase the capacity of the zone's surface.

This area should be close to the place where the sieving is going to be realized or it could even be considered the same area.

| Post-treatment area | Commentaries |
|---|---|
| **Duration (time)** | About 3 weeks. It can vary depending on the climatology conditions |
| **Machinery** | Front loader / turner (self-propelled, towed (with tractor) or manure spreader) |
| **Turning frequency** | It depends on the climatology conditions |
| **Type of ground** | Concrete floor or pavement. Windrows should be under roof or covered with canvas |
| **Area ($m^2$)** | According to the average quantity of organic waste received. Using a table heap for maturation of the material (2,5 m high)<br>- 500 $t \cdot year^{-1} \approx 90\ m^2$<br>- 800 $t \cdot year^{-1} \approx 120\ m^2$<br>- 1000 $t \cdot year^{-1} \approx 135\ m^2$ |
| **Electricity supply** | It is not needed in this area |

**Table 7.** Aspects to considerer about the maturation area.

## Sieving area

Sieving the material is the last step that must to be done to obtain the final compost, so it would be more efficient to have the process completed close to the bulking area. . The convenience of having this area under roof or not will depend on the climatology of the zone and on how the compost is demanded. In some facilities, depending on the needs of the final users or customers for the compost obtained, sieving cannot be necessary, especially when the bulking contains a particle size below 40 mm, or the compost is demanded in bulk. Nevertheless the composting facility should be interested in sieving the material to recover part of the bulking material for reuse. By reusing bulking material, consumption of bulking can be reduced significantly, for 70% of the mass can be recovered after each cycle of composting.

The sieving is an operation that must be done with a moisture content level of about 30% (total solids = 700 $g \cdot kg^{-1}$) to be efficient. If the moisture is higher, part of the compost is rejected because it forms balls or adheres to the bulking material.

If the design of the facility has respected the concept of a circular distribution rejected material areas, which are  comprised mainly by pieces of wood that were only partially degraded that may be used again as bulking material, mixing them with fresh organic waste.

| Sieving area | Commentaries |
|---|---|
| **Duration (time)** | About 3 weeks. It can vary depending on the climatology conditions |
| **Machinery** | Front loader / sieve (mechanical or fixed) |
| **Frequency** | It depends on the needs of compost and the disposable space in the facility to store it after of before sieving |
| **Type of ground** | Concrete floor or pavement. It should be done under roof or in a covered area protected from the wind and the rain |
| **Area ($m^2$)** | Depending on the kind of sieve used and whether it is fixed or mobile. |
| **Electricity supply** | If the sieve has an electrical engine. |

**Table 8.** Aspects to considerer about the sieving area.

## Storage areas

Any facility should need independent areas for the storage of the bulking material and the final product. Depending on the work protocol or the model of facility it could be also necessary to include an area for the reception and storage of the fresh organic waste (for very short periods of time).

- Bulking/complementary material storage area: it could depend on its source and on the characteristics of the area, but the most common circumstance related to this material is its high temporality. It is usually generated in some specific months of the year, mainly when the prunings are realized. So this area should be designed to store a certain part of the bulking needed for all the year, considering also that, after sieving (and if the particle size of the bulking is the recommended), about a 60 - 70% of the initial mass of total solids of the biowaste used is recovered. This area does not need any special requirement except its location inside the facility. It should be close to the reception/mixing area and close to the screening area. This location it reduces the movements of bulking material for the phases when it is needed.

  Ground should be of concrete or asphalt, to avoid the contribution of stones and other inappropriate materials to the bulking.

- Compost storage area: The final product, the sieved compost, can be stored during a certain period of time. If it is not going to be sold in the next four weeks it is not very interesting to sieve it, unless to get more space in the treatment areas is needed. The compost continues maturing in the heaps or final windrows in better conditions than after being sieved.

  This area should be covered or be under roof, to prevent the compost could get wet or to reduce the possibility of being contaminated for weed's seeds or undesirable particles from the environment where the composting facility is located.

  Ground should also be of concrete or asphalt, to avoid the contribution of stones and other inappropriate materials to the compost.

Electricity is not needed in these areas except for lighting if it is considered needed by the stakeholders.

## Watering and leachates management / Leachates tank

The compost process has a negative hydric balance. It means that water needs to be added to the materials in order to complete the biological process. But the high initial moisture content of the organic waste (especially manures, food waste, harvest waste) can produce the liberation of that water as leachates if there is not an adequate management of the organic waste, specially in all the aspects related to reception, mixing with bulking material and extreme dimensions of the windrows, heaps, etc… during the decomposition stage.

Also the episodes of rain, snow, etc… that fell over the windrows, if they are not covered, sweep particles and soluble organic matter along the ground and, depending of the phase of the process, can be a source of contamination for the environment.

At the same time, if those lixiviates are collected and stored, they can be used for watering the material during the intensive phases of the process, when the temperatures of the windrows can guarantee the elimination of any pathogen that the leachates could contain. In this way the treatment of the organic waste and the leachates can be combined to improve the efficiency of the composting facility.

***Collection of leachates***

Considering the slopes in the decomposition and maturation areas the capture of the leachates has to be along the perimeter (Figure 37). From there they should be collected and carried to the leachates storage tank. It is very important to have a decantation system previous to the storage tank, to minimize the presence of solid particles in the tank.

**Figure 37.** Examples of capture of leachates along the perimeter of the composting areas.

Considering the different areas of the facility, the followings should be taken into account to determinate the needs and the dimensions of the leachates collection tank: reception, storage of the organic wastes (not bulking), mixing, decomposition and maturation areas.

***Calculus of the leachates tank***

The Catalonia's Waste Agency[43] recommends the following system to calculate the minimum storage capacity that the leachates storage tank should have:

$$V_{da} = Q_d \times (0,05) \times (1 year / 52 weeks) \times t_d \times 1,5$$
$$V_{ma} = Q_d \times (0,01) \times (1 year / 52 weeks) \times tm \times 1,5$$

Where:

**$V_{da}$ and $V_{ma}$** = are the volumes of leachates ($m^3$) from the decomposition and the maturation area respectively.

**$Q_d$** = Organic waste treatment capacity of the facility ($t \cdot year^{-1}$).

**0,05 and 0,01** = it is estimated that about 5% and 1% of the fresh mass of the organic waste will be leachates.

**$t_d$ and $t_m$** = duration, in weeks, of the decomposition and maturation stages of the process respectively

**1,5** = security factor

To calculate the water from precipitations that will be also collected must be considered the area of the following spaces of the facility (if they are not covered): reception, mixing, decomposition and maturation, as well as the roads around these areas where the wheels of the machines could get dirty by material in process.

$$V_S = S + MP + SF/1000$$

Where:

**$V_S$** = is the volume ($m^3$) of leachates produced by the rainfall that have to be store from the mentioned areas (if they are not covered).

43 http://www20.gencat.cat/portal/site/arc?newLang=en_GB

**S** = Surface of those areas ($m^2$).

**MP** = Maximum rain in 24 hours for a return period of 10 years ($L \cdot m^{-2}$).

**SF** = Security factor. If yearly average rainfall is bellow to 600 $L \cdot m^{-2}$ it will be 1,25. If it exceeds that value it will be 1,50.

***Location and types of storage tanks***

There is specific legislation regarding these subjects that should be consulted in each case. A perimeter fence must also be considered to avoid any accident of people or animals falling into the tank. But it should be always recommended to have a closed leachates tank to prevent bad odours and to avoid to receive water from the rain (Figure 38). Obviously it also means to include a pump to take out the liquid and use it for watering the material in the decomposition stage of the composting process.

**Figure 38.** Examples of different leachates storage room. Left, opened tank with a perimeter fence. Right, a tank closed to avoid odour problems and the excess of rainfall.

If there are surfaces at different heights in the facility, the leachates tank should be at the lower ones to use the gravity and facilitate the leachates collection.

I may be prudent to also consider the possibility of have another storage tank for rain-fall water collected from the “clean” areas of the composting facility. This water will be used to water the material in process during the maturation stage when the leachates cannot be used to maintain the moisture of the material of that age.

***Pumping system***

The pumping system does not need to be special. They can be submerged in the tank (discharge pump) or it can be located in a space outside the tank and be connected to it through a pipe (vacuum pump). It needs to have a filter to avoid the capture of solid particles.

It should be remembered the importance of minimizing the deposit of solid materials in leachate tanks. The minimization can prevent many problems, including the generation of bad odours. By placing a decantation system before the leachates tank to prevent solid particles from going inside the tank is will be sufficient.

The pumps must be connected to the pipe system which conducts the liquid to the decomposition area. A hose can then be connected to take the liquid to the watering system of the turner machine, or by any other watering system.

***Another options of leachates management***

Even when the composting windrows can absorb all the leachates collected, it may be necessary to have another depuration system in case that the foreseen quantity of leachates is very high. Constructed wetlands[44] are an efficient and economic method within Mediterranean weather and moderate temperatures, to efficiently depurate and reduce wastewaters.

[44] More information can be found in: http://water.epa.gov/type/wetlands/restore/cwetlands.cfm

## Other areas

Depending on other specific circumstances for each facility there could be another areas that may not affect the biological process of composting neither the quality of the compost produced. These areas are:

- Buildings or constructions: to be used as offices, storages for tools and instruments, locker rooms, WCs,…, or even to keep the machinery under cover.
- Scale: Depending of the collection model and the business plan for the facility, it could be necessary to have a scale at the entrance of the facility to weigh the trucks or convoys that provide the organic wastes to be treated. There are some experiences where it is used a public scale that is located close to where the facility is. Other facilities use the estimated volume of the load of the truck and the known density of the organic waste to calculate the mass of the organic waste that is entering to the facility.
- Area for bagging the compost and/or the elaboration of substrates: depending on which presentation of the compost is demanded by the customers it could be necessary to include an area to fill bags. Also, it can be an elaboration of different substrates or organic fertilizers mixing the compost with other materials (sand, urea, sulphur…). The machinery, mainly mixers, that is necessary to do this will need a specific area in the facility, which it should be under roof. Obviously all these operations can be realized in other place outside the composting facility.

## 2.4. Machinery

There is a big variety of equipments that can be used to operate this kind of composting facilities. So there are very different options or combinations of machines, with different costs, efficiency and work capacities. The selection of the most appropriate should be made according to: the quantity of organic waste to be treated daily (or with the maximum frequency), the disposable space in the facility and the proportion of bulking that can be used to mix with the organic waste during the year. These factors will regulate the frequency of turnings and the characteristics that the machinery should have to be useful and efficient.

It is not hard to find these equipments in the second hand market, with an important reduction of its original cost.

## Front loaders

Considering the capacity of the facility, the industrial activities in the area and the second hand market, there are many possibilities regarding this equipment of the models. We will consider two main options: the front loader Bobcat (or similar) or a tractor with loader (Figure 39).

The front loader will be specifically needed if there is a self-propelled turner machine in the facility. However, if we are using a towed turner or a manure spreader for mixing and turning the organic wastes, we will need a tractor in the facility. This is so it can have a loader to combine its functions in two: movement of materials and towing/powering other equipments.

The main advantage of the front loader is its manoeuvrability and efficiency. In the disadvantages we should consider its cost and that it is quite limited to perform other actions (although there are other kits to transform it in a sweeper for example).

The tractor with the front loader will allow to have two machines in one with the consequent saving of money. But its main disadvantage is precisely that it is not designed to be a front loader, so it will suffer more than a specific machine, takes more time to do the same tasks than a front loader and with a long and continuously use will need more maintenance.


**Figure 39.** Left, Bobcat front loader. Right, tractor with front loader working in a composting facility.

## Shredder

Depending on which is the origin of the bulking material will have to study the real needs of a shredder for the management of pruning, branches, bushes and small-diameter logs. This is equipment directly related to many factors of the characteristics and circumstances of the region, the location of the facility, the organic wastes to be treated, etc.

It will be most useful to have it working “in the field”, where the pruning are being processed, in order to maximize the efficiency of the transport of the bulking material to the facility.

In other cases, it may be prudent to rent the machine for shredding and produce all the bulking that it is going to be necessary in the composting facility during a certain period of time.

The capacity and/or the efficiency of this machine must also be a key factor to select the most appropriate for each project. This is the kind of equipment should have an oversized capacity in order to accommodate large amounts of bulking material. Considering the cost of those operators by hours and the time required to produce enough bulking for the composting process, it is not difficult to understand that what it could be considered a saving of money will result an extra cost of managing the facility.

Another option that should be considered about this equipment is that it could be shared by other composting facilities or for other activities that can need the shredded wood or need to shred wood materials. Even it could be rented (with its operator) during the time that it is not needed in (or for) the composting facility, to give service to other companies or public administration. The same composting facility could give a service of pruning for the local parks or forest areas.

This is a short list of examples that can be use, but other brands or models can be found:

* JENZ. Model AZ 30.

* LOMA. Model K50 HPMF 65.

* HUSMANN. Model HFG II

## Turners / Mixers

In the proposal model mixers will not be needed because the turning of the windrows by the turners will have the same effect, and they can be use in the pre-treatment area to achieve a homogeneous mixture of bulking and organic waste. The different options of turners will vary depending on they are self-propelled or towed. There is also the option of using a manure spreader. It should be also considered that a simple turner is not very sophisticated equipment, and maybe it can be possible to find a local provider or manufacturer (Figure 40).

This is a short list of examples that can be use, but other brands or models can be found:

- Self-propelled turner. Backhus model 16-30.


- Towed turner. ST10.

- Manure spreader. Joskin Siroko


- Manure spreader. Camara.


**Figure 40.** Self-propelled turner machine made locally in Egypt.

## Sieve

This element will be preferably mobile, but at the same time, depending on the needs in terms of particle size distribution of the final compost and the frequency of demand, it can be replaced easily by equipments or very simple elements made locally (Figure 41).

As in the case of the shredder, the sieve does not have to be working in the facility continuously. So there are different options or strategies of use this equipment. It can be rented, it can be shared by different facilities or give a service to others or it can be self-made.

There are two main kinds of sieves: with movement (vibratory or rotatory) or fixed (a perforated surface). In the first group (with movement) there are two types: vibratory sieves and trommels.

This is a short list of commercial examples of mobiles sieves that can be use, but other brands or models can be found:

- Trommel. Ultrascreen.

- Vibratory sieve. EZ Screen. Model: EZ-550

**Figure 41.** Different examples of self-made sieves.

## 3.5. Other possible composting system

Another possible model of composting is one that ensures the optimal conditions of process by forced ventilation of the windrows during the fermentation phase. The windrows are on a circuit of ventilation (perforated pipes) connected to a centrifugal fan with high pressure which, through a functioning either timed or programmed according to the evolution of certain process parameters, keeps oxygen levels suitable inside the windrow.

**Figure 42.** A force aerated composting system where it can be seen the ventilated area empty (left) and with the windrow in process (right).

Compared to the first explained option has the advantage of allowing a finer process control to maintain aerobic conditions in the windrows during the most intense phase of the process. The disadvantages are that do not achieve the homogeneity of the materials, the bags opening and the influence on particle size that increases the surface exposed to the action of microorganisms.

Furthermore, it makes the costs of civil work raises having to establish the ventilation circuit under the floor and a collection and channelling of leachates that may be collected in that circuit. Another determinant of this system is its dependence of having the proper amount of structural material during all the year, to ensure the porosity of the entire windrow and that air can circulate inside it homogeneously. But at the same time it should be considered that it needs less surface than a windrows system.

The airflow is forced to pass through the windrows by overpressure: blowing or suction. Each direction of the airflow has different effects in the biological process and many factors should be taken into account before deciding which is the most suitable design of the ventilation system for each facility.

It should be also considered that all the volume of air that is moved through the windrow is released to the atmosphere. In many cases, it is necessary to depurate it to prevent problems of odours. This can be realized through a biofilter or others depurations systems.

## Reception and mixture area

With a static composting system, a key factor is to achieve an optimal mixture of bulking and organic waste. This must be done immediately, to ensure that the forced ventilation spreads equally by the entire volume of the windrow. Therefore it will be necessary to have mixer equipment for this operation, as well as an area space to receive and temporally store the organic waste.

The mixer can be a convoy feeder for cattle or a manure spreader.

## Decomposition area

There is a limitation of the treatment capacity because the windrows must fit on the area where the ventilation circuit is located. This area can be limited by walls at three sides, taking the form of a silo (Figure 43), so the only option to increase its treatment capacity is to constitute higher heaps or windrows in it. It means that it is not a very suitable system for a composting facility where there are different entrances of organic waste along the year. The changes of height of the windrows must consider characteristics of the fan, to have the guarantee that all the windrows can be kept under aerobic conditions when the static pressure rises by the height increase of the material.

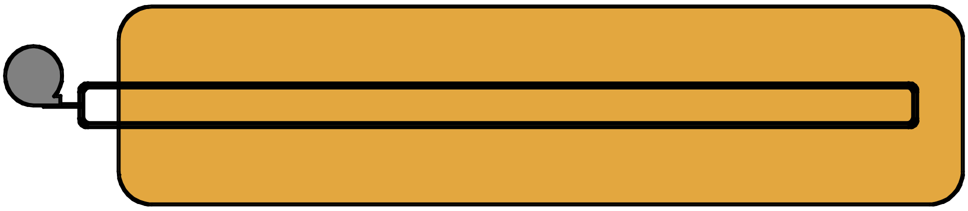


**Figure 43.** Scheme of the ventilation circuit for each windrow.

## Maturation area and the others spaces in the facility

This composting system has a main disadvantage related to the lack of turnings of the windrows that implies that longer time of process will be need to get a mature compost. So it is really appropriate to include some turnings during the process, maybe between the decomposition and the maturation stages. The main objectives of these turnings will be to re-homogenize the material, keep its porosity, reduce the particle size and if watering is included, correct the moisture levels of the materials and keep the biological activity during the maturation stage.

The advantages of keeping the forced aeration in this stage are only related to guarantee the oxygen levels during the process and if the fans can give enough airflow and pressure, to control the temperature of the mass. Other key parameters of the process like moisture cannot be kept under control in all the heap or windrow unless any turning could be realized.

In any case, after the maturation stage it will be necessary to extend the process time during a post-maturation stage, before or after sieving. During this stage it is absolutely necessary to correct the moisture of the material and realize some turnings to have the conditions to complete the composting process.

The rest of the stages of the composting process and the areas of the facility can be the same that the previously described for the general model.

## 3.6. An example of how to determine the areas in a composting facility for SCOW general model

To calculate and determine the spaces needed in the facility, the duration of the process, the mass balance and the most suitable work protocol, many factors have to be taken into consideration:

- Characteristics of the biowastes: composition, moisture, organic matter (concentration and typology), density…
- Location of the facility: climatology, distance to urban areas, form and orography of the terrain…
- Collection and transport of the organic waste: quantities, frequency, distribution of the quantities along the year, elapsed time since the biowaste is generated and arrives to the facility…
- Others: disposable machinery, expected use or requirements of the compost, expected stakeholders of the facility, mid and long-term future of the facility (quantities and typology of the biowastes to be treated),…

As an example, the following tables display how the composting facility that will be build in Sort (Catalonia) for the SCOW project has been sized.

The urban areas where the urban organic waste will be collected have an important rising of the quantities during the summer holidays season, when it is almost double (Figure 44). So the capacity of the facility must be calculated to be able to treat that peak of organic waste that will arrive during those months (Table 9 and Table 10).

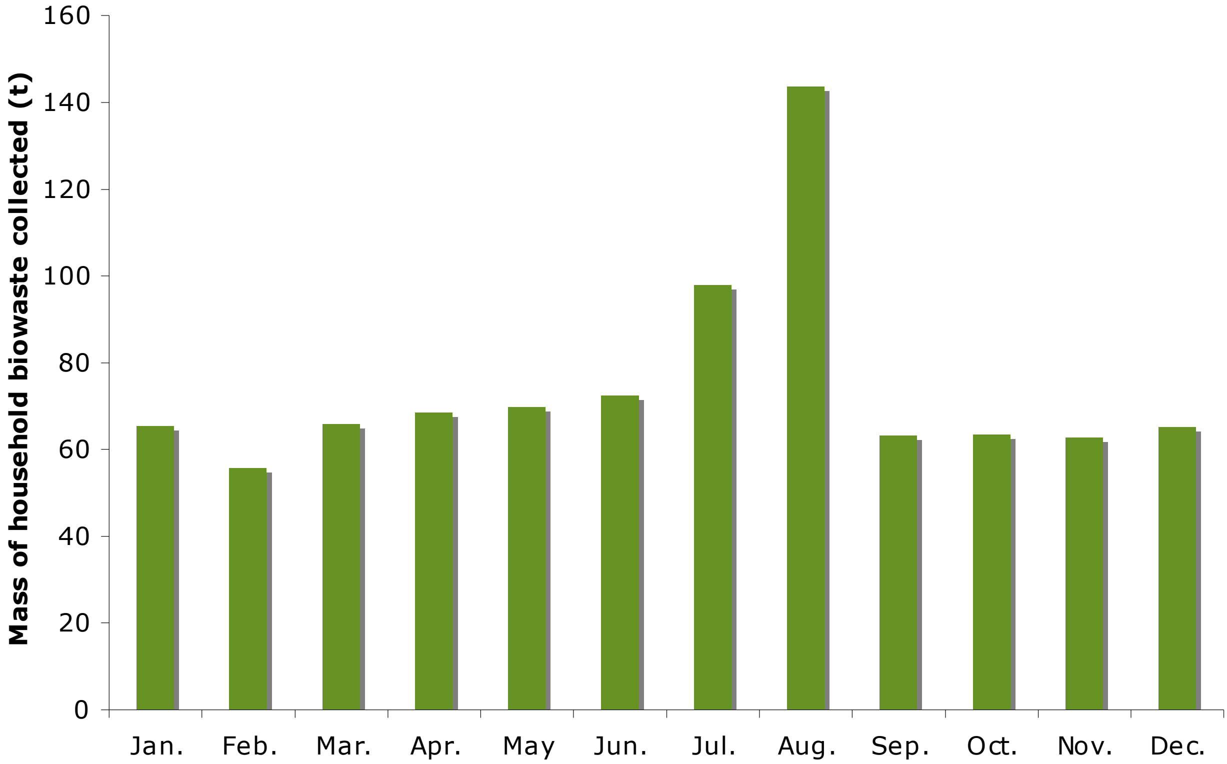



**Figure 44.** Distribution of the mass of household biowaste collected along the year.

The initial data that must be considered are shown in table 9.

| Parameter | Value | Units |
|---|---|---|
| Yearly working weeks | 52 | weeks |
| Weekly working days | 5 | days |
| Biowaste treatment capacity | 900 | $t \cdot year^{-1}$ |
| Maximum entrance of biowaste (monthly) | 145 | $t \cdot month^{-1}$ |
| Volumetric mixture proportion (bulking:biowaste) | 2:1 | vol:vol |
| Necessary amount of bulking | 780 | $t \cdot year^{-1}$ |
| Amount of recirculated bulking | 624 | $t \cdot year^{-1}$ |

**Table 9.** Initial data for the dimensioning of the facility.

### *Decomposition stage*

In the calculus of the dimensions of the windrows is necessary to consider the density of the materials and the reduction of the volume during the mixing of the materials.

| Parameter | Value | Units |
|---|---|---|
| *July - August* | | |
| Weekly new windrows | 2 | windrows·week$^{-1}$ |
| Nº of windrows during decomposition stage | 8 | windrows |
| Height and width of each windrow | 1,3 x 3 | m |
| Length of each windrow | 24 | m |
| *September - June* | | |
| Weekly new windrows | 1 | windrows·week$^{-1}$ |
| Nº of windrows during decomposition stage | 4 | windrows |
| Height and width of each windrow | 1,3 x 3 | m |
| Length of each windrow | 21 | m |

**Table 10.** Sizing of windrows in the phase of fermentation for the months of maximum entries (July and August) and the rest of the year.

### *Maturation stage*

For the maturation stage it is necessary to consider that there will be a very high reduction of mass and volume of the windrows during the previous stage (if the process is preformed appropriately). Because of that it is possible to save much space in the maturation area. It is also possible to form table heaps instead of windrows, that will save even more space, but only if the conditions and characteristics associated to the facility allow it.

In table 11 are shown two proposals for the Catalonian facility. During the summer months where the entrance of biowaste is very high, the maturation will be realized in table heaps. This will also take advantage of weather conditions, temperature, and low rainfalls, which will aid in improving the biological process conditions.

The rest of the year the maturation stage will be realized in turned windrows.

| Parameter | Value | Units |
|---|---|---|
| *July - August* | | |
| Weekly new maturation windrows or heap tables | 1 | windrows·week$^{-1}$ |
| Maximum height of the table heap | 2 | m |
| Surface of the table heal | 370 | $m^2$ |
| *September - June* | | |
| Weekly new maturation windrows | 0,5 | windrows·week$^{-1}$ |
| Nº of windrows during maturation stage | 4 | windrows |
| Height and width of each windrow | 1,3 x 3 | m |
| Length of each windrow | 22 | m |

**Table 11.** Sizing of windrows in the phase of maturation for the months of maximum entries (July and August) and the rest of the year.

### *Mass balance*

The final mass balance have to consider also the quantities of bulking material that will be recovered after sieving and recirculated to be mixed with the new biowaste. In table 12 it is shown the complete mass balance for solid materials.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **WORKING DAYS IN THE FACILITY** | | | | | | | | |
| Yearly weeks | 52 | weeks | | | | | | |
| Weekly days | 5 | days | | | | | | |
| **Biowaste** | | | | | | | | |
| Type of biowaste | Household | | | | | | | |
| Volume to be treated | 5,8 | $m^3$áday$^1$ | = | 1.500 | $m^3$ á year$^1$ | = | **900** | t á year$^1$ |
| Total Solids content | 25 | % | | | | | | |
| Organic Matter content | 85 | % | | | | | | |
| **Bulking** | | | | | | | | |
| Type of bulking material | Wood chips from prunings | | | | | | | |
| Volumetric proportion of mixture | 2 | parts of bulking for each part of biowaste | | | | | | |
| New bulking needed during the start of the facility | 58 | $m^3$ á week$^1$ | | | | | | |
| New bulking needed during the stationary phase | 12 | $m^3$ á week$^1$ | = | 600 | $m^3$ á year$^1$ | = | **180** | t á year$^1$ |
| Quantity of recirculated bulking material | 46 | $m^3$ á week$^1$ | | | | | | |
| Total quantity of bulking used | 58 | $m^3$ á week$^1$ | = | 3.000 | $m^3$ á year$^1$ | = | **900** | t á year$^1$ |
| **COMPOST** | | | | | | | | |
| Quantity of compost produced | 12 | $m^3$ á week$^1$ | = | 647 | $m^3$ á year$^1$ | = | **336** | t á year$^1$ |

**Table 12.** Mass balance of solid materials in the future facility.

# 3.7.Other alternatives models (decentralised versions)

## Examples of decentralised models

To adapt the design of the facility to the conditions of the area, specially climatic conditions, there are different possibilities to conform the work protocol of the facility without the need of change the design.

If the characteristics of the area in terms of population density, urban configuration, types of producers and its location, legal or planning requirements, , make it necessary to avoid the management of biowaste in a single facility. The concept of a "centralized" model should be changed to have a certain number of very small facilities, spread along the territory, with a simpler design and extremely easy to manage by a single operator.

## Design

To be able to be easily operated the size of the facility should be only a little higher than the community composting sites, so its main characteristics will be:

- Closed or semiclosed system, so the biowaste in treatment can be kept in a vessel to be easily handled and, in a certain way, to have some control on the process conditions. It is also possible to include a simple forced aeration system as it is described below.
- Modular, with a small size for each module that allows treating in the same vessel the biowaste received approximately in a month or little more. To be easy to handle the maximum volume for each module should not be much bigger than 1 $m^3$. It means an estimated capacity between 40 to 50 $kg \cdot d^{-1}$ of household biowaste. It will also depend on the proportion of bulking used as well as of the biowaste and the area characteristics.

- Easy access and enough work space. Considering that it will be handle manually, or with very simple technology (a Bobcat loader, a mixing machine,…) , it must have a free area around to allow  space needed for easier operation
- Usually the modules are in direct contact with the soil, or just on a perforate concrete platform. It means that leachates are not usually collected because the work protocol allows keeping them in the process, or the quantities that can get to the ground are really low and can be absorbed by the soil without problems[45].
- Protected from the weather conditions, mainly from rain, snow or direct sunshine. A simple roof could be perfect suitable for this purpose.

The material used for the construction of the composting modules should be cheap, easily to find and easily to repair. The most usual material is wood, and for construction purposes, it can be reinforced with some parts or pieces made in stainless steel46.. Also the use of bricks could be adequate in some cases.

## Location

45 In this case the proximity to any course of water should be extremely taken in account before to decide the location of the facility.

46 Please note that the composting process creates a highly oxidizing atmosphere, so any ferric piece or surface in contact with the biowaste or the composting matrix will have a fast degradation.

This facility model promotes the decentralization of the biowaste management. This means that facilities should be located close to areas of biowaste are generation. It does not mean that facilities must be adjacent of buildings or households. However, in the case of campsites, small villages, and other smaller communities, placement possibilities are listed below:In other cases, it is a model of facility that can be built in the terrains of any farm or cultured area, on condition that it fulfill any local regulation about biowaste management. These are very small facilities, so it should not have problems to be easily adapted.

**Figure 45.** Examples of decentralized and small composting facilities.

## Force aerated or not?

In some cases, it could be considered interesting to have a simple forced aerated system to guarantee the aerobic conditions of the biowastes inside the composting module. But, in any case, it never means that the bulking material would not be necessary. Obviously it is necessary a minimum porosity of the mixture of biowaste and bulking/complementary material that is going to be composted. Also it should be remembered that in any case a periodic turning must be realized to avoid compacting and a vertical stratification of the moisture content of the mixture. It will also contribute to a higher efficiency of the degradation process.

The forced aerated system is very simple to build. As it can be seen in the Figure 46, it only needs a closed circuit (plenum) of PVC or polypropylene pipes, with a diameter of about 40 to 50 mm (1 ¼" - 1 ½"). The aeration circuit must be under a false floor that it can be perfectly made of perforated wood boards. They will let the air pass through them and at the same time will protect the pipes from all the labours and movements of the materials that are being composted.

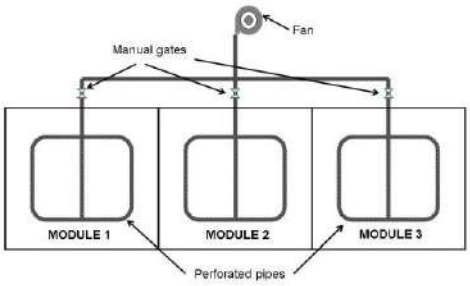




**Figure 46.** Scheme of a tri composting module facility with a forced aerated system.

The aeration requirements for this type of composting module are very low, because the main objective is to guarantee the aerobic conditions of the mixture of biowaste that is being composted. There is no intention to control the temperature levels since the volume of biowaste in process and the exposed surface allow losing temperature by conduction and convection. In this way, a very simple centrifugal fan is enough to achieve these results. The minimum requirements of the centrifugal fan are:

- Air flow: about 85 $l \cdot s^{-1}$.
- Static pressure: about 1300 Pa.

One centrifugal fan of these characteristics should be considered for each two or three composting modules. A simple timer must be installed to program the ON/OFF cycles of the fan. The program should begin with a cycle of 40 minutes OFF and 3 minutes ON Cycles may be changed to a higher or lower frequency depending on the evolution of the temperature of the biowaste in the composting module.

In order to regulate that the air flow goes to the composting modules that are being used at every moment it is necessary to incorporate a gate (manual) in the pipe that goes to each module. Opening or closing each gate, it is possible to ventilate  a single module or various.

## Work protocol

The simplicity of any composting facility independently from its size, is directly related to the availability of the materials and/or elements (with special relevance to the bulking/complementary material) that could guarantee the optimal conditions of the biowastes to be composted during the initial phases of the biological process. Obviously there are other considerations to be taken into account, like the nature and characteristics of the biowaste, the weather conditions, etc..., but the starting point is to be able to guarantee that the initial mixture of materials meets the optimal initial conditions about moisture, porosity and C/N rate.

In that way, the key factor for the success of this kind of composting facility is to assure that there is enough bulking/complementary material and that the mixture with the biowaste/s is made in the appropriate conditions. Considering the normal characteristics of the household biowastes and its high moisture content (about 75%), the best volumetric proportion to mix bulking with biowaste is 2:1 (bulking:biowaste – vol:vol). If the

bulking material has the required properties (mainly low moisture and an adequate particle size) the mixture of both materials will have an initial moisture around 60% and a good porosity to guarantee the aerobic conditions of the biological process. It is also possible to work with a proportion of 1:1 if the frequency of turnings is respected and there is not high environmental moisture.
The mixing can be done by hand (with the adequate tools, i.e.pitchforks) or with a type of mixer machine[47].

Before to be used, each composting module or unit should have a layer of shredded wood or wood chips on the floor (even the forced aerated ones). This layer must be about 5 cm height and it provides the possibility of natural aeration from the bottom of the composting "heap" that is going to be created in the module. It also will capture any leachate that could percolate from the biowaste during the process.

Daily, or with the frequency that is determined by the collection system, the mixture of biowaste and bulking/complementary material is introduced in the composting module.
Once a week the entire content of the module must be turned or removed to guarantee the homogeneous conditions of the mixture. In the case, adding more water to increase the moisture content is needed, which must be done during the turning.

When the first composting module is completely full the material has to be moved to the next module. This is a real turning of the material and the main objective is to improve again the conditions of the mixture in terms of its porosity and moisture content. Doing this the material is ready to begin the next step of the composting process with homogenous conditions.

The newly received biowaste is introduced into  the first composting module, that now is empty and, when it is full again, it is necessary to move the material that is in the composting module 2 to the 3 (doing a turning and adding water if it is necessary), leaving a free space to put the material from the composting module 1 in the module 2 (Figure 47).

[47] There is an example of a mixer equipment in the list of references of this kind of composting facilities, in Montreal (Canada).

At this stage, the first set of biowaste that was treated is in the composting module 3. Depending on the stability required for the compost and the volume reduction it can be decided when the process is considered finished. After another month (three months of composting process for this material) it may be necessary to take it out of the composting module 3;space is needed for the material from the composting module 2. If the volume reduction was high, it could be possible to have space in the composting module 3 to include also the material from the 2. If not, or if it is not wanted to do that, the material from the composting module 3 has completed the process and should be considered compost. The screening can be utilized if the users demand a compost with a small particle size.

If it is necessary to prolong the composting process, it can be done in a maturation heap placed under a roof or covered with a semi-permeable tarp or blanket.

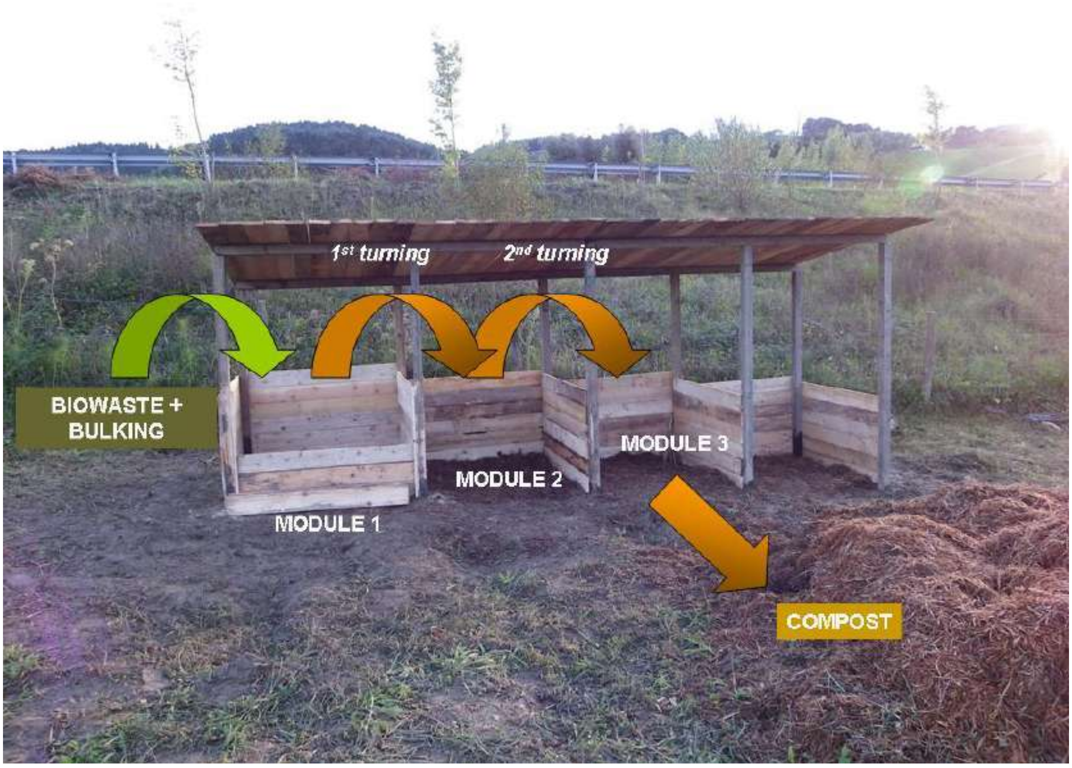



**Figure 47.** Use of the composting modules and movements of the material that is being composted.

## Examples of this type of composting facilities:

- **Larrabetzu**: A composting facility in Vizcaya (Spain) that has developed a pilot experience to treat household biowaste from their neighbours adapting the Austrian model, where a local farmer collect door to door the biowaste (3 times a week) and take it to his small composting facility. There he mixes the biowaste with shredded prunings and applies the composting process. Almost all the compost production is used to improve the quality of the soil of the farmer's lands.

  - **Capacity**: Currently 16 t of household biowastes yearly., from 105 families and 2 big producers.
  - **Surface**: 14 $m^2$ (including the composting modules and the working area).
  - **Investment:** about 800 €. The council pays 3000 € by year to the farmer for the service.
  - **Distance to the nearest residential area**: 300 metres.

- **Aritzaleku**: A composting facility in Navarra (Spain) which treats the biowaste generated in the camping and in the nearest village (*http://goo.gl/maps/RwBhY*).
  - **Capacity**: 30 t biowaste yearly (plus the prunings and green waste generated in the camping and village).
  - **Surface**: 130 m$^2$
  - **Investment**: less than 5.000 € (including land preparation).
  - **Distance to the nearest residential area**: less than 15 metres.


- **Berriz**: A composting facility in Vizcaya (Spain) that treats the biowaste generated by 60 families[48] (http://goo.gl/maps/XwuQZ).
    - **Capacity (total)**: 100 t biowaste yearly (plus the prunings and green waste generated in the nearest park).
    - **Surface**: 40 $m^2$
    - **Investment**: about 60.000 € (including purchase of the electric truck for the door-to-door biowaste collection).
    - **Distance to the nearest residential area**: it was built in a recreational area (park and sport fields).



[48] It is in a first stage of demonstration, so currently is treating the equivalent to 40 -50 t of bio-waste by year.

- **Parc Jeanne-Mancé**: A composting facility in Montreal (Canada) that treats the biowaste generated by 120 families, 2 restaurants and a grocery store (*http://goo.gl/maps/u8r5J*).
    - **Capacity**: 85 t biowaste yearly.
    - **Surface**: 50 $m^2$
    - **Investment**: 33.370 €
    - **Distance to the nearest residential area**: at the side of a main street (see pictures bellow) and the wall of a hospital.

- **Abonos Lourido**: A composting facility in A Cañiza (Pontevedra, Spain) that treats biowastes from clean forest and animal manure. There is no connection to the main electric power supply. (*http://goo.gl/maps/cZwUs*).
  - **Capacity**: 1600 t biowaste yearly.
  - **Surface**: 1500 $m^2$
  - **Investment**: about 100.000 €
  - **Distance to the nearest residential area**: 1,5 km




Selective Collection of the Organic Waste In tourist areas

- Boadella **i les Escaules**: A composting facility in Girona (Spain) that treats household biowastes from the town (230 inhabitants + 200 visitors yearly + 2 restaurants + 1 take-away store). (*http://goo.gl/maps/EsI1D*).
    - **Capacity**: 180 t biowaste yearly (plus bulking material).
    - **Surface**: 250 $m^2$
    - **Investment**: about 50.000 €
    - **Distance to the nearest residential area**: 500 m

## 3.8. Upper Galilee Regional Council – The model of in-farm composter & collection systems

In certain areas where special conditions are met, like extreme temperatures, lack of bulking resources, important needs of organic matter in the soils,…, the priorities and circumstances of the composting model are different and it can be adapted or modified. The main objectives are:

- Stabilization of the organic matter.
- Minimum consumption of resources like energy, bulking material and water.
- Avoid the environmental impacts of the biological process when utilized under non-optimal conditions.

In these circumstances closed and dynamic composting systems can be adapted without needing high technology (Figure 48), as Upper Galilee has demonstrated with the design of their own composing machine. The special conditions of those areas have to take into account, specially climatic conditions, but there are different possibilities to conform the work protocol of the facility without the necessity of changing the design.

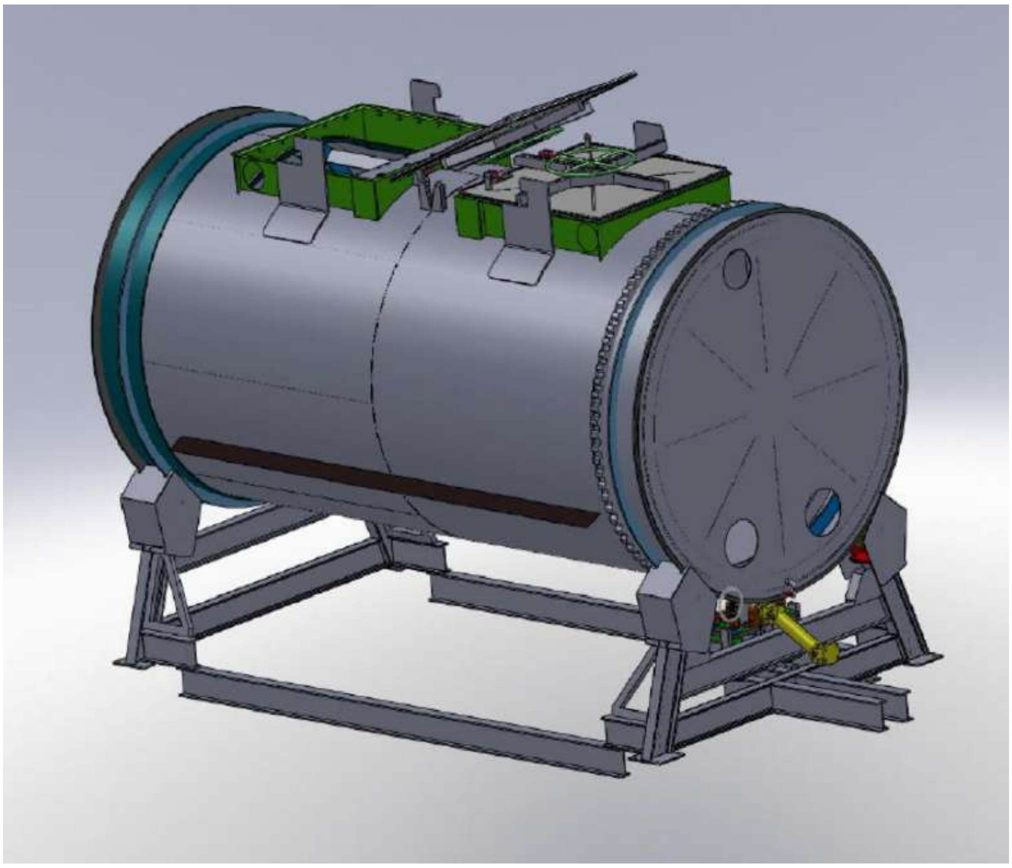


**Figure 48.** Drum composters developed by Upper Galilee Regional Council (Israel).

## Working protocol

**Collecting system**: Separate organic food waste from residents & businesses, together with newspaper is transported to street brown bins without using nylon bag.

The inhabitants are allowed to use organic biodegradation bags.

The wasteis collected by a special truck (mixing & shredding tank on a 15 ton lorry) twice a week. The truck is uploading the mix waste (1:0.65 organic waste + newspaper : bulking agent) into the composter upper open (by diverting the composter toward the truck).

**Composters distribution**: The whole area of the Council is dividing into 15 clusters with 15 composters. Each Composter is designed to absorb up to 20 tons of organic waste (including newspaper but not including the bulking materials).

**Composter operating protocol:**

1. One turning to right and one turning to the left each 20 minutes.
2. 1-4 minutes operating of the aerating fan each 18- 15 minutes.
3. Process time: 2 weeks absorbing waste, 2 weeks process time.
4. After 4 weeks from the beginning of the uploading with fresh waste, the downloading of the compost through the main open is carried out, down to belt conveyor, which moves the compost to a vibration sieve on a collecting trolley.
5. The sieved compost is sent to curing for 4 weeks (at least) and then to public & privet gardens inside the farms, or small agricultures fields. For storing during the winter, it should be kept under cover.

**Monitoring:**

- Temperature: though special monitors inside the composter.
- Humidity: through sight and touch. The results are affected by the fan time, and sometimes by the duration cycle.
- Leachates: the composter is sealed against leachates from leaking. It can be operated, as far as the turning cycle time is keeping under 20 minutes between eachcycle.

  In case of fault there is a special drainage tap, for the maintenance team for pumping.
- Bulking management: it is used a shredded municipal trimming (a municipal duty of the Council in all the Kibutchim). The material is transferred from the collecting & shredding area to the composter area. In the winter the trimming is covered from the rain.

| **Facility's data** | |
|---|---|
| BIOWASTE | |
| Typology | Household, hotels, campsites, restaurants, food services, Academic, commercials area |
| Maximum yearly ($t \cdot year^{-1}$) | 960 (3,200) |
| Maximum monthly ($t \cdot month^{-1}$) | 120 (360) |

| | |
|---|---|
| Minimum monthly (t·month$^{-1}$) | 60 (180) |
| BUL-KING/COMPLEMENTARY MATERIAL | |
| Maximum yearly (t·year$^{-1}$) | 48 (180) |
| Typology | shredded municipal trimming & privet gardens waste + papers |
| Origin | Shredded municipal trimming & privet gardens waste, + household papers & newspaper |
| Mixture proportion bio-waste:bulking (vol:vol) | 1:0.65 |
| Estimated compost production (t·y$^{-1}$) | 480 (1,800) at maximum production |
| Use of the compost | Public gardening, community resident privet gardening, Communities gardens |
| **Composting system** | |
| nº of fermentation units/modules | 4 (15) |
| Dimensions of the units | |
| *length (m)* | 2,6 |
| *width (m)* | 2,5 |
| *height (m)* | 2,5 |
| *volume ($m^3$)* | 11.5 $m^3$ |
| Area reserved for fermentation stage ($m^2$) | A barrel enclose plant |
| Time of process (weeks) | 2 + 2 |
| Work protocol | The drum is loaded during 2 weeks with the mixture of biowaste and bulking<br>A rotation frequency of the drum is one turning to each side every 20 minutes |
| nº of maturation units | 4 (15) |
| Dimensions of the units | |
| *length (m)* | 2,6 |
| *width (m)* | 2,5 |
| *height (m)* | 2,5 |
| *volume ($m^3$)* | 11.5 $m^3$ |
| Area reserved for maturation stage ($m^2$) | A barrel enclose plant |
| Time of process (weeks) | 2 |

| | |
|---|---|
| Leachates management | Collection |
| Total surface of the facility ($m^2$) | 92 $m^3$ (345 $m^3$) |

Note: the data is referred to the implementation of four composters under the SCOW project. The data in brackets is the information for the whole number of machines that will be implemented in the zone.

**Table 13.** Technical characteristics of the composting facility for the Upper Galilee Council

# 4.- Monitoring the composting process

## 4.1. Main parameters to be monitored

The composting process has two main biological: the fermentation stage and the maturation stage. The evolution, needs and requirements of the biological process are different in both stages. There are different strategies of how to measure and control the process and which the parameters that should be monitored depending on the moment are.

There are many environmental parameters related to the composting process: physical, chemical and biological. They can be more or less difficult to measure, and some of them need to take a sample and analyze it in the laboratory. But for this document only the most important for the biological activity of the microorganisms and those which can be directly measured by electronic devices or probes are considered.

Low cost and simple plants imply no need to monitor a lot of parameters, only the most important to ensure the good functioning of the process (so the resulting material has the proper characteristics), and also the use simple equipments.

Two kinds of parameters can be considered: those that give direct information about the biological activity and those that give information about the environmental conditions (that affect to the microorganisms and their activity), in any case the importance or incidence of these parameters in the biological process is different during the fermentation and the maturation stages.

### The fermentation stage

During this phase the biological activity is very intense so it is necessary to guarantee that the conditions of the material are appropriate to maintain a high biological activity. The combination of temperature, oxygen levels and moisture are the best indicators of information to know how the process is evolving.

These parameters have to be measured with a high frequency during the first weeks of process.

But it should be considered that, depending on the specific regulation for each country or area, there could be already a list of parameters to be measured in the composting facilities and its frequency.

In any case, the measured parameters must be registered, automatically or by hand, for every stock of biowaste that is introduced into the treatment.

***Temperature***

During the initial phase of composting (mesophilic phase), the raw materials are invaded by native mesophilic microorganisms (bacteria and essentially fungi) and their activity generates an increase of temperature (from environmental to 45 °C). This increase of the temperature continues and defines the following phase (thermophilic phase), when the biomaterials reaches elevated temperatures (until approximately 60-70 °C). These levels are optimum for thermotolerant or thermophilic microorganisms (the activity actinomycetes and fungi and the development of thermophilic bacteria will stop). The temperature can reach 70 to 80 °C, however, above 70 °C temperatures are not recommended because they can cause excessive drying, a too important loss of material, and even stop or reduce the efficiency of the biological process (destruction of living organisms) and thus degradation of the quality of the compost (instead of combustion transformation of organic matter). After a certain period of time (depending on the nature of the biowaste and the process conditions), the temperatures reached in the thermophilic phase will be lower and lower.

Moreover, the turning process (in the dynamic systems) ensures that all the elements of the windrow will pass for the same process conditions, so that the end product will be homogenous and fully remediated. During the fermentation stage, the turnings will produce a rise of temperature because it redistributes and improves the process conditions (moisture, porosity, disposition of fresh organic matter,…). When the process is in the maturation stage, even after different turnings, the temperature will decreases until an ambient temperature is achieved.

The temperature of each windrow can be measured several times in the same windrow in order to obtain an average of the temperature of the windrow. At the beginning of the composting process the temperature could be measured each day and then every 3 days during the phase of maturation. It also could be important to collect the daily ambient temperature.

The temperature of the material is measured with temperature probes: Pt100 or thermocouples (type J, K). These probes are introduced in the material at 30 to 90 cm depth (depending of the volume of the material that is being composted), so they have the form of a spear with a cross section to handle it (about 150 cm length).There are many providers of this kind of probes at almost any place and to find a company that would manufacture is easy. The main requirements are their correct calibration and that they must be made of stainless steel. Usual prices are about 180 - 200 € each unit.


**Figure 49.** Temperature probes

Here there are some examples of temperature probes, but it is perfectly possible to find manufacturers that could produce them under demand:

- The *Reotemp Heavy Duty Composting Thermometer* features a clear, easy-to-read dial, with the pointer directly driven by the sensitive bi-metal helix in the bottom of the stem which gives an accurate reading every time. Price from $ 114.99 to $ 254.99 depending on the length (from 36 to 72'' or from 91 cm to 182 cm).
- *Reotemp Fast Response Composting Thermometer* has all of the assets of the *Reotemp Heavy Duty Thermometer* but it is stronger and quicker. The readings are twice as fast and the stem is reinforced with 3/8" stainless steel. Price from $ 164.99 to $ 299.99 depending on the length (from 36 to 72'' or from 91 cm to 182 cm). The Green Mountain Technologies temperature probes 36'' (about 91 cm) and 48'' (about 122 cm) - http://compostingtechnology.com/products/compost-management-tools/web-appios-app/probe-hardware/ (99 $ and 129 $).

These sensors could be fixed in the compost piles or handheld.

- Pt100 probe for compost and wheat with indicator from Itsensor (http://www.itsensor.it/temperatura/sensori-e-pt100/per-biomasse-compost-e-grano/sonda-pt100-per-compost-e-grano-con-indicatore-cod-sci.html#prezzi): probe with a length range from 1 m to 2,5 m and a measuring range from -20°C to +150°C. The price is from 204,80 € to 299,30 €, depending on the probe length. Its sensor has also other probes for the temperature measurement with other specifications (lower measuring range, ATEX…), which could be a little bit less expensive. The mentioned probe is the most popular among all the Itsensor probes for temperature.

- Omega - A12P-0-100F-12 (http://www.omega.com/Temperature/pdf/A12P.pdf) is a thermocouple probe in stainless steel, with a length of 72'' (about 182 cm) and a maximum head temperature of 93°C. The price is about 66 $.
- Dry-it-Out TP3MC digital probe (http://www.dry-it-out.com/Compost-Digital-Temperature-Probe-1-5-Metre) is a thermocouple probe in stainless steel, with a length of 1,5 m and a measuring range from -20°C to +140°C. The price is 202,80 £ (about 246 €).
- KIMO Instruments - SKP 1000, SKP 1500 and SKP 2000 are thermocouple probes, stainless steel protective sheath with a range length from 1000 to 2000 mm and a measuring range from -50°C to +250°C. The price is from 152 € to 198 €, depending on the probe length.
- Single and dual probes of SW & WS Burrage for temperature (Pt100) and oxygen, with a length of 1,25 m and a measuring range from - 20°C to 100°C.(http://www.burrage.u-net.com/cp.html).

*These temperature sensors are handheld.

According to the size of the composting facility and the composting system, the number of temperature probes, their location and the measurement frequency have to be decided. The recommendation would be to have some system to take the measures constantly[49], but in a small facility it could not be necessary. The operators can measure the temperature of the windrows daily or at least three days a week. The frequency of temperature measurement is very important to be able to identify and diagnose any problem in the biological process in the composting windrows.

The types of temperature probes that should be avoided for this specific application are those like the one on the left picture. By the action of introducing and taking out

[49] See the information about the systems

repeatedly the probe in the composting windrow, the point where the wires are connected to the probe will be easily damaged.

***Oxygen (and other gases)***

The composting is an aerobic process, so the oxygen level inside the windrows is a very important parameter to be monitored. Oxygen levels show the consumption and demand of the microorganisms and this data give us information about the intensity of the biological activity.

To measure and monitor gases inside the material, air samples should be taken and conducted to the analyser. So there are two different parts of the system: the part of taking the gas sample and the part of the analyser.

To take the sample is needed to introduce some kind of pipe inside the windrow, at the desired depth, and suctioning gas. This sample is canalized to the gas analyser, but previously a pre-treatment to reduce the moisture and clean the gas of any solid particle that it could incorporate is needed.

The analyser can be electrochemical, but there are other models or technologies to analyse this parameter. The analysers can be portables or can need to be fixed in the facility, depending on the measurement system decided. Portable analysers are strong, easy to use and relatively cheap. The fixed analysers require a more complex installation, because they need to have a different pipe or conduct for every measured point. To avoid it and reduce the costs, they usually have multiplexed piping circuits electronically controlled, with a PC or a PLC (Programmable Logic Controller).

The most useful and practical systems to measure the oxygen content in windrows are the portable analyzers connected to a hollow spear to take the gas sample from inside the windrow.

Some example of Oxygen probes:

- A potential probe for the $O_2$ measuring is *Reotemp'sOxyTemp Probe*, which combines a percent oxygen probe and a temperature probe into one unit. The *OxyTemp* draws a sample of air from deep within the compost pile, blows the sample across the oxygen sensor and displays the percentage of oxygen in a matter of seconds. The probe measures the temperature at the same time and displays the temperature information as well. The price of this probe is about 1470 €.

- A similar probe model is the compost digital oxygen and temperature probe of *Dry-it-Out: Demista OT21* (*http://www.dry-it-out.com/compost-digital-oxygen-and-temperature-probe*), which combine oxygen and temperature probe. The price is about 838,80 £ (about 1020 €).

- Another model is the *Sensotran's* probe*.* In this link it can be found more information of this very useful model, but there can be others (*http://www.sensotran.com/products/product-31.html*)

- LSI Lastem temperature and oxygen DME840 and DME841 probes (*http://www.lsi-lastem.it/WebDocument%5CINSTUM_00753_it-en.pdf*).

- Single and dual probes of SW & WS Burrage for temperature (Pt100) and oxygen, with a length of 1,25 m and a measuring range from - 20°C to 100°C (http://www.burrage.u-net.com/cp.html).

The measurement frequency for oxygen only needs to be high if there is a force aerated system to maintain the aerobic conditions in the windrows. In static or turned windrows, without air forced aerated system, the measure of the oxygen content should be realized to check the evolution of the biological activity and take the necessary actions to avoid anaerobic conditions.

It may also be prudent to measure the $CO_2$ levels, because it is directly related to biological activity and so it is possible to deduct the $O_2$ concentration by a measurement of the $CO_2$ concentration, which measure is often more affordable. As these two parameters are linked together, it is possible to obtain the $O_2$ concentration from the $CO_2$ concentration in an indirect way. Many compost makers use this meter to determine rela-

tive oxygen. The method to obtain $O_2$ concentration indirectly from $CO_2$ measured concentration is the following: when $CO_2$ is high, oxygen is typically low and vice versa ($CO_2$ 21% = $O_2$ 0%). However, the $CO_2$ concentration can indicate both the $CO_2$ generated by the aerobic process and the $CO_2$ generated during anaerobic processes (this last could happen if the environmental conditions are not suitable) because these systems do not distinguish the two origins of $CO_2$. So it is a parameter which must be studied at the same time that others like temperature or $O_2$ levels to be correctly analyzed.
One of the possible instruments is the *$CO_2$ meter & long probe* (http://www.groundgrocer.com/products/CO2-Meter-%26-Long-Probe.html).
This Carbon Dioxide Meter and Long Probe is an affordable way of measuring $CO_2$ in the compost pile. The probe is easily applicable in all condition thanks to the small tip (larger probe's tip have difficulty penetrating the compost pile) and to the 91 cm long probe.
This probe is based on a KOH solution which works as trap for the $CO_2$: the liquid solution expands and on a graduate scale is read visually the $CO_2$ concentration. A sample of flue gas is pumped into TESTORYT by means of the Aspirator Assembly. Absorption of $CO_2$ by absorbing fluid creates a suction which causes the diaphragm at the bottom to flex upward permitting the level of the absorbing fluid to raise an amount proportional to the gas absorbed. The scale indication is then read as percentage of the gas absorbed by the fluid.
*The price is about 1000 €.
This solution does not use any data logger, because the measure has to be read directly by the operator.

***Moisture of the material***

During the first weeks of the process, if the mixture of the materials (biowaste and bulking) has the adequate proportions and is homogeneous, the initial moisture of the windrow should be around 60%, equivalent to 400 $g \cdot kg^{-1}$ of total solids. In that value, if the other conditions are the appropriate, the composting process begins.
So, in the first weeks, it is not necessary to realize an exhaustive following of the evolution of the moisture. During this first stage of the process (fermentation) the material loses the excess of water mainly by evaporation and leaching. Only when the maturation phase begins is really important to know the real moisture content in the windrow, and follow it from that moment till the end of the process, deciding if it is necessary to

watering the windrow or not, to maintain the moisture levels that guarantee the biological activity and the process efficiency.
It is difficult to measure this parameter using probes. The main difficulty to measure the real moisture of the windrows is the environmental conditions of heat and water vapour. Any metallic probe introduced inside the windrow when the process is active will condense water because of the difference of temperature between the metal and the windrow. Those drops of water will affect to the measurement of the moisture if the probe uses the electric charges or field between two or more points to calculate the water content of the materials. Most of those moisture probes are designed to be used to measure the moisture in soils, where the environmental conditions are really different from in a composting windrow.

Some example of moisture probes:

- *Reotemp Instrument Corporation* produces two low cost probes specific for the compost moisture measurement. These give a relative "wetter than" or "dryer than" reading (scale from 1 to 10). It will not give a percent moisture result:
    - The first probe is *Moisture Meter* (75 €). The meter must first be calibrated until it reaches “5” on the 0-10 scale. Then it is possible to check the compost moisture. If the reading is above “5” it is too wet, if it is below “5” it is too dry. The meter uses the conductivity which is sensitive to salts content changing. The salts content of compost often varies according to the location making a consistent reading sometime hard to achieve. The meter is intended to give a good idea of the moisture of the center of the pile. The meters come in stem lengths from 60 cm up to1,5 m.
    - The second probe is *REOTEMP's Backyard Moisture Meter* (25 €) with a 43 cm stem. It is designed for monitoring relative moisture in a backyard sized compost pile. It is necessary to calibrate the meter for a standard pile to get a relative 0-10 reading. The meter is sensitive to changing salt content and can be used to give the moisture content. The backyard moisture meter has a shorter stem than the long stem moisture meter precedent described. It is intended for smaller compost piles.

These solutions do not need any data logger, because the measure has to be read directly by the operator.

- *KIMO Instruments – HRI 300* with a probe length of 300 mm (it is possible to have a longer probe but it is not a standard model) that has to be connected to a reader instrument that can also be used as a data logger (KIMO HD200). The total price is 915 €.
- *EXTECH Instruments - MOD. SDL550* (490 €) with a probe length of 600 mm.
- *LSI Lastem - DQA345* (http://www.lsi-lastem.it/ItemBySERP.aspx?ItemID=334&Query=Compost and http://www.lsi-lastem.it/WebDocument/BLT_01137_en.pdf)

Of course there is the option of taking a sample of the windrow and analyze it in the laboratory. Apart from the time needed for the operation, the key factor is to be sure that the sample taken is representative of the whole windrow. The laboratory necessary instruments are a stove and a moisture balance. In the case of the simple an open pile facilities, it is recommended to use this method for the measure of the moisture content with **a good training of the plant operators**. So it will be possible to check easily if the moisture is adequate or not, and if the material needs water or not.

***pH***

This parameter it is not really important at the beginning of the process, when the wind-row is made. But it is a key factor in the moments that the temperature passes from mesophilic to thermophilic levels (45 – 55ºC).

If there is an adequate work protocol in the facility and a composting "recipe" appropri-ate for the kind, characteristics and quantities of the biowastes to be composted, it should not be a problem, but in any case it is recommended to check it.

The direct measure of the pH in the material can be realized with an on-field pH-meter, but those equipments usually have a considerable margin of error. The pH of the mate-rial can be measured in the condensate from the atmosphere inside the windrow. Any system to collect air from the inside of the windrow and condensate it in a recipient with a pH probe can give the pH of the windrow with a very small deviation from the real value analysed in the laboratory. The pH-meter can give a signal of the measure (4 – 20 mÅ) to any data logger or reader device. This system is very useful if the compost-ing system is a force aerated windrow with control of the temperature.

Another possibility is to use a classic pH-meter. One can be the *Spear-shaped pH electrode (Electronic Temperature Instruments)* and costs about 100 €. It is 12 mm long and the glass, spear-shaped, penetration electrode is ideal for insertion into semi-solid materials.

Other measurement system can be the paper pH indicator.

It is not necessary to connect the pH-meter with a data logger because this parameter will be useful only during the first days of the process. The evolution of this parameter is very slow, so it does not need to be measured continuously.

## The maturation stage

If the fermentation stage is correctly done, when the windrow enters in the maturation stage the biological activity is not so intense. Because of that the requirements of monitoring and control the process are much less intense, and the main objective is to maintain the adequate conditions of the windrow to maximize the efficiency of the biological activity at every moment.

The weak points of this stage are:

- The moisture of the windrows. Because of the intense biological activity and the high temperatures during the fermentation stage, the loss of water by evaporation is very high. The moisture levels at the maturation stage can be so low that the biological activity would be totally or partially inhibited.
- The temperature of the windrows. Because of the low biological activity, there will not be critical heat production. Depending on the size of the windrows, the duration of the fermentation stage and the kind of biowastes, the windrows could not be able to keep the temperature and cool it down till environmental values. This cooling of the material will negatively affect the biological activity of the microorganisms, and the efficiency of the composting process.

***Temperature***

It can be measured with the same probes (or kind of probes) that are used in the fermentation stage. The only difference is about the frequency of measuring that is really needed. There will not be a direct control of this parameter as it can be realized in the fermentation stage (depending on the composting system used), so the interest is to know and to follow the evolution of this parameter.

The frequency of measurement of temperature can be twice a week, so the operators can do it manually.

***Oxygen (and other gases)***

The biological activity will not be intense during this stage, so the demand of oxygen or the $CO_2$ production will be lower. There should not be risks of achieving anaerobic conditions if the fermentation stage is completed, so the measurement of the oxygen content inside the windrows can be realized once a week.

The same equipments proposed or decided for the fermentation stage can be used in this stage.

***Moisture of the material***

This is the most important parameter during the maturation stage. The tendency during the composting process is to have a negative water balance because of the evaporation by the heat and the pass of air through the material. If the moisture level drops below 35% - 40% the microorganisms will be inhibited and the biological activity will be drastically reduced.

So the evolution of this parameter should be measured with a frequency that allows to program corrective actions in advance. Depending on the season of the year and the climatologic conditions the measurement frequency can vary from every week to every two weeks.

***pH***

This parameter is not really important to control the process during the maturation stage, so it does not need to be measured till the end of the process, to know its values in the final compost. At the end of the process, appropriate values of pH should be about 7,5.

***Density***

Density is an indicator of maturity level of the compost level of maturity: during the process, the density of the compost should increase.

The best way to measure the density of the compost is the application of a precision balance to obtain a series of values weighing for a determinate volume of compost.

***Maturity***

There are different ways to measure this important parameter, but most of them need to take the sample to an external laboratory or to have specific instruments to analyse the compost maturity in the facility. Like the Dynamic Respirometry Index (DRI) that gives good and reliable results about the stability of the organic matter, but needs specific instruments to measure it. So, considering the low cost-low tech facility, four methods that are quite simple, also quite reliable and do not need a high investment, are listed here under:

- *Rottegrade* test:

This is a classical test, based on heating a compost sample in an insulated container. Logically, the more stable the compost is, the less temperature is achieved and thus a standard degree of maturity is defined (table 18).

| ∇max. sample's temperature – environmental temperature | Degree | Maturity level |
|---|---|---|
| 0 – 10 °C | V | Very mature |
| 10 – 20 °C | IV | Mature |
| 20 – 30 °C | III | No mature |
| 30 – 40 °C | II | Under composting process |
| 40 – 50 °C | I | Fresh material |

**Table 14.** Range of temperatures (sample's temperature – environmental temperature) and it correspondence with maturity grades by the Rottegrade test.

Laboratory material needed for this test:

- Sieve with mesh size of 10 mm
- Dewar flasks (at least three of a volume higher then 2,5 litres)
- Thermometer thermostatically controlled cabinet at 20 °C, or at least with little differences of temperature during the day (environmental temperature must be also measured).

The moisture of the samples must be adjusted, so, to have more accurate results, the following material can be also needed:

- Drying stove
- Balance (accurate to 0.1g)

- Plants germination test:

This is the simplest and most reliable method. The plants test most commonly used are garden cress (*Lepidiumsativum*) and lettuce (*Lactucasativa*). Seeds of the plants test are sown in compost in a humidified sealed jar. After three days, maturity is measured by the percentage of germination and possibly the amount of green material obtained. It also gives information about toxicity and germination index of the compost sample.

- Circular paper chromatography test:

  This method, based on the principle of paper chromatography, was developed by Pfeifer (*Biochemical Research Laboratory, Spring Valley - USA*) and tested by Hertelendy. It uses the fact that different substances, dissolved in the same solvent (solution of 5% sodium hydroxide), have varying affinities capillary migration on an absorbent surface (round filter paper sheet). This absorbent surface is pre-treated with silver nitrate, which serves as developer. Alkaline solution of compost is introduced drop by drop at the center of the filter paper. After migration of the solution, the chromatogram is enabled to develop in subdued light. Immature compost is characterized by a dark image at the periphery and a clear central spot, on the contrary, mature compost shows a dark central spot with bright streaks toward the periphery.

- *Solvita test:*

  The kit measures both carbon-dioxide ($CO_2$) and ammonia ($NH_3$) which are the two most common gases released during composting. High release of either or both gases indicates an unstable and possibly odorous condition associated to very actively degrading compost. The test results are combined in a unique fashion to obtain a Maturity Index. It is a volumetric procedure: it measures respiration and emissions per unit volume of compost, and not per unit weight which is customary if a sample is sent to the laboratory. The test is applicable on-site to monitor the process, and for gauging the end of composting. The detection is based on gel-colorimetric technique, analogous to Beer-Lambert's law governing optical-chemical reactions to changing concentrations of dissolved molecules, carbonic acid and ammonium hydroxide.

Each *Solvita Classic kit* is furnished with 6 $CO_2$ + 6 $NH_3$ test strips, incubation jars and an instruction manual that provides insight into the compost process and gives guidelines for proper use of compost products at each level of maturity and activity (90 €).

*Digital Color Reader* increases the reliability, precision and functionality of Solvita Kits. The DCR is pre-programmed to read High-$CO_2$, levels of Low-$CO_2$, and Ammonia-$NH_3$ in accordance to measuring compost. The DCR is both battery and USB powered. By using the USB port, the user is able to upload the reading for use in a spreadsheet or report. The DCR comes with 6 probes and 2 test jars for Compost analysis (1,100 €).

*Lab pack* includes 50 $CO_2$ and 50 $NH_3$ tests and colour chart (450 €). Every time that a sample is analyzed it is necessary to use a new kit.

http://www.agritaliadige.eu/39,solvita-compost-maturity-test.html

Another provider for Solvita test is: Dry-it-Out (http://www.dry-it-out.com/Solvita-Compost-Maturity-Test-Kit-x-6). Price for 6 test kits is 126 £ (about 153 €).

## 4.2. Systems of data collection

For the composting facilities based on low cost-low tech, the idea of simply technology is not contradictory with the introduction of a data measurement system that can allow to measure and register the data automatically. Currently there are many systems to collect data that are quite simple and low-cost.

From the list of parameters to be measured, the temperature will require a more intensive and continuous register of the data. It can be realized by hand, copying the measured data to an excel sheet, or it can be done automatically.

At this point, there will be different options depending on if an automatic response to the evolution of the data is needed or not.

***Data loggers***

In this category, there can be different kinds of models considered. The most simple equipments register just the data measured at a programmed period of time (minutes, hours, days,…).

From time to time the memory of the data logger needs to be downloaded to a PC (usually to a excel file) and this has to be realized by the operator. It means that till the moment that the data is in the computer it is not possible to study and analyse the evolution of the temperature in the windrow.

This type of system costs around 950 € (*Windrow Data Logger COMBO*) and is described below:

- Walk the windrows, using the WDL to record a temperature for each location as you go.
- Reconnect the WDL to your computer and upload the data. You can export into excel and save.  Each tag will have its own sheet in excel.

Features/Benefits

- Temperature Range Type K Thermocouple: -200 ºC to 1372 ºC
- Resolution 0.1 ºC
- Accuracy < 1.0 ºC
- Water-resistant sheath
- Construction Conforms to IP54 standards
- Data capacity 5000 data items when in collector mode.
- Tag Names Maximum of 50,

each comprising of up to 8 alphanumeric characters

- Operator Names Maximum of 10, each comprising of up to 8 alphanumeric characters
- Comments Maximum of 32, each comprising of up to 8 alphanumeric characters
- Alarm function Upper and Lower-limit alarms
- Display LCD with backlight

There are models that send the signal by radio to the PC, so the data is being registered directly in the hard disk. It allows to have immediately all the information about the evolution of the temperature in the windrow.

Another kind of data loggers are designed to substitute the PC. They are directly connected to a determinate number of probes (temperature and others) and all the data can be seen in the screen with different kind of graphics and representations. The historical data can be copied in a USB memory card and transferred to a PC.

Their main limitation is the number of probes that can be connected to them, but it is possible to increase this number with other modules.

***Programmable Logic Controller (PLCs)***

These systems are widespread in the industrial world because of its flexibility and high capacity to monitor, control and realize almost any task. In the composting sector they have been linked to the "in-vessel" systems, like the tunnels, where the control of parameters like temperature and/or oxygen by the functioning of centrifugal fans is realized by PLCs.

They can receive multiple signals of different kind of probes and at the same time the PLC can have configured different “exits” or signals to control other instruments or equipments, by example, centrifugal fans.

The PLC can be programmed to control different tasks, memorize the data received, etc… Every manufacturer has his own software to program his equipments, so there are big differences between the complexity and capacity of the software and the knowledge that is required to program it.

## 4.3. Quality of the compost obtained

In order to obtain a compost which can be treated as a product or considered as a good quality material, there should be taken into consideration the different European regulations and/or directives regarding compost quality and the different parameters and characteristics involved.

| DIRECTIVE | | Organic farming | EoW | EU ECO Label | Stabilised Biowaste | | |
|---|---|---|---|---|---|---|---|
| LEGAL BASIS OR STANDARD | | Council Regulation (EEC) No 2092/91 | End-of-waste criteria on Biodegradable waste subject to biological treatment | COM Decision (EC) nº 64/2007 eco-label to growing media; COM Decision (EC) nº 799/2006 eco-label to soil improvers | Sewage Sludge Directive | | |
| POTENTIAL TOXICS ELEMENTS (PTEs) CONCENTRATIONS (mg·kg$^{-1}$ d. m.) | Quality / Standard | | | Voluntary (Mo: 2; Se: 1,5; F: 200 if industrial processes are included) | Compost/ digestate Class 1 | Compost/ digestate Class 2 | Stabilised biowaste |
| | As | - | - | 10 | - | - | - |
| | Cd | 0,7 | 1,5 | 1 | 0,7 | 1,5 | 5 |
| | Cr (tot) | 70 | 100 | 100 | 100 | 150 | 600 |
| | Cr VI | 0 | - | - | - | - | - |
| | Cu | 70 | 200 | 100 | 100 | 150 | 600 |
| | Hg | 0,4 | 1 | 1 | 0,5 | 1 | 5 |
| | Ni | 25 | 50 | 50 | 50 | 75 | 150 |
| | Pb | 45 | 120 | 100 | 100 | 150 | 500 |
| | Zn | 200 | 600 | 300 | 200 | 400 | 1500 |
| PERSISTENS ORGANIC POLLUTANTS CONCENTRATIONS (mg·kg$^{-1}$ d. m.) | Total PAH | | < 6 | | 3 | | |
| | Total PCB | | | | 0,4 | | |
| IMPURITIES | Total (> 2 mm fraction) | | < 0,5% | | < 0,5% | < 0,5% | < 3% |
| | Total (> 5 mm fraction) | | | | < 5% | < 5% | - |
| QUALITY REQUIREMENTS | Organic matter | | > 15% | | | | |
| SANITISATION MICROBIAL INDICATORS | *Salmonella sp.* | | absents in 25 g | absents in 25 g | | | |
| | *Escherichia coli* | | < 1000 CFU/g | < 100 MPN/g | | | |
| | *Others* | | | *Helminth Ova* | | | |
| OTHER ASPECTS | Weeds (plants·l$^{-1}$) | | ≤ 2 | ≤ 2 | | | |
| | Stability Maturity | | Rottegrade III / OUR < 25 mmol $O_2$·kg$^{-1}$ VS·h$^{-1}$ | | | | |

**Table 15.** Compost quality and characteristic requirements of different EU regulations.

## 4.4. Result Indicators

In order to monitor the management model in each of its phases as well as assess the achieved results, it is important to calculate a panel of indicators and collect and record the related necessary data.

Here under there are listed a proposal of indicators panel divided into the main management stages: collection, treatment and compost application.

**ecivres noitcelloC**

- Tons of collected biowaste
- % of impurities present in collected biowaste
- Number of population served with the collection system
- Number of big producers served with the collection system (it can be divided by type)
- Number of seasonal population served
- Total number of containers/bins (it can be divided by type) and final available collection capacity installed
- Total number caddies distributed (it can be divided by type)
- Number of containers collected per service day (containers systems)
- Number of bins and bags collected per service day-household (door to door systems)
- Number of bins/containers collected per service-big producers (door to door/container systems with specific bins for big producers)
- Frequency of collection for biowaste (days per week)
- Number of trucks providing the service
- Number of workers providing the service
- Km of the collection route
- L of combustible used per year by the collection service
- % of usage of compostable bags
- Number of incidences detected and informed per service day (door to door systems)
- Number of cleanings services per container per year (containers systems)

**Treatment**

- Tones of the different flows of biowastes treated
- Tones of the different flows of bulking material used
- Time of fermentation, time of maturation process
- % of compost produced from the quantity of biowaste treated in the facility

- Tons of compost produced
- Entrance fee for biowaste and bulking material
- Incomes generated by the compost sale
- Final balance of cost/benefits per ton of biowaste treated
- Number of staff and hours of staff work
- Energy consumption of the facility
- Waste consumption of the facility

**Compost application**

- Tons of compost provided to the different final uses and related quality
- Tons of compost distributed in bag and in bulk
- Surface of agricultural land where the compost is applied
- Quality of the compost produced in correspondence with the European Directives. EcoLabel, End of Waste, Organic farming (Council Regulation (EEC) No 2092/91)

**Other**

- Tones of $CO_2$ eq. reduced at the landfills and transportation
- Tons of organic nitrogen applied to the soil (kg N•t-1 applied compost),
- Tons of phosphor applied to the soil (kg P applied compost)

# 5.- Compost marketing

## 5.1.- Properties, qualities and uses of compost, comparison with other fertilizers

**The organic matter losses in the European soils, and very especially in the Mediterranean basin, which have been intensively cultivated for a long time** (Rusco *et al*, 2001), are calculated around the 35 $t \cdot Ha^{-1} \cdot year^{-1}$ (Perez, 2005). In the southern Europe 75% of their soils have an organic matter content under (3.4%) or very low (1.7%) of organic matter (Figure 50), amount that agronomists consider already like a pre-desert soil (Soliva & Felipó, 2002). The levels of organic carbon in the upper layer of the soil from the whole of Europe show that there is 45% with content between 2 and 6% of organic carbon and another 45% of the area with values lower than 2% (table 3).

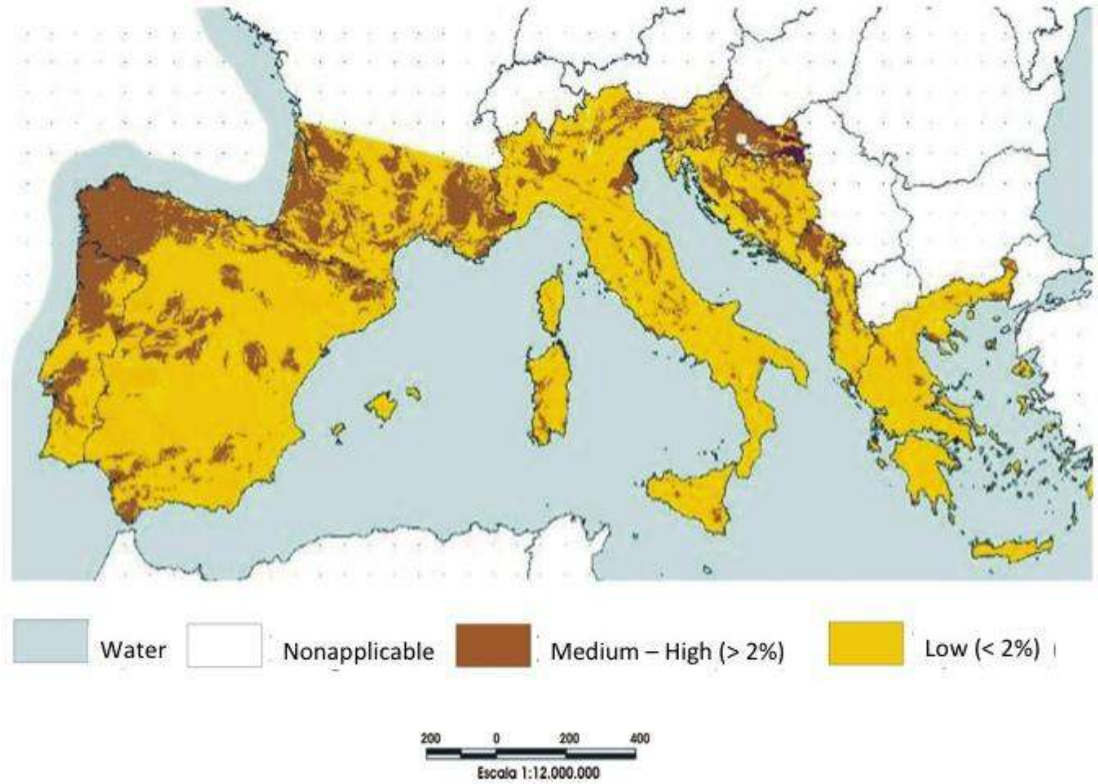



**Figure 50.** Estimated content of organic carbon in the surface layers of soil in the South of Europe. (Source: European Soil Bureau (2004). Map according to Jones *et al,* 2004's concept).

| Surface (Ha) | Organic Carbon (%) | Area (%) |
|---|---|---|
| 66.558.238 | < 1% | 13 |
| 163.967.166 | 1-2% | 32 |
| 232.325.106 | 2-6% | 45 |
| 22.173.470 | > 6% | 5 |

**Table 16.** Organic carbon content in European soils. (Source: Montanarella, 2002).

**The use of fertilizers to maintain the soils productive is estimated in Europe on 17 Mt per year**, but it could almost say that this data is modest in comparison with China, which consumes 47 Mt per year, or with the United States, where only maize uses 10 Mt of fertilizers by year (Kluger, 2010). The energy costs involved to produce this amount of fertilizer would be between 37 and 130 MJ per each kilogram of nitrogen fixed from the atmosphere (depending on the method used) (Flotats, 1999). In addition it should be included in the balance sheet the greenhouse gases generated in production (Favoino & Hogg, 2002).

**We know that agriculture has a significant effect on the soil organic matter content, resulting in its loss through consumption, exposure to the atmosphere, erosion**,... (Montanarella, 2002). The annual loss of organic matter varies greatly depending on agricultural practices (Waters & Oades, 1991), the type of crop, the drainage of the soil and weather conditions, and unless this organic matter is quickly replaced, the system will be in a state of continuous degradation that will end up taking it to consume more resources than those produced (World Bank, 1993).

**A soil with a poor organic matter content will have affected its properties like:** changes in its structure, more tendency to cracking, erosion, tendency to compaction, increased temperature, decline in retention of water and nutrients, and reduction of its fertility, its biodiversity and its biological activity (Soliva & Felipó, 2002). Hence the very important role played by the compost as input and return of stabilized soil organic matter.

**The knowledge of the intrinsic characteristics and the agronomic evaluation of organic matter for the increase of the fertility of the soil is the key in the use of compost** (Sequi *et al*, 2000). However, always remembering that the application of compost up to rates in excess of the requirements of the plant or the assimilation capacity of the soil may be a risk of leaching and nutrient losses (Easton & Petrovic, 2004; Vietor *et al*, 2002). Therefore it should be considered more as a soil conditioner than as a fertilizer since the nutrients provided by the compost have a slow release and the improvements in the production of crops can be seen in the following years. So it is very difficult to assess the true value of the agronomic application of compost, and even less pretending to compare it with chemical/mineral fertilizers (Tittarelli & Canali, 2002; Shimozono *et al*, 2008). **The application of compost to soil cannot be simply evaluated because of its agronomic effects in the short term, but as a sustainable agricultural practice** (Tittarelli & Canali, 2002).

Undoubtedly, the organic matter in the compost is the more important component because most of the other products used in agriculture do not have it, or have it in lower concentration. In this way, and although during the composting process the Total Organic Matter of compost decreases, the finished compost not only must have notable contents of organic matter that provides it that "organic value", but also this organic matter should be largely resistant organic matter that gives stability to the amendment and benefits soils after its application. If the compost of household biowastes is compared to another type of organic products (compost of other origins, manure, etc.), it can be observed that it has concentrations of organic matter much higher than other products, being only the manure the one that presents higher values in organic matter in relation to the Biowaste compost.

**Among the compost benefits for the soil it should be pointed out** (Golueke, 1982; Montanarella, 2002; Dorahy *et al*, 2006; Provin *et al*, 2007):

- **It improves fertility,** not only due to the contribution of N, P, S and trace elements, but it may also increase the pH in acid soils, improving nutrient availability. This results in significant energy savings in the production of fertilizers, as an application of 10 $t \cdot Ha^{-1} \cdot year^{-1}$ of compost would save 160 to 1.340 kWh of energy that would be needed to produce the equivalent amount of 190 kg of nitrogen as fertilizer (Favoino, 2010).
- **It improving the structure,** giving the soil a greater capacity for ventilation as well as a better drainage, getting better and more easily the water and reducing irrigation requirements. Likewise the continue application of compost during the

years reduces the difficulties and costs of the soil work, with consequent energy saving.

- **It improves the microbiota,** and can serve as a pests and plant diseases suppressor, including nematodes, which implies not only an environmental benefit in reducing the pesticides use, but also an energy saving in its production.
- Depending on the type of soil can even act as a **corrector of salinity and conductivity**. A well-structured soil improves the infiltration of rain water and the permeability of subsurface, washing the soluble salts (Avnimelech *et al*, 1994).
- It contributes to the **sequestration of atmospheric carbon,** acting as a carbon sink, that along with good agricultural practices, would contribute to mitigating the greenhouse effect (Barral *et al*, 2001).
- It **reduces the need for peat,** implying a lesser extraction of fossil carbon, favoring the control of greenhouse gas emissions.

**Obviously not all the compost are the same, because one of the most important and influential factors in the quality of compost is the raw material or biowaste** from which has been produced, together with the way in which the composting process has been developed in the facility. But this concept of quality in the compost, as well as being very subjective on its own, is subject to various pressures and interests. The intrinsic quality of the compost would be given by its different properties and physical characteristics (particle size, presence of foreign particles, moisture holding capacity, odor), chemical (content and stability of organic matter, content and speed of mineralization of the plant nutrients contained and the presence of contaminants, inorganic and organic) and biological (presence of weed seeds, pathogens); but there are other relevant criteria in terms of the evaluation of this intrinsic quality: the destination of the product, the protection of the environment and the requirements of the market (are they real or manipulated?) (Soliva, 2000).

**The strategy to achieve a certain quality of the compost cannot be separated from a comprehensive approach of the waste management.** There is a non sense in applying restrictive rules for the manufacture and quality of compost if other materials such as sludge from urban and industrial wastewater treatment plants are applied in agriculture with much less requirements (EU Directive 86/278/EEC), or if there is not a compost market, which should be developed along with an awareness in terms of quality (Soliva, 2000).

**When compost is applied to the soil the reason must be for a source of organic matter or as a source of phyto nutrients**. And in the first case it is sought mainly to improve the structure, characteristics and composition of the soil, so it is needed a very stable compost and with a high content of organic matter. In the second case it is well known the composition of nutrients (mainly nitrogen) in the compost, as well as its speed of mineralization; at the same time the conditions of the soil where it will be applied and the needs of crops must be also identified.

For example, in Germany three types of compost in function of its use or application are considered: fresh compost, mature compost and compost for pots or seeding; establishing requirements and characteristics for each (Siebert *et al*, 2008). As it is evident the third is the most demanded in terms of its content in soluble nutrients and mineral salts, but this is not a reason for the other two types of compost to be sold and used to improve soils and for fertilization. As a reference, Soliva (2000) has also proposed three qualities of the compost that would define their possible uses (Table 17)

| Low quality | Medium quality | High quality |
|---|---|---|
| Sealing dumps | Extensive agriculture | Substratum |
| Recovering marginal soils | Silviculture | Nursery |
| Recovering degraded soils | Erosion control | Gardening / Horticulture |
| | Landscape restoration | Sport field grass |
| | | Private and public gardening |

**Table 17.** Possibilities of application of compost on the basis of its quality (Soliva, 2000).

In Table 18 it is clear that not all the compost are suitable for such uses. Compost from household biowastes (source separated) and green wastes have a great acceptance in almost all applications (with the exception of the preparation of substrates), which greatly differs from more restricted applications for the compost produced from the organic matter contained in the Residual fraction of the municipal wastes.

| More adequate applications for compost from… | Manure | Bark | Green wastes | Sludge + Green wastes | Mixed wastes + Rest fraction | HB + Green wastes |
|---|---|---|---|---|---|---|
| Agriculture | ● | | | ● | ● | ● |
| Private gardening | ● | ● | ● | ● | | ● |
| Public parks and gardens | ● | ● | ● | ● | | ● |
| Landscape restoration | ● | | ● | ● | ● | ● |
| Recovery of degraded areas | ● | | ● | ● | ● | ● |
| Recovery of vegetation on public works | ● | | ● | ● | ● | ● |
| Substrates preparations | | ● | ● | ● | | |
| Sport fields | ● | ● | ● | ● | | ● |

**Table 18.** More desirable applications for certain types of compost. HB: Household Bio-wastes. (Gea, 2005).

**The use of compost in agriculture does not have as many restrictions as those for other destinations** (mainly gardening). Even so, it is very important to always keep in mind what kind of crop exists in the target soil to avoid potential problems of salinity for sensitive crops and to adapt the doses of "product" if necessary. The characteristics of fresh compost, as the important contribution of organic matter (more than 35%), no substantial contribution of nutrients N, P, K[50], as well as the salt content (electrical conductivity), with no more than 8-9 $dS \cdot m^{-1}$ values, make enough interesting its application in agriculture.

[50] At general level, compost from household biowastes has values of contribution of nitrogen - approx. 2% of fresh product as reference value - superior to those of potassium and phosphorus; and contribution of potassium values slightly superior to the phosphorus - media 0.6% of phosphorus against average values of 1% potassium in fresh product.

## 5.2.- Composting an organic waste or producing a compost? – The strategy of the compost managers

Many factors should be considered when implementing the project of a composting facility, but with regard to the model of business, or the financial sustainability of the project, the decision should be between two basic options:

- The **charge for the treatment of the organic waste** that comes to the installation to be composted = $€·t^{-1}$ of organic waste treated.
- The **charge for the compost produced** and sold = $€·t^{-1}$ of compost produced.

Obviously there can be an intermediate position, where the facility has a charge for the income of organic wastes to the facility and sells the compost produced. But in any case there is a different strategy for those options.

**In the first case, the design of the composting facility should be adapted to be able to correctly treat different types of organic wastes**. In some cases there will be a main organic wastes to be treated (sludge from wastewater treatment plants, manures, organic fraction from households waste,…), so the design of the facility must be realized to optimize the biological process according to the needs and characteristics of that organic wastes and the environment where the facility will be located. In other cases, the facility should be designed to accept very different types of organic wastes, so the design and the composting system selected must be flexible to be able to adapt to the most critical needs of the organic wastes. To achieve the maximum efficiency of that kind of facility to have the maximum economic benefit is a key factor; means to get a stabilized organic matter as soon as possible and with the less consume of resources and energy. The quality of the compost is not so important, but obviously it have a minimum to assure that the outcome of the product has no costs.

**The second type of facility has its benefit of the sale of compost**. It means that the maximum quality of the compost produced is absolutely necessary, so it also means that the key factors is to have the best quality in the organic wastes received and to realize the composting process under the best conditions. There are many factors related to this strategy:

- Which **main customers** are **in the area** for the compost (gardeners, horticulture, agriculture,…)

- What kind of **product** they want and with which **characteristics**: mature compost, some type of substrate that mixes compost and other materials, macronutrients content (N, P, K), micronutrients (S, Mg, Si,…),
- If producing an **ecolabel compost can improve their sales** and if possible, to produce a part or all the compost with that category.
- The **type and quantities of organic wastes that are generated in the area** and how far they are from the facility location.

**In this strategy the balance between the costs of the treatment must be as low as possible but with the guarantee of the better conditions for the microorganisms, so the knowledge of the biological process is also a key factor**.

There are not many facilities like these. Only in the areas, regions or countries where there is a demand of high quality compost and it can be sold at good prices.

**The intermediate position, a composting facility that gets its incomes by the gate fees for the organic wastes that are received and by the sales of compost,** also needs to consider the same factors, maybe with different priorities, **but always taking in mind the information of the availability of organic wastes of the area** (types, quantities, distance, current treatment and its costs/prices, bulking availability) **and the potential commercialization of the compost produced** (potential quality of the compost -macronutrients, heavy metal contents, eco-labeled or not, quantities produced, potential customers, their requirements of the product, form of application, form of commercialization -bags, bulk, etc…).

**It is always necessary to invest time, personnel and money during the first year or two years of the facility to create a net of customers around the facility for selling the compost.** Usually people will not be coming to the facility asking for compost and the consumers who could be interested need to know the product and its characteristics taking the decision of whether their want it or not. Other information including the speed at which the nutrients are released (specifically the nitrogen) or the recommended doses for each culture, are normally required.

Composting is a form of recycling the organic matter and returns it to the soil, so it should be assured that there is at least a minimum quality to avoid dumping it.

## 5.3.- Types, necessities and requirements of the customers communication and awareness

First of all, it **must be considered that the marketing of any product requires**:

- Understanding requirements of the customers.
- Maintaining a quality control to ensure that product meets the specifications of the customers.
- Preparing the product to maximize its value.
- Presenting the product with a consistent positive image.
- Delivering the product in a timely manner; providing customer service.
- Pricing the product.
- Creating a trademark. It must be consistent with the use or final destination of the compost and not related to the origin of the "product", with the intention of occupying a highly competitive segment of the market.

However, the compost has some **characteristics that make it completely different from any other products, so they will define the strategy to develop the marketing lines**. First of all, it must be considered that its production is continuous and is not based or directly conditioned by the market or customer demands.

The economic incomes of the facility, the revenues, are more important for the gate fees of the organic waste than for the compost sales. At the same time it must be considered that the final composition and characteristics of the compost are highly influenced by the initial organic waste. So to maintain the composition of the product along the time can be limiting.

There is a constant evolution of the compost if it is stored under non-adequate conditions. Even so there is a change of the product if it is stored for a long period of time, because the biological process of degradation and transformation of the organic matter continues, but at a very low rate.

## Definition and knowledge of the market

It must be remembered that not all compost is the same, not only in quality (heavy metals content) but also in the nutrient content and other chemical parameters. **It means that if there are different kinds of composts, there are different uses or applications for those composts**. It means that different customers have different needs, and these will depend on how compost is going to be used.

Here there is another important step, the fact **of trying to understand the real needs of the customer, we must first answer these initial questions**:

- What are the specific project goals?
- How is the compost going to be used?
- What is the alternative product(s) available?
- How is the product going to be delivered and handled?
- When is the product needed?

In addition**, economic savings of substituting certain inputs should be measured and disclosed**; either because the compost already provides some of their components or because the increase of organic matter in the soil favours the saving of watering. This reduces the energy consumption of the mechanical work or may even promote the fight against particular types of phytopathologies.

The compost requirements for nursery and greenhouse cultures demand higher quality composts (maturity or stability, low salt content, macronutrients) and a high price can be obtained. This also means that those customers will require a stable quality along the time.

| Use | Landscapers | General turf | Sports turf | Topsoil manufacturing | Agriculture |
|---|---|---|---|---|---|
| Yard trimmings | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕ | ⊕⊕⊕ | ⊕⊕ |
| Biosolids | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ |
| Manure | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ |
| MSW | ⊕⊕ | ⊕⊕ | ⊕ | ⊕⊕ | ⊕⊕ |
| SSHB | ⊕⊕⊕ | ⊕⊕ | ⊕⊕ | ⊕⊕⊕ | ⊕⊕⊕ |

| Use | Erosion/Sediment control | Reclamation | Resellers | Wholesale nurseries |
|---|---|---|---|---|
| Yard trimmings | ⌖⌖⌖ | ⌖⌖⌖ | ⌖⌖⌖ | ⌖⌖⌖ |
| Biosolids | ⌖⌖ | ⌖⌖⌖ | ⌖⌖ | ⌖⌖⌖ |
| Manure | ⌖⌖ | ⌖⌖⌖ | ⌖⌖ | ⌖⌖⌖ |
| MSW | ⌖ | ⌖⌖⌖ | ⌖ | ⌖⌖ |
| SSHB | ⌖⌖ | ⌖⌖⌖ | ⌖⌖ | ⌖⌖ |

**Table 19.** Compost feedstock and its acceptance within selected compost markets. MSW: Municipal Solid Waste; SSHB: Source Separated Household Biowaste. (Source: Alexander, 2012).

## Presentation of the product: bulking or bagging?

**The main differences between bulking and bagging of the compost are related to the kind of market where the compost will be sold.** It is supposed that the home gardener market gets higher prices for the compost, but it means higher investments in the facility for bagging (sieve, packaging,…) and also involves that in the facility the compost must be extremely cared to achieve the conditions required for bagging (maturity, moisture, particle size,…). All these needs will increase the production costs in the facility.

The sales of bulking compost means lower prices, but it also entails lower costs of production if the work protocol in the facility is adequate and is well defined attending the organic wastes characteristics, the environment and the composting system. Farmers and professional gardeners are the main customers for this compost presentation, but also in public works, sport fields, wetlands, etc…

## Production and demand of compost

Another frequent problem in the marketing of compost produced by a facility, is that after the first years is to get **a balance between the production of compost and its quality and characteristics**. If the product is good it will have more customers, but there is **the risk that the producer could try to increase the quantity of compost sold, by introducing to the market as unfinished compost** if there is the chance to have good sales during a short period of time. It can be really risky if the customer has

any problem with the compost because it is not finished and this will reduce or close the future sales of the compost produced in that facility in the following years.
The customer must have a guarantee of the product quality.

## Information

**Customers want to know the characteristics of the product and usually demand information about certain parameters** like:

- Nutrient content, especially nitrogen (and its chemical forms), potassium and phosphorus.
- Soluble salts or conductivity, that will limit the uses of the product,
- pH
- Doses of application to their crop fields.
- Methods and/or machinery for the application.
- Pathogens, because it must be hygienized for certain microorganisms (*Salmonella*, *Escherichia coli*, *Clostridium*,…)
- Seeds of weeds, because they must not be present in the compost.
- Heavy metals content, according to the national legislation
- Origin and/or kind of organic wastes used in the process of production. That is to have a traceability of the product and its raw materials (organic wastes). It should be noted that the composts that could be ecolabelled and certified have a high demand for organic farming and usually command higher prices.

To get all this information chemical analytics are not only needed, butalso studies of germination and fertilization of different kind of plants with the product. Some kind of link or relation with a research center or university to develop tests on field, maybe in some crops of local farms, will be a very interesting experience to get information of the product, and also to obatinphysical results to be shown to potential customers.

## Creation of a compost market

**Through means of investing time, staff and money in visiting the potential customers in the influence area around the facility, to know them, to learn what they need,** what products they are using as fertilizers, pesticides and/or soil conditioner, the prices that they are currently paying, etc… With this information it will be possible to create a marketing plan, to establish real objectives and define the needs and efforts to achieve such goals. (staff, time and budget). It should be considered at least from two to three years to have a customer base and to compare the results of the product with its competitors.

The operators of the facility have to consider also that they can have other products apart from compost like compost tea or vermicompost. The compost can also be presented as pellets or granules to make easier and more efficient to spread on the crop fields.

It is certain that the main current and future fate of the compost is the agriculture, reason why, and for this scope of action, the material can enter to the nutritional market as **a "product with organic value", as a "product with nutritional value" or as a "product with organic-nutritional value”.** In some cases, to improve the possibilities of commercialization, it can be interesting to improve the nutrient quality of the compost adding mineral elements (urea, phosphorus…) to satisfy the requirements that certain cultures, customers or the close market could demand.

## Customer service

The sale of the compost to the customer should not mean the end of the relationship with him. **A post sale support about how to use it, how to spread it, the recommended doses, the season to be applied,** etc… can be provided to be sure that the product is rightly used and the customer has all its benefits.

In some cases it may be prudent to have a conveyor spreader to give the service or to be rented by the farmers for compost application on the crop fields.

## Education

**Not only with the scope of extending the customer base it will be necessary to promote and divulge among the closer cities**, towns and/or villages, information about what composting is, how the biological process works, its possibilities, the importance of soil fertility and its relationship with the organic matter content, the benefits of the compost, etc…

This kind of information can be in the form of presentations (educational centers, associations, farmer cooperatives,…), reports in local media, organizing visits to the composting facility,…. These activities would not be difficult to organize and will report, at a medium term, good reputation to the facility and that could be well known.

## Administrative regulations

To assure the quality of compost generally **two strategies** are followed. On the one hand, some countries only take into account the final characteristics of the obtained material, regardless their origin too. On the other hand, **a majority of countries opts for establishing positive lists** (i.e. discriminate positively at the entrance the organic wastes to the facility), on the basis of the principle that **a good quality at the entrance ensures a good output quality**.

According to this principle, the **legislation and the rules of standardization of each country link some of the categories of compost to certain used input materials** (for example, the term "quality compost" is restricted to the compost produced from a positive list of "clean" materials with source separation, while the compost obtained from mixed municipal waste is called "waste compost" or “Stabilized organic wastes" or similar).

Depending on the regulatory framework, waste-derived compost can remain as a residue or become a product. So the **introduction on the market of the compost and its use can be done under the waste legislation or as a fertilizer product.** Frequently, in countries where there is no regulation of bio-waste/compost, simple systems for fertilizer registration are found.

Only Austria has specific legislation considering compost as a product or residue, while the European Commission is preparing a proposal of criteria at European level of End of Waste for biodegradable residues that are biologically treated.

**The external Quality Assurance Systems (QAS) are an effective tool to establish an environment of confidence for compost in the market**. Composting plants as well as their products are certified by quality assurance organizations. These organizations have been established in ten Member States: AT (2 organizations), BE / Fl (mandatory for all composting plants), DE, CZ (phase), ES (trademark in Andalusia), HU, IT, LU (mandatory for all composting plants), LV (in the initial phase, based on the EU eco-label), NL (2 organizations), SE (incorporates a single national standard of quality of compost), United Kingdom (PAS 100 Protocol of quality compost). In AT, DE, BE, NL, LU and NO such systems are contained in national regulations, although through different regulatory forms.

# 6.- Conclusions – Collection models and composting facilities under the SCOW's objectives

## 6.1.- Collection of biowaste

- A level of impurities below 2% (expressed by weight) in the Biowaste is indispensable to be able to produce a high quality compost and to ensure adequate functioning of composting facilities, especially the smaller sites.
- Differentiate whenever possible leftover food (household biowastes) from the green wastes. Those can be used as bulking/complementary material for Biowaste composting.
- The collection of food leftovers inside houses (source separate Biowaste) should be realized using vented caddies/receptacles (with the appropriate capacity) combined with compostable bags to improve the efficiency and avoid leachates and bad odours.
- Integrate the new Biowaste separate collection in the configuration of the other flow services, rethinking the rest of collections, especially for the Residual Fraction.
- The type of municipality and population should be considered to select the best time to start the implementation, with the maximum population participating in campaigns and when others local events cannot overshadow the new collection.
- Biowaste requires a high frequency of collection as its nature makes difficult to maintain the material inside homes or on streets more than 3-4 days in Mediterranean countries and especially during summer (usually frequency increases are needed).
- The areas of high tourist influx (or second residences) and economic activities density require greater attention and a service adapted to the needs of the existent typology of Biowaste producers and to the seasonal variations, with higher collection frequencies in some periods of the year (or weekends).
- The frequency of cleaning of the containers should be graduated in intensity in periods with higher temperatures.
- To choose and dimensioning the collection service is important to have an exhaustive knowledge of the characteristics of population and economic activities,

as well as of some urban aspects such as: number and type of housing, presence of urbanizations and isolated houses and mobility aspects.

- The implementation of the door-to-door collection can be easier in areas with low population density but it is also possible in big cities. The separate collection results of door-to-door systems, in general, are much higher than the rest of the systems, with regard to both quantity and quality.
- The implementation of delivery systems base on surface containers can also achieve good results for Biowaste fraction but it should be accompanied with an adequate communication campaign and with the introduction of some measures to ensure the quality of the material such as small overcovers, use of plastic bags, etc.
- The woody vegetal fraction is needed to cover the demand of bulking material for those models with separate Biowaste collection and treatment in biological facilities, so this residue has to be collected using the appropriate systems: door-to-door or on demand collection, delivery to recycling points, etc.
- Other elements for the proper design of Biowaste collection systems have to be taken into consideration: usability, information clarity, system flexibility, impacts on the public space and population, service image, optimization measures for routes and vehicles as well as waste transfers.
- It is necessary to address and deploy other complementary instruments to ensure a proper separate collection and plants management, such as instruments of education and communication, economic and fiscal measures, and control and monitoring of the model and service.

## 6.2.- The concept of mini-facilities and their key aspects (strategic, technical, economic and environmental)

*About composting of biowastes*

- Composting of household organic waste is a very suitable method to recycle organic matter and produce an organic amendment with both high environmental value and economic value.
- Other sources of organic matter from different organic wastes can be treated simultaneously improving the efficiency of the composting process.

- The application of the composting process to the biowastes management can be realized at very different scales (home composting, communal, mini-facilities,…). Moreover, the management of biowastes through composting allows establishing a strategy of decentralized facilities that increases the efficiency of the global results:
    - Reduces the transport of biowaste that in most of cases has very high water content (about 70%).
    - Converts the organic wastes in a local resource, so it is transformed in the same area where it is generated.
    - Increase the efficiency of the composting process because at a small scale it is much easier to control it.
    - Improve the local economy and the creation of “green jobs”.
- Bulking/complementary material is a necessity for the composting of organic wastes. Rests of wood from pruning of public or private parks and gardens, management of forestry areas, rests from some industrial process, etc. can be sources of this material.
- The main parameters for the correct beginning of the composting process are: structure, moisture, C/N rate and pH. During the process temperature, oxygen content, moisture and pH must be controlled to guarantee its efficiency.
- Open systems in composting, like turning or static windrows (with forced aeration), permit a great flexibility in the concept and design of the composting facility, being the most suitable system for small-scale facilities.
- The weather conditions of the area, as well as other environmental characteristics should be also considered to prevent negative affections of the composting facility.
- Other biological treatments of the organic wastes, like anaerobic digestion and vermicomposting, can be complementary to the composting process, increasing the benefits of the recycling of the organic matter, obtaining apart from the compost (or vermicompost), biogas and animal protein.

## Final product and its marketing

- There is an important lack and need of organic matter in European soils, especially in the Mediterranean basin, that affects to their fertility and conservation.
- The use of compost in soils has many advantages like:
    - Improves fertility of the soil.
    - Improving the structure of the soil.
    - Improves the microbiota.
    - Can act as a corrector of salinity and conductivity.
    - Contributes to the sequestration of atmospheric carbon.
    - Reduces the needs of peat.
- Because not all the composts are the same, when compost is applied to the soil the reason must be clear: as a source of organic matter or as a source of phytonutrients.
- The marketing of the compost implies many factors that must be considered to sell the product:
    - Knowledge of the potential local compost users and consumers: their needs, interests, quantities,…
    - Quality, characteristics and presentation of the product according to the customer's needs and requirements.
    - Stability of the quality of the product during the different seasons.
    - Providing information and support to the customers. Not only of the product's characteristics, but also of the doses to use in different cultures, form of application, liberation of nutrients, etc.
    - Divulgation and information campaigns in the area about what is composted, its benefits and advantages. Also about the composting facility and how it works.
- To create a compost market means to invest time, staff and money in visiting the potential customers in the influence area around the facility, to know them, to learn what they need, what products they are using as fertilizers, pesticides and/or soil conditioner and the prices that they are currently paying.

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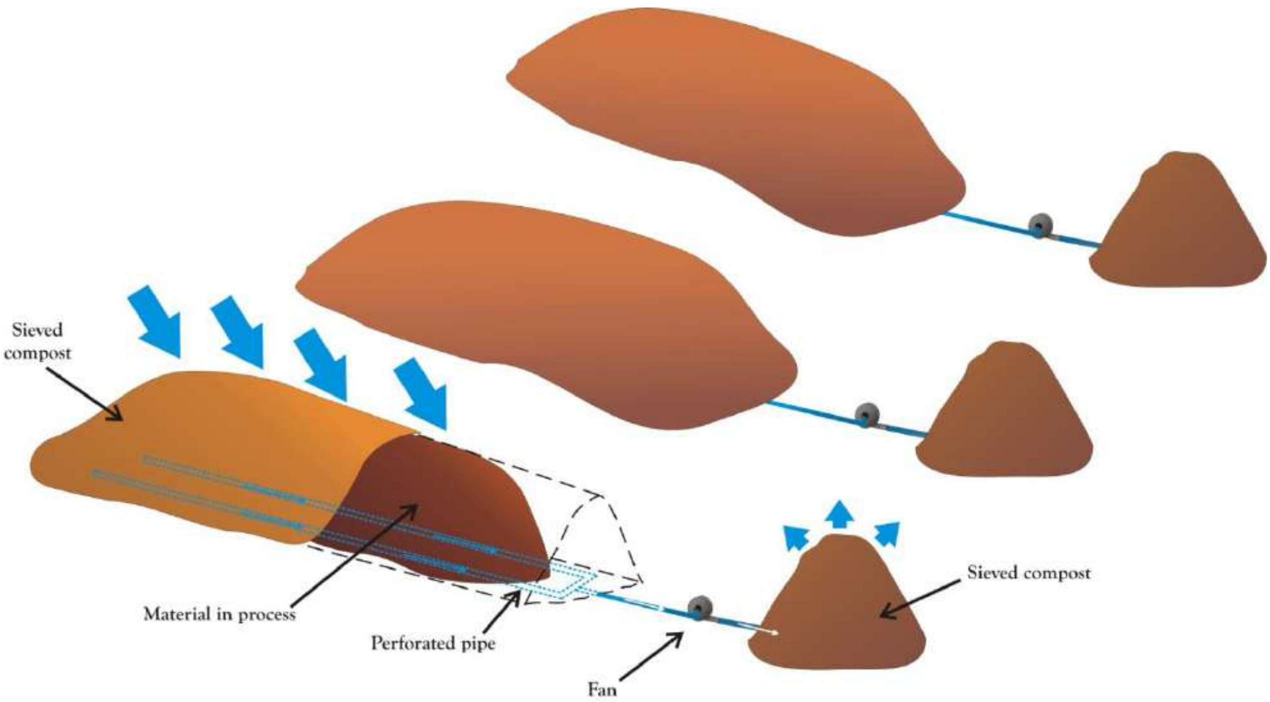
# Annex I – Control of the composting process in static windrows – Belstville and Rutgers systems

In the department of agriculture of the University of Beltsville, MD, a composting system was developed in which a static windrow was periodically ventilated by an aspiration system of air from the ground. The development came from the research in composting of sludges coming from urban wastewater treatment plants, more specifically the problematic of bad odours that were generated during the process.
This method, denominated *Beltsville*, consists in placing in the ground two pipes of 15 cm of diameter perforated all along with holes of 0.25 inches and connected by its ends.

These pipes are covered with a layer of chipped wood or compost without sifting, of about 30 cm height. The mixture to compost of sludge with chipped vegetal material that would acts like bulking, is made in a volumetric relation of 1:3.

With this mixture, a windrow of 12 meters in length, 6 meters of width and 2.5 meters of height is constituted over the covered pipes, covering next with a layer of 30 cm of screened compost. The system of pipes is connected to a centrifugal fan that works in aspiration taking air from the outside through the pipes and the windrow. Their cycles of turn on and off are established by a timer guaranteeing interstitial oxygen concentrations in the windrow between 5 and 15%. The gases caught by the fan are depurated making pass them through a windrow of screened compost. The suction is maintained between 16 and 20 days, after that, the position of the fan is changed to introduce air in the windrow by overpressure during other 8 to 10 days.

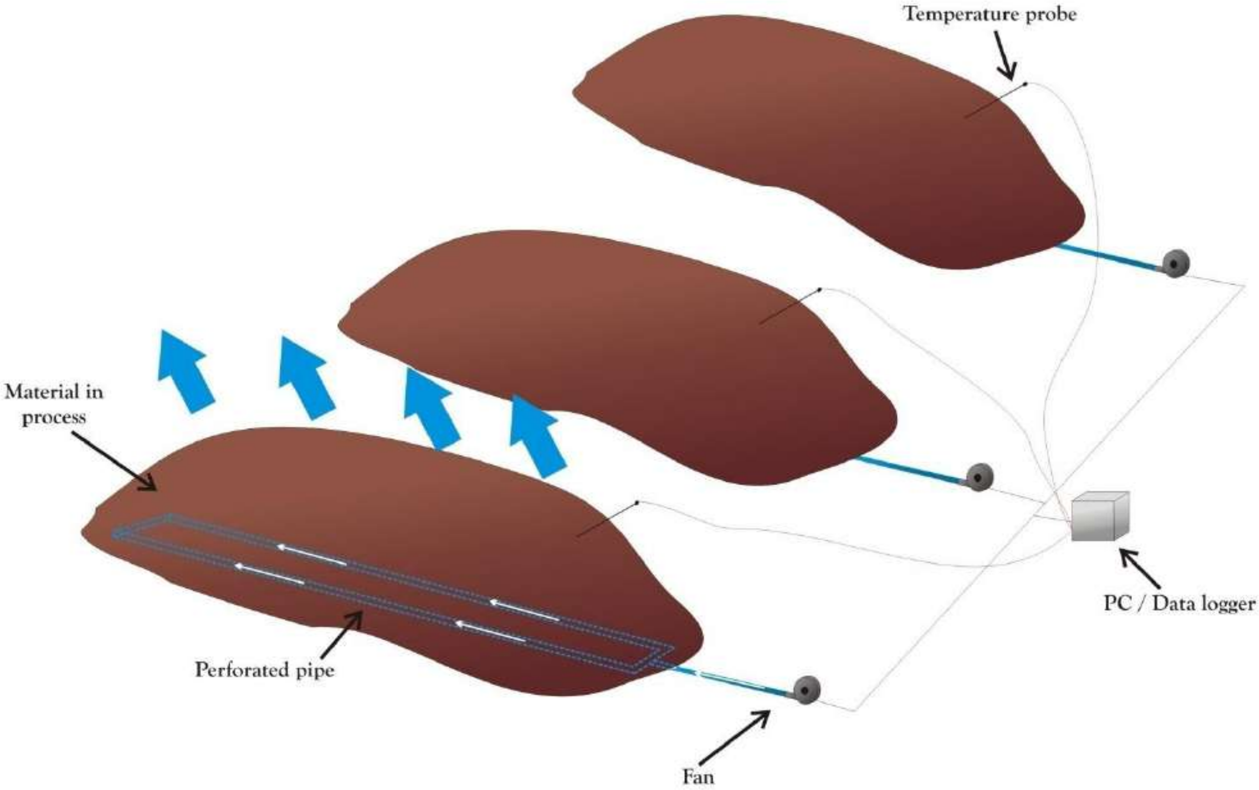
The *Beltsville* system supposed a very important step in the history of composting. For the first time, one of the key factors of the process was directly affected, controlling it since the beginning. Its simplicity and the facility of the operation turn it into a system very extended for the treatment of sledges from wastewater treatment plants. The main problem of the system is that it does not exert any control on the temperature. Besides, maintaining the aerobic conditions of the material throughout the process favours initially the derivative microbial activity and therefore the rise of temperature. This added to the insulating conditions of the material causes that the temperature arrives at 80ºC in several points of the mass, with a vertical gradient of a temperature higher than 40ºC. These high temperatures inhibit most of the microorganisms which participate in the degradation of the organic wastes, reducing the rate of decomposition of the organic matter, needing more time to complete the process and to obtain a stabilized product.




Professor Melvin Finstein and his collaborators from the University of Rutgers (NJ, United States) took another step developing a system in which a new strategy was considered: the control of the material temperature according to the necessities of the process. This system was denominated *Rutgers* system. Its main differences with the *Beltsville* method are focused on the control system of the mass temperature that it does not allow increasing temperatures higher than 60ºC, with the fan acting in overpressure or blowing, first thanks to the use of the timer and when the temperature of the material is higher than 60ºC, thanks to fan self-connexion according to the demand.

To control temperature in static windrows, the *Rutgers* method is used with a forced ventilation system, using pipes buried in the material or in narrow trenches made in the ground under the windrow. If the process control is accomplished through oxygen levels, the *Beltsville* method would be the most adequate choice, although the usual is to find methods with the combination of both, alternating ventilation periods of time with force aeration blowing with aeration by aspiration (Haug, 1986; Sesay *et al*, 1998).

The main advantage of these windrows is the good control of oxygen and temperature, while the weak point is the heterogeneity that appear in the material between the external and the deep layers, or between the upper (wet and hot) and lateral areas (drier and cooler).



# Annex II.- Other biological treatments of biowaste on a small scale

## Anaerobic digestion

Between the considered renewable energy sources it is also included the **anaerobic digestion or methanization, a natural biologic process of organic matter degradation where, as metabolite of the process, gas methane is generated and from which combustion is possible to obtain energy.** There are three potential advantages: it is a natural process (it does not need an energetic or material input to be produced, to create the organic matter), the organic waste is degraded, completing the matter cycle, and it generates a fuel gas (methane) useful to obtain energy through heat production. The equilibrium between the organic matter degradation efficiency by anaerobic digestion and the economical rentability of the produced energy is polemic in the industrial application of this process.

The main defined characteristic of this biological process is its production can only be achieved in anaerobic conditions (in absence of oxygen).

### The biological process

The organic matter degradation by anaerobic digestion has several consecutive phases that integrate different groups of bacteria ,in which during their activity go consuming the organic matter and generating different metabolites and new individuals. Commonly there are **three steps well defined in the process**, but to simplify it is often referred as only two steps process. In total, there are four different bacteria trophic groups for obtaining biogas (Figure 51)

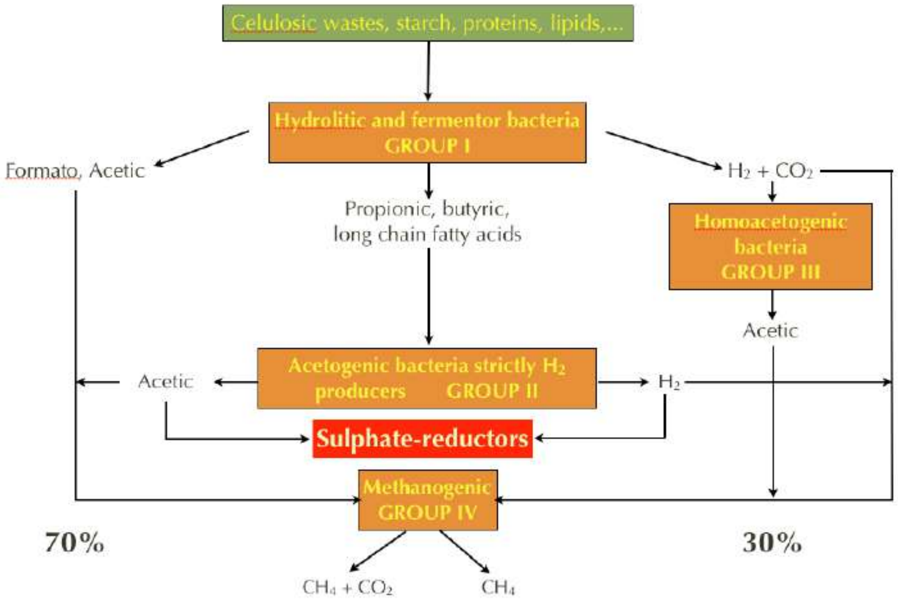
The first step is an organic matter **hydrolysis**, up to make it soluble in more simple components that can be absorbed by the microorganisms. In this process act hydrolytic bacteria, that break the molecules carbohydrates, proteins, lipids, etc. and that produce fat acids. The biologic activity rate of these microorganisms is high and tends to make the medium more acid and not being a limitation for them.

The second step is an **acetogenesis** where two groups of bacteria are implicated: the acetogenic ones, that mainly catabolize the fat acids generated in the hydrolysis and that produce hydrogen ($H_2$); and the homoacetogenic ones, that catabolize the $CO_2$ and the $H_2$ and hydrolyze polysaccharides to obtain acetic acid ($CH_3COOH$), but also butyric acid, propionic acid and ethanol are produced.

The final step is the **methanogenesis** process that produces $CO_2$ and $CH_4$ (the main components of the biogas) from the degradation of the acetic acid and the reduction of $CO_2$ by the $H_2$. Other important differential characteristic is that they present a high sensitivity to the presence of fat acids, because of the absence of muramic acid in their cellular wall. This is a key aspect of the biology of these microorganisms and of all the methanization process. **The methanogenic bacteria groups do not support acid environments**, so it is necessary an equilibrium between their biologic activity and the hydrolytic bacteria biologic activity, in such way, the high activity of the last ones do not acidify the medium, because it could be lethal for the methanogenic ones.

Depending on the organic matter composition that is being degraded and depending on the medium conditions, other kind of bacteria that use the metabolites of the methanization process are developed. It is the case of the sulphate differential bacteria, than generate sulphuric acid ($H_2S$), product that will be part of the biogas composition.

**Figure 51.** Biological process of the anaerobic digestion.



## Process parameters

One of the most important factors of the process is the **temperature**, because it influences on the methanogenic bacteria's biological activity, and in consequence in the yield and quantity of generated $CH_4$. There are three specific temperature intervals: psichrophylic (lower than 30ºC), mesophylic (between 35 and 37ºC) and thermophylic (between 50 and 55ºC). Depending on the research and technical literature that we consult, those margins could be more or less ample, but those are the values that are often used at an industrial scale, mainly those that belong to the mesophyll interval. The advantage of this in comparison with the others is that it allows the development of high variety of hydrolytic and methanogenic bacteria, increasing the efficiency, but their $CH_4$ productivity is lower than in the case of the thermophylic bacteria. In certain manner, the lower energetic consume that suppose to maintain the medium at thermophylic temperatures compensates this diminution in the potential production of $CH_4$.

To be a process where coexist and act in cascade three trophic groups of bacteria with different biological activity rate and whose medium optimum conditions are also different, it is essential to arise an equilibrium between the different populations to guarantee a yield in biogas production.

There is a sequence of factors or environmental parameters that limits the process, so its monitoring will be essential to be able to act over the medium and correct any disequilibrium of the adequate conditions.

The control ability of the process by ourselves is partially limited, because we will mainly act regulating the organic matter flux or caudal that we give to the process and, since certain point, its “quality”, that are the most influent parameters on the biological process. When the nutrition caudal is regulated to the digester the **hydraulic retention time (HRT)** is modified. This is not more that the quotient between the digester volume and the input. The HRT is a key factor in the sizing of any methanization facility, because it is calculated to obtain a permanency time and, of course, of the biological process that allows guarantee a minimum biogas production to promote energetically (it means, economically) the facility. The composition and characteristics of the organic matter to be methanized must also be considered at the moment of calculate the HRT to obtain a reduction in the desired organic charge of the digester’s output material.

## The biogas

As previously stated, Biogas is mainly composed of $CO_2$ (25 – 45%) and $CH_4$ (50 – 75%), presenting also other gases in lower proportion and that they depend on the degraded organic matter composition, like nitrogen ($N_2$), sulphuric ($H_2S$),... From those two gases, the $CH_4$ is what allows a calorific energy production from its combustion in order to generate a biogas as rich as possible in $CH_4$, that would be equivalent to natural gas. It must be considered the $H_2S$ concentration that the biogas can have, because it is highly corrosive and it limits the possibilities of the biogas energetic use if it is not eliminated. The richness or quality of the biogas is referred to the percentage of $CH_4$ that it has in its composition. A problem may exists when erroneous concepts are assumed, because these key aspects of the anaerobic digestion process must always be considered:

- Anaerobic digestion is a biological process, this means, that very concrete groups of microorganisms are acting on the organic matter degradation. A biological process has to be controlled, not a common chemical reaction.
- The original kind of organic matter, by its origin, composition and characteristics, is going to directly affect the quality and composition of the biogas generated, especially its methane richness or concentration. The importance of the different groups of organisms responsible of the process and the necessity to choose a system or technology in accordance with the kind of microorganisms, characteristics and necessities of the material to be methanized can not be forgotten.
- If the objective is to obtain a very high energetic production, the most important is not to have a big facility, if not to assure enough waste (or wastes) quantity that in its anaerobic degradation would produce an important biogas quantity (production) and that it would be rich in methane (productivity). The production is expressed as $Nm^3$ of biogas and the productivity in $Nm^3$ of biogas (or $CH_4$) by ton of organic matter (or volatiles solids), but sometimes this value is expressed in dry matter (total solids).

Another important aspect of the methanization but frequently overlooked, is the final product, the digestate. Duringthe final of the process, depending on the initial organic matter characteristics and composition, the HRT and the process conditions, an organic matter more or less stabilized will be obtained. It must be adequately managed to ensure that it does not produce any kind of environmental affections. The anaerobic digestion, with the exception if the HRTs are too long or if we are working with very easily degradable organic matter, this will not be the final treatment.. The digestate will need a posterior process, typically an aerobic one, to arise the stability, in order to guarantee its hygenization and to be stored without problems.

## Strategy and requirements

The increasing demand for energy in Europe after World War II, spurred intrest in anaerobic digestion, applied in livestock, industry and waste water treatment. Today in Europe, there are facilities that have been operating for more than twenty years, have been installed in hundreds of farms, where simplicity dominates design. Europe also leads the world ranking of centralized facilities (Erickson *et al*, 2004).

Today China has installed about ten million of anaerobic digesters on farms and rural homes, and is continuing the installation of small home digester models constructed of new materials such as glass fibre, to obtain gas for heat and cooking.
In many developing countries, or in rural areas of developed countries (as for example Costa Rica) small household digesters are used as a simple yet effective way to obtain cheap gas to cook Figure 52).

Anaerobic digestion has big **advantages** in the treatment of organic waste:

- It can **work almost at any scale** and with simple technologies, always in line with the characteristics of the organic waste to treat and the approach the use of the biogas energy.
- It is obtained **a source of local power**, whose initial concept is that of energy production is decentralized in a way that can be used for self-consumption (heat and/or electricity mainly).
- It is an energy source that in some cases can be considered **renewable or green energy**.
- An initial step in the processing and **recycling of residual organic matter** before its return to the soil. Depending on the HRT and other factors that return to the soil , the majority of cases it will be necessary to have a later stabilization of aerobic systems.

- $CH_4$ is a large green house effect contributor  The $CH_4$ molecule causes 25 times more greenhouse gases compared to the molecule of $CO_2$. If there is an uncontrolled fermentation of residual organic matter that $CH_4$ will release directly to the atmosphere.

**Figure 52.** A simple anaerobic digester for pig manure and rests of food in the town of Bagaces (Costa Rica) to produce biogas that is used in kitchens.

Each system may always encounter disadvantages, as perfection is impossible to always achieve. (Erickson *et al*, 2004):

- **Long periods of time** are needed until an adequate microbial population is reached and all bacteria groups involved in the process have environmental conditions suitable for their survival.
- It is a process that **does not tolerate variations** in the characteristics, and types of organic materials that are intended to methanize.
- **High costs of investment in the industrial application** for the need of closed tanks, pumps, management of biogas, heat exchangers...
- Most of the technologies work with low total solids content, so the **relationship with the volume of the digester that is needed to treat a certain amount of organic material is high**. Depending on the characteristics of the organic waste, can also be needed a more or less complex pretreatment system.

- There is a major difficulty in achieving an adequate and viable, environmental and economically **management of the digestate**.
- There is usually a critical **consumption level of water**; unless it is used to treat liquid organic wastes like pig manures or similar.
- A **pasteurization process is needed** to ensure the sanitation of the treated organic materials (digestate).

## Vermicomposting

Vermicomposting is defined as **an organic matter bio-oxidation and stabilization method, mediated by the combined action of earthworms and microorganisms, obtaining a thin grain homogeneous and stabilized final product denominated vermicompost**. As in all biological treatments related with organic wastes management, there are processes that happen in a natural way in Nature and that close the organic matter cycle. For this reason, if we want to understand and apply those processes we need to know the implicated organisms, their characteristics and necessities.

Its **advantages** come from the direct use of the earthworms behavior, like its detritus feeding and its movement by galleries; and from an indirect use, stimulating the microbial activity, favored by the mechanical transformation of the waste when it goes through the worm digestive system, reducing the particles size into crumbles. It supposes a higher surface of the organic particles, facilitating its degradation by the microorganisms. **The combined action of worms and microorganisms intensify the organic matter decomposition**. It is important to consider that the worms obtain their food from the high number of microorganisms that exist in the soil or in the organic matter in decomposition, because they could not assimilate the high part of not cellular organic nutrients. During the vermicomposting, apart from the microorganisms, the worms feed with partial or totally degraded components from the organic wastes, transforming the organic matter into an aerobic humus that can be used in horticulture. Apart from these microorganisms, in numerous occasions, the worm and microorganism's actions can work together with other soil micro fauna as mites, traeids, collembolans,...

The vermicomposting systems will obviously vary depending on the installation scale, the area circumstances, and the characteristic of the waste to be treated and/or the final product to be obtained. But in all cases it will be necessary to consider that adequate conditions must be maintained to the development and the organisms activity that are going to realize the organic matter degradation work. The same as in composting, the previous conditions (conditioning) and control process can be classified. In the Annex II there is more information about the biological process and the parameters that should be monitored to control it.

## Strategy and requirements

**The application of vermicomposting to organic wastes management is normally realized at small or semi-industrial scale**, because it is difficult to assure the best environmental conditions for the earthworms and have an automatic system to realize most of the process (movements of materials, moisture maintenance, extraction of the final product, etc…).

Vermicomposting is applied under two circumstances:

- The organic waste to be managed must have these characteristics: is homogenous, high moisture content, low conductivity/salinity and easily degradable.
- The quantities to be treated can be easily managed by hand or with low technology requirements.

Currently, there have been developed equipments that increase the capacity and efficiency of the treatment system. In those the load of the fresh organic waste and unload of the vermicompost are automatized.

**Figure 53.-** An automatic vermicomposting system that allows a continuous feeding with organic waste by the upper side and the unload of the vermicompost by the bottom (Elkarkide, Navarra, Spain).

Vermicomposting of household biowaste or rests of food requires pretreatment when high quantities are going to be treated by vermicomposting. Usually is enough with shredded the food waste to reduce the particle size and increase the microbiological activity to degrade the organic matter, resulting in an increase of feeding efficiency of earthworms in the material and the decomposing organic matter.

Some examples of these systems can be found in the University of Wisconsin-La Crosse (USA) for the treatment of the biowastes generated in the campus (Perroy & Schiller, 2012), or in some urban farms like Elkarkide in Navarra (Spain) where all the harvest rests are treated by vermicomposting (Figure 53).

# Annex III – Control of the vermicomposting process and its main parameters

**Previous culture parameters (conditioning)**

If we contemplate a natural grassland soil where there is high abundance of earthworms will verify that the land texture is spongy and soft, no compacted. Any substrate where worm's inoculation want to be made for vermicomposting must to have a porous **physical structure**, so  that it does not inhibit t the worms excavate galleries, as well as compromise the water and air flow to the interior. It is essential that the substrate will be in aerobic conditions to allow the survival of any epigeous worm.

Moisture is an essential factor linked within these conditions. With the exception of Annelids, the only group with terrestrial life is the *Oligochaeta* (earthworms included).

and not all of them, because many of them are fresh water, like the *Hirudinea* (another group of annelids), since the *Polichaeta* are mainly marine ones. So we are talking about one kind of animals that have been evolved from an aquatic medium to a terrestrial one, with the necessary adaptations to overcome some problems like to maintain the body form in a lower density medium, to ensure the embryo development rounded by vital fluids, to adapt the respiration system for oxygen capture from air instead than from water, to adapt to a terrestrial nutrition and to maintain an interior homeostasis. This means that they must control their interior medium, eliminating the metabolic residue products without excessive ions and water's loss. To do that, they have adapted their respiration and excretory systems from the aquatic model of their ancestors. Wormssecrete a mucus that can maintain the body surface moisture and that allows the cutaneous respiration by passive diffusion, and that their excretory system creates an abundant hypotonic urine for urea and ammonia elimination. Due to this, the medium or substrate where the worms would live, must have a constant high moisture level, but always between certain margins, because a moisture excess or flooding will kill the worms. This is one of the reasons for the necessity of a physic structure of the substrate where the worms are going to live that must allow a water partial retention and also the excess' percolation.

Both factors are directly going to influence the organic waste characteristics, waste that is going to be the nutrition of the worms. Sewage sludges, for example, due to its high moisture and density, need a previous conditioning (due to its dosage or mixture) to be able to correctly be vermicomposted.

For being animals that greatly depend on moisture of their habitat, they are especially sensitive to **salinity**; because of they must maintain a delicate osmotic equilibrium for their survival. Inorganic salts high concentration in the medium inhibits the reproduction and could be responsible of their death.

The **ammonia** is a very easy soluble component in water, in the same way of inorganic salts, its high quantity in the medium would be greatly toxic for the earthworms. This is one of the most critical problems when trying to degrade organic materials as excrement and some sewage sludge, for its often high ammonia quantity. One common solution consists in a previous aeration of the material to be treated to volatilise the ammonia before being given to the earthworms.

The **pH** is related within te parameters stated above. The most used species prefer a neutral pH, but there are species that evolved to withstand pHs lower than 5.5.
It is necessary to considerthe possibility of finding elements or toxic substances in the organic matter to be vermicomposted.

**Process control parameters**

, If the previous conditions are respected within the substrate and amterila to be composted, the earthworms will begin their detritus feeding activity, moving and eating the organic wastes that are given. For successful maintence of the system, it is essential to ensure that the medium conditions is conducive to the development of worm sexual maturation, its reproduction, and development. There are crucial conditions to achieve in order to maintain and controlthe correct development of the process.

In most of the cases, the initial worm population represents a low density in respect with the available medium volume. To optimize the system in relation to the degradation rate of organic wastes that are feeding the worms is necessary to rise an adequate worm **population density**. If the medium conditions are adequate, the worms will quickly increase their biomass, they will have a higher reproductive rate and new generations will be obtained with higher number of individuals in the medium each time. However, the abundance of the population tends to be stabilized when they arrive at certain numbers. The use of an auto-regulation mechanism could exist, and when the bed tends to the super population, the reproductive rate diminishes. This is the principal parameter that affects the growth and reproduction, so it must be important once that optimum medium conditions are achieved and controlled, the waste degradation velocity comes given by the worms population density; so it will be of high interest to have a clear knowledge about the optimum population density to ensure a high biomass production as well as a fast waste degradation. This highlights the periodical necessity of keeping out individuals from the medium to obtain that density which does not interfere over the degradation rate.

As previously statedin several occasions, the waste **moisture** is a main parameter for the worms survival, and it is also necessary to ensure this moisture rate constant during the process. For that it is required to make periodical waterings of the medium to maintain the moisture in levels close to the optimum, that for example, in the case of *E. fetida* are situated between 80-90%.

The **temperature** tolerance range of the earthworms is quite ample, so it must not be a problem. Whatever it is a factor that directly affects worm metabolism, and, in consequence, to their activity and reproduction, so it is convenient to maintain the temperature as close as possible to the specie optimum. For *E.fetida* the optimum is between 15 and 20 ºC for vegetal and animal wastes degradation, but some authors situate the medium temperature in 20ºC.

To maintain the medium in **aerobic conditions** is a factor that not only must be foreseen during the conditioning of the material to degrade, it is also important to remember that an increase in the water content or a posterior waste package, can develop anaerobic conditions that could be terrible for the earthworms. For this reason, for an industrial scale vermicomposting system, it would be necessary to foresee an appropriate drainage system to avoid water excesses, and to ensure the material porosity, that normally is produced by the worms movement.

**pH** values must also been controlled because, as we explained before, directly affects the worms activity.