Chapter

Co-Composting of Various Residual Organic Waste and Olive Mill Wastewater for Organic Soil Amendments

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Abstract

The valorization of different organic residues like municipal solid wastes, sewage sludge and olive mill wastewater is becoming more and more worrying in the different modern communities and is becoming relevant and crucial in terms of environmental preservation. The choice of the treatment technique should not be only from the point of view of economic profitability but, above all, must consider the efficiency of the treatment method. Thus, an attempt to remove polyphenols from olive mill wastewater would have a double interest: on the one hand, to solve a major environmental problem and to recover and valorize the olive mill wastewater for advanced applications in food processing and soil amendments. It is also interesting to think of associating two harmful wastes by co-composting such as sewage sludge-vegetable gardens, sewage sludge-municipal solid waste, and green wastes-olive mill wastewater..., to get a mixed compost of good physical–chemical and biological qualities useful for agricultural soil fertilization. Finally, in order to be more practical, we will describe specifically in this chapter a new variant of composting and co-composting technology intended for waste treatment that is very simple, inexpensive and easy to implement.

Keywords: Valorization, Wastes, Olive mill wastewater, Compost, Soil fertilization

1. Introduction

Compost makes up a stable, hygienized and humus-rich product resulting from the mixing of various municipal, plant or animal residues, gradually fermented to ensure the decomposition of organic matter (OM), and used as a fertiliser, amendment or growing medium. Thus, compost is the resulting product of a complex microbial process of decomposition and transformation of biodegradable organic residues. This process operated under varied microbial communities that develop and grow in aerobic conditions [1–3]. Fermentable organic wastes are coming in many forms and with different proportions and accessibility to microorganisms. The raw materials used in composting are much diversified, we can cite as examples raw manure, bedding, feed residues, straw, various crop residues, olive pomace and varied products from agro-food industries [4].

Composting is a biochemically continuous phenomenon of organic matter mineralisation or oxidation in the presence of oxygen. The mineralisation or oxidation is achieved by microorganisms that use oxygen from the air and organic carbon for all their all-metabolite biosynthesis. To make the degradation or the oxidation easy, two operations may be implemented. These two operations are always considered as optional. First, the waste can be sorted to separate the fermentable fraction from the non-recyclable one. Second, the waste may be mechanically shredded to improve the structure of the waste mass; thus, on the one hand, the waste shredding facilitated the biodegradation, reduced the treatment time and make handling more pleasant; and the second hand to make homogenisation of the waste mass easy by allowing a uniform distribution of the different waste components. Once the residual substrate has been prepared, fermentation that resides at the heart of the process, is started. This fermentation leads to a rapid decomposition of easily biodegradable organic matter that generates some fewer complex molecules. Subsequently, the substrate biodegradation leads to slower maturation. These steps are commonly known as the processes of humification and stabilisation of the compost [5]. Once the compost has reached maturity, it will undergo screening and sieving. This operation is allowed to give two products: a commercial product known as compost and a refusal product to refine and/or to landfill. All these mentioned operations are well conducted in all common composting processes. Despite, some precise differences could be existed and lie in the location of the screening phase and the choice of the fermentation system. The originality aim of this book chapter is to describe, in the composting plant implemented under semi-arid pedoclimatic conditions, a description of new and simple process of composting and co-composting of municipal solid wastes, olive mill wastewater, waste farm and garden cutting, straw and sewage sludge. All these residual materials resulting from the main human activities commonly known at the present state in modern societies, with especially the olive mill wastewater resulting from oleiocultural activities, will be considered in this a new process of composting description, mainly characterized as simple to implement and to monitor [6, 7].

Indeed, the process is directed in two principal successive steps: step of prefermentation (uncontrolled fermentation) and step of maturation (controlled fermentation), respectively.

2. General composting process operation

Composting is a complex bio-physical–chemical operation that comprises biodegradation of organic waste under controlled conditions of temperature, humidity and aeration. Two important following one another biophysical phenomenon could include the common composting process. The first process brings the organic residues to the state of fresh compost. An intense aerobic degradation concern essentially the decomposition of fresh organic matter at a high temperature of 50–70°C under the action of thermophilic bacteria; while the second process is done by a less sustained degradation mainly achieved by mesophilic bacteria. These bacteria transform the fresh compost into a mature compost, rich in humus. This maturation phenomenon, which takes place at lower temperatures of 35–45°C, leads to the biosynthesis of humic compounds by fungi.

The composting process of organic residues takes place in three distinct and important phases. First, the temperature rises rapidly to around 40°C or 45°C following the respiration of aerobic mesophilic microorganisms; in parallel, the most degradable compounds such as sugars and starch are consumed. Second, the temperature rises progressively to around 60°C or 70°C and the mesophilic microorganisms will be replaced by thermophilic ones, anaerobic fermentation by aeration of the waste mass must be avoided; pathogens, parasites and weed seeds will be destroyed by the temperature. Third, the degradation is complete when aeration no longer increases the temperature, the amount of material easily operational by the microflora becomes scarce and the biosynthesis of humic compounds becomes predominant, and at the end the thermophilic species in favour of more common species disappears and appearance of new mesophilic species [8].

3. Physical-chemical parameters monitored during the composting process

The principal physical–chemical parameters of the process monitoring are summarised in the parameters that condition the good development and progress of microbiological activities, and their monitoring is essential to test the effective conduct and behaviour of the composting process [9, 10]. This is achieved by optimising nutrient supply and regulating pH, temperature, water content and aeration conditions.

3.1 Grain size of wastes

The waste particle size is an important parameter to consider in the composting process since (i) it determines the size and volume of the pores created by the arrangement of the particles in the waste matrix, (ii) it is involved in increasing the specific surface area of the raw organic matter, (iii) it facilitates the diffusion of oxygen inside the compost waste matrix, thus allowing homogenisation of the waste, and at last (iv) it is the site of main microbiological activities that take place on the surface of the organic particles.

3.2 Interstices oxygen rate

This parameter shows the real proportion of oxygen in the interstices of the waste mass. It is critical to the oxidation of the organic matter, and directly related to the size, humidity and aeration of the waste during composting. Oxygen requirements decrease along composting whether they are proportionate to the organic matter gradually disappearing over the mineralisation process. However, maintaining and preserving good aeration avoids the start of an anaerobic process that could induce the generation of malodorous compounds. Moisture in the waste mass always interacts negatively with the system aeration. The supply of oxygen allows the drop in humidity. If this humidity is high, a probable temperature rise will take place leading to a significant improvement in the substrate mass homogeneity. The minimum threshold of oxygen needed to maintain aerobic conditions is of the order of 5% as reported by Jammes [9].

3.3 Prevailing humidity in the waste mass

Humidity is both a raw material-related parameter and a monitoring parameter. It hosts the development of the microbial flora within the compost. The optimal water content during composting is around 60%. However, high water content promotes anaerobic fermentation. If the water content exceeds 70%, the water fills the voids and space, making oxygen exchange very difficult. On the other hand, if this prevailing humidity drops below 20%, the decomposition of organic matter will be inhibited.

The quantity of water lost by vaporisation during the release of heat exceeds those formed during the reaction of oxidation; therefore, to compensate this lessening, it is tolerated and needed watering materials during composting. Although it is difficult to determine the volume to be added, water can be added as long as no runoff appears under the pile of waste or the waste mass.

3.4 C/N ratio of the waste mass

The C/N ratio of the waste mass qualifies the biodegradability of organic waste by ensuring the trophic balance necessary for the flora optimal development. Suitability of fermentable waste for composting is determined by the C/N ratio of the mixture of their various constituents (fermentable, paper and cardboard). Putrescible materials whose C/N are of the order of 15, are substrates easily biodegradable, while paperboards, with C/N ranging from 60 to 107, are substrates hardly biodegradable.

During aerobic fermentation, microorganisms consume carbon 15 to 30 times more than nitrogen. The initial C/N ratio is around 30 to 35, while that of the final product is less than 15. Sometimes the C/N ratio of waste can be so low that it is unsuitable for composting. This can be remedied by adding a specific substrate with a high C/N ratio, which brings the initial C/N value back towards the optimum [9]. If the initial ratio is less than 30, nitrogen losses are accompanied by the odour nuisance. If the ratio is low, ammonia nitrogen losses may reduce pH. **Tables 1** and **2** showed examples of the C/N values of some compostable materials.

3.5 Temperature developed inside the waste mass

The increase in temperature is caused by microbiological activity. During the degradation of organic matter, there is energy initially contained in the chemical bonds of the constituent molecules, which are released, part of which is recovered by the metabolism of microorganisms, and the other part is dissipated into the atmosphere. Therefore, the minimum temperature is necessary for degradation and the evolution of the temperature during composting is allowed distinguishing four successive distinct phases [1].

Categories	Season	Average C/N
Fermentables	Spring	18.3
Paper-Cardboard	Spring	63.4
Fermentables	Summer	13.1
Paper-Cardboard	Summer	59.2
Fermentables	Autumn	15.6
Paper-Cardboard	Autumn	107.5
Fermentables	Winter	15.2
Paper-Cardboard	Winter	79.1

Table 1.
Average C/N ratios of some fermentable components.

	Municipal wastes	Cattle manure	Sewage sludge	Olive pomace
C/N	< 20	20	11	49.3

Table 2.
Average C/N ratios of main fermentable components.

3.5.1 The mesophilic phase

Mesophilic microorganisms (especially bacteria and fungi) invade the raw material, so their activity causes a rise in temperature (from 10 to 15°C to 30–40°C), a significant release of CO_2 and subsequently a decrease in the C/N ratio and acidification.

3.5.2 The thermophilic phase

During this phase, the temperature reaches 60 to 70°C, values to which only thermo-tolerant microorganisms like actinomycetes and thermophilic bacteria could remain in operation in this very hostile environment, and the degradation activity of resistant fungi will be stopped. Along this hostile phase, the nitrogen mineralized as NH4+ will be lost as NH_3. This hostile environment takes place specifically inside the waste mass centre, hence leading to the need to turn over the waste mass for ensuring homogeneous and disinfected products.

3.5.3 The cooling phase

This phase is followed by the operation of turning and watering the mass of waste being composted. Thus, it is mainly characterised by the reappearance of ambient temperature and mesophilic microorganisms that decompose materials remained intact during the previous phase and nitrogen of some complex components.

3.5.4 The maturation phase

The microbiological activity regresses considerably during this phase, and the waste receives new colonisers that are the macrofauna, particularly earthworms. The organic matter becomes stabilised and humified compared to their initial state. It should be pointed out that a temperature above 70°C should be avoided, as it leads to extreme drying, a very significant loss of material and even a halt in the process by the microflora destruction.

3.6 pH or acidity degree

The hydrogen potential known as pH is a measure of the chemical activity of protons or hydrogen ions in solution inside each medium. The pH largely influences the development of the microflora responsible for the waste decomposition. Its value is determined and imposed by the raw material used, but varies according to the progress of the composting process. The pH monitoring is mandatory since it provides information on the different phases of the process. The optimal pH prevailing in the waste mass during the composting is on average between 6 and 8.

3.7 Undesirable and non-biodegradable waste products

The composition of municipal waste may show undesirable non-biodegradable elements that could affect the process and the ultimate product quality. These elements may be notable as packaging and special wastes, rich in metallic elements. Therefore, these undesirable materials should be separated by sorting. The operation of sorting can be made at the domestic level known as source sorting prevailing and well distributed in very advanced modern societies and/or in composting sites.

4. Description and implementation of a new composting process

We are prompted in this paragraph to describe a suite of a new composting process, traditional, very easy to implement, economical, but it is a time and space-consuming process on the plant composting platform. The process is simply summed up in two successive stages, recognized as the pre-fermentation and maturation stages.

As earlier said several times, the composting process at the microbial level involves many interrelated factors, mainly metabolic heat generation, temperature, ventilation as O2 input, moisture content and nutrients. Temperature profiles registered during the two steps of pre-fermentation and maturation are shown in **Figure 1** in two experimental wastes windrows W1 and W2 the three classical temperature steps of composting, including the mesophilic, thermophilic and cooling phases, respectively (**Figure 1**).

The step of maturation with around 60 days appeared to be as less active as compared to the first step of pre-fermentation with around 90 days since the values of temperature, registered during the second step of maturation, are less important than those to be recorded during the first step. Differences in temperature averaged 15°C. This result is mainly related to differences in the availability of easily decomposable organic matter content as nutrients in the organic fraction. So, composted materials used during the first step of pre-fermentation seem richer in these easily decomposable organic elements as compared to those of the second step of maturation.

Analytical investigation of some key monitoring biological parameters of composting such as dehydrogenase activity [11], microbial biomasses C (BC) and N (BN), extracted total DNA content and microbial diversity in waste masses during composting were examined. So, the dehydrogenase activity is studied during the composting process for two major reasons: the first concern the follow-up of the biodegradation level of substrates, and the second because it represents a reliable indicator of the stability and maturity of the finished product. The dehydrogenase

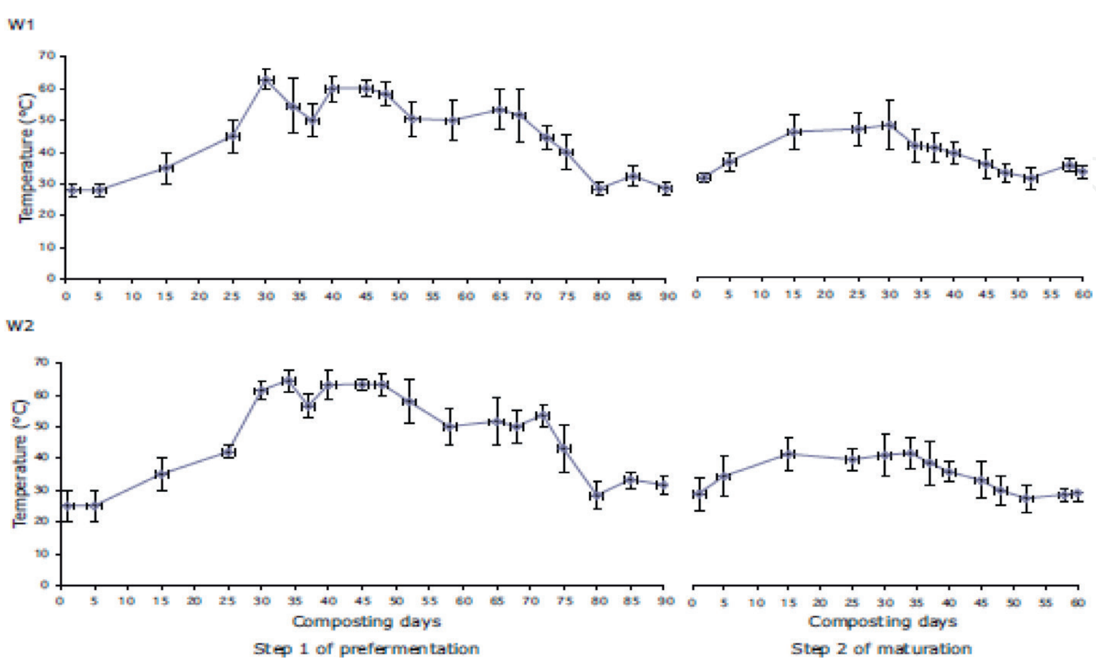

Figure 1.
Temperature changes in the two windrows W1 and W2 during the two steps of composting. (i) The first windrow W1 constituted with 100% of municipal solid wastes, (ii) The second windrow W2 composed by weight of 60% of municipal solid wastes and 40% of dried stabilized sewage sludge, and (iii) The form of windrows of 12 × 6 × 2.5 m (length x width x height, respectively).

activity showed a net increase between 2 and 0 and 15–35 days through the pre-fermentation and maturation steps, respectively. A good positive correlation is observed between the values of dehydrogenase and of temperature registered ($r = 0.96$, $P < 0.01$). These values of dehydrogenase activity fluctuated between 3.2–5.84 and 1.7–5.66 mg TPF/g of waste dry weight/24 h during the step of pre-fermentation in the two windrows W1 and W2, respectively (**Figure 2**). By the same, these values varied between 3.6–4.9 and 1.96–3.22 mg TPF/g of waste dry weight/24 h during the step of maturation in the two windrows W1 and W2, respectively. So variation of the dehydrogenase activity appeared very narrow (around 1.2 mg TPF/g of waste dry weight/24 h on average for W1 and W2) during the second step of composting and showed a certain homogeneity and consistency of the waste materials used in this second step of maturation; and in the opposite, a high heterogeneity and assortment of the waste used during the first step of pre-fermentation since variation of dehydrogenase values generally recorded were relatively large (around 2.64 and 4 mg TPF/g of waste dry weight/24 h for W1 and W2, respectively).

On the other hand, it is important to mention that the dehydrogenase activity values appeared slightly higher in the windrow free of sludge than in the one with sewage sludge. The microbial biomasses C and N behavior biochemical transformations in waste materials, and BC/BN ratio is closely related to the changes of the microbial population during composting. BC/BN ratio values usually showed a net increase during the thermophilic phase, 30–70 and 20–50 days, for the steps of pre-fermentation and maturation, respectively (**Figure 2**). The BC/BN ratio values are on average around 4 or 6 and 3–4 during the first and second steps of composting, respectively. The concept of the microbial biomass inventory regards the microorganisms as only one and a single entity. The evolution of BC/BN ratio translates a microbial diversity, with phases where they are the bacteria and the actinobacteria which are dominant, and others where the fungi prevail; a net increase of this ratio is synonymous of a good microbial activity [12–15].

Microbial total DNA extracted from composting materials and followed during all the two steps of the composting process showed a net variation over time, and

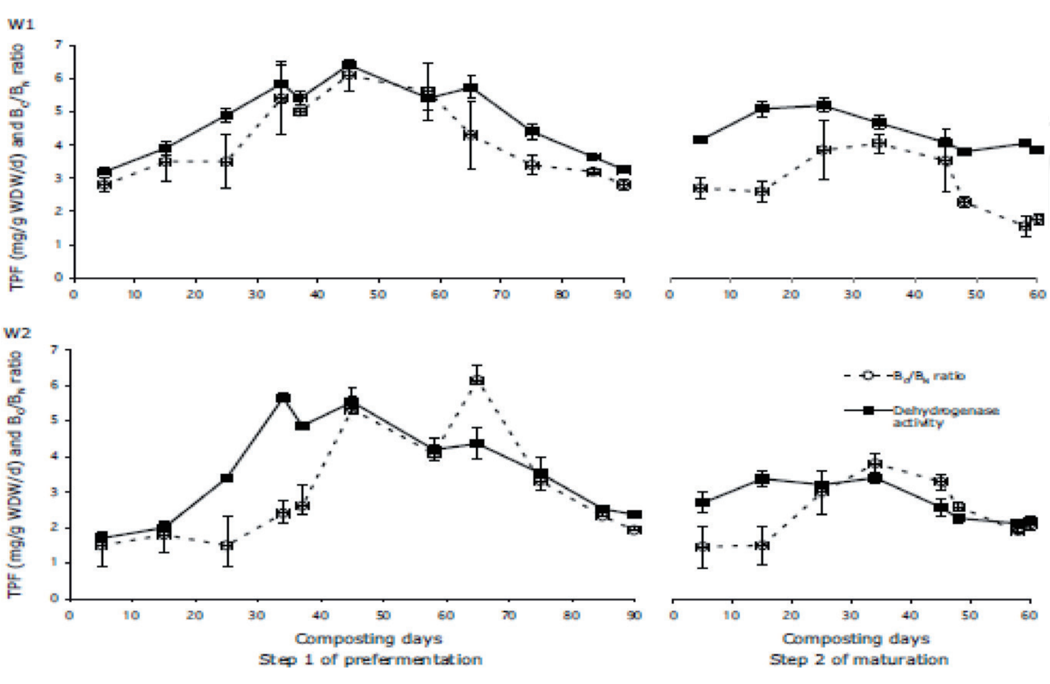

Figure 2.
Dehydrogenase activity and BC/BN ratio changes in two windrows W1 and W2 during the two steps of composting.

revealed a good parallel increase with the temperature progress inside the waste materials (**Figure 3**). This increase varied between 13.2 and 26.1 μg of total DNA per g dry weight. The lowest values of DNA are observed at the start and the end of each step of the process (around 13.2 μg of total DNA per g dry weight) and the highest values are always registered during each thermophilic phase (around 26 μg of total DNA per g dry weight). The ratio of absorbance at 260 and 280 nm is usually used to assess the purity of DNA and RNA. A ratio of ~1.8 is generally accepted as 'pure' for DNA; a ratio of ~2.0 is generally accepted as 'pure' for RNA. If the ratio is appreciably lower in either case, it may indicate the presence of protein, phenol or other contaminants that absorb strongly at or near 280 nm. The determination of A260/A230 and A260/A280 ratios usually defined as a coefficient of purity of DNA. For compost DNA showed a significantly lower value (0.96 and 1.2) than those for DNA solutions of pure cultures (1.57 and 1.89) showing that compost DNA was coextracted with humic and protein compounds, respectively.

Therefore, the investigation concerning microbial diversity in the composted wastes allowed to assess the changes in microbial diversity that could occur during the two steps of the process by DNA extraction and polymerase chain reaction (PCR). Main investigation and results showed that along the first process step, there is a net variation in microbial diversity. This diversity appeared very rich and obvious in case of windrow W2 added with sewage sludge. The principal characteristic of the first step of pre-composting or pre-fermentation consists in subjecting directly to fermentation raw wastes, without sorting and crushing.

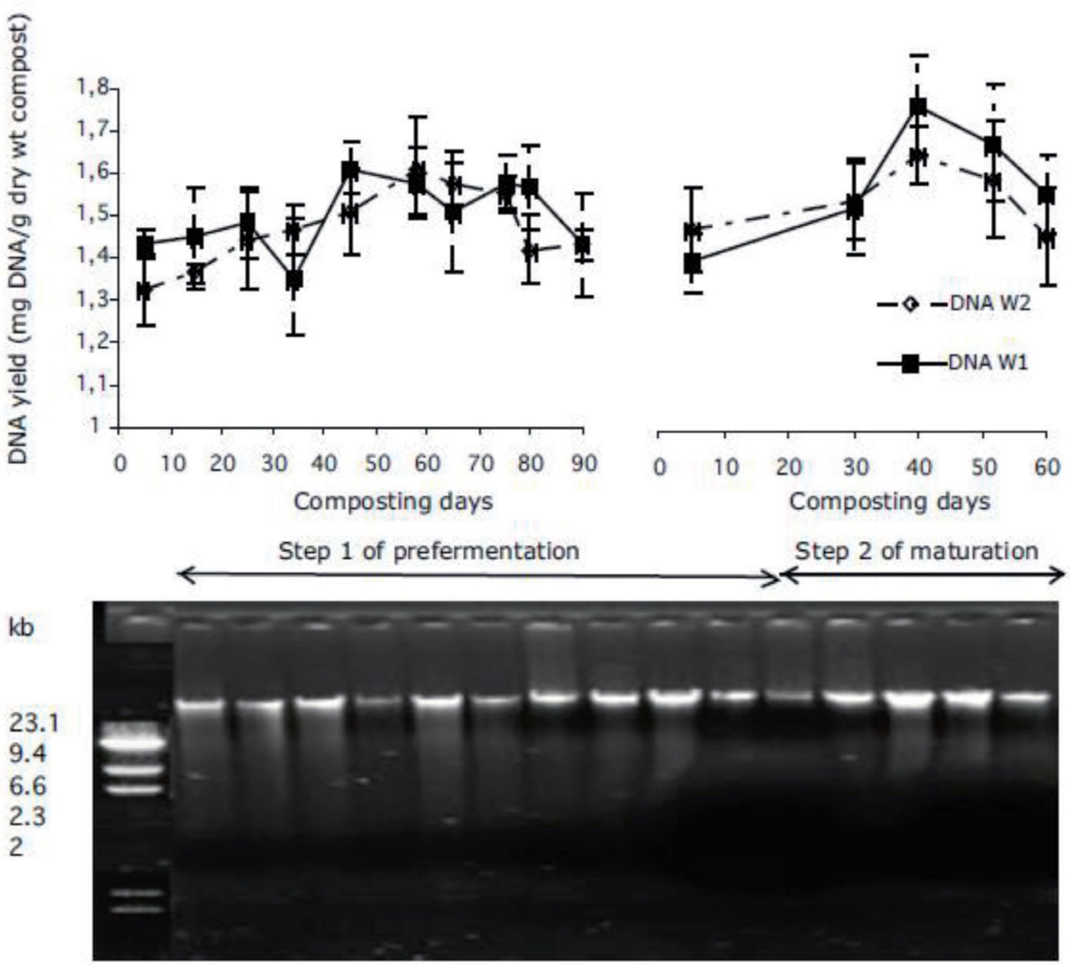

Figure 3.
Total compost DNA contents and agarose gel electrophoresis of total DNA extracted from composting materials (W1) during the two steps of composting. First lane: HindIII-cut bacteriophage lambda molecular size markers (1 mg), step 1 and step 2 lanes: DNA extracted from waste of W1.

The usual processes suppose the use of a pre-sorted and crushed raw material. In the case of the present composting technique adopted in this process, raw wastes not sorted upstream are very heterogeneous, and then the separation of organic material is practically impossible. Thus, the operation of pre-fermentation supports accessibility to this organic material. During this first step and earlier evoked, the rises of temperature appeared important and reach the 60–65°C inside the two windrow W1 and W2 of waste masses. Also, the degradation of organic material makes possible the decrease of plastic bags and the release of organic matter that it is frequently locked up there.

This pre-fermentation is preferred done into two pyramidal windrows forms and pile of waste should be often covered with a layer of fresh sewage sludge (approximately 30% of total waste weight). In fact, this layer of sludge participates efficaciously to minimize the fire hazard and to avoid the take-off of certain particles of waste, such as plastic, paper, and many others.

The optimal duration of this phase of pre-fermentation was previously studied, and evaluated to three months on average. Consequently, a maximum organic material recovery is ensured during a minimum time interval.

The second step of the process of controlled fermentation (step of maturation) is characterized by a degradation of the organic materials by microorganisms. The purpose of management of this second step of composting is to ensure favorable conditions in order to force the microbiological activity. The procedure of microbes during this second step of composting appeared on average less active than the one registered during the first step of pre-fermentation. All parameters considered in the present paragraph are in favor of this conclusion. We could explain this result by several factors mainly by the decrease or exhaustion and depletion of readily degradable compounds in the mass of waste materials.

This chapter review confirms amongst others that temperature is the main parameter to consider in composting. This important factor conditions the functioning of all the other parameters, specifically the microbial activity. As a result, the level of temperature conditions and depends on the type of microorganisms operating during composting. So mesophilic microbes dominate at the beginning and at the end of each step of the composting process; on the other hand, thermophilic microbes control the important step of composting, the thermophilic phase.

Finally, this paragraph reviews a new and simple composting process tested and used in an industrial plant for compost production under semi-arid pedo-climatic condition, and some important chemical, physical and biological monitoring parameters should be investigated in order to understand and to master the general process of composting of various solid residues. A molecular detection procedure, using ribosomal intergenic spacer analysis, was tested for microbial community diversity assessment. At last, analysis of compost microbial communities is one of the challenging areas of research due to the enormous complexity of biodiversity caused by the heterogeneity of the physical and chemical structure of compost environments [16, 17].

5. Co-composting process of municipal solid wastes, green cutting waste straw and olive mill wastewater

As earlier evoked, olive production represents one of the oldest agricultural activities in the Mediterranean basin. For these countries, the production of olive oil is an economic fortune transmitted over several generations. However, it has the disadvantage of generating huge quantities of by-products with a complex organic fraction and high chemical oxygen demand (COD). Indeed, 100 kg of olives produce on average 35 kg of pomace and 100 liters of vegetable oil [18]. Thus, these residues are commonly considered as an important polluting industrial waste.

Currently, with the promotion of the beneficial virtues of olive oil for human health, its demand continues to increase and consequently production is constantly growing at the expense of the environment. The discharge of effluents from olive oil mills has until now been a challenging ecological concern in the Mediterranean region. Oil plants furnished with modern equipment produce large quantities of 6 to 7 million tons/year that could reach 80–110% of the initial batch of olives, while with traditional devices, the production of olive oil mills is 50%. Given these excessive volumes of waste, treatment is essential to reduce the environmental impact. The problem posed by olive oil mills discharges resides mainly in their high polyphenol content that could reach 18–125 mg/g according to the variety of olives, the level of production, the period of olive picking and extraction.

From the preceding, it is clear that an attempt to remove polyphenols from the olive oil mills also known as olive mill wastewater would have a double interest: on the one hand, to solve a major environmental problem and, on the other hand, to recover and valorize the olive mill wastewater for later applications in agro-food.

It is also interesting to think of associating some other kinds of residual wastes that could be disruptive and sometimes harmful to the natural environment like gardening and crop residues, straw, green waste and dried sewage sludge for an attempt at recovery in terms of co-composting in order to evaluate the quality of the compost produced.

In this paragraph, a variant of the co-composting technique has been presented and described: olive mill wastewater with municipal solid waste, or olive mill wastewater with garden and cutting wastes, olive mill wastewater with dried sewage sludge.

5.1 Setting up waste windrows

As mentioned above, the technique adopted for this application is that of windrow co-composting. The windrows will be set up as the waste arrives at the composting plant. Care will be taken to ensure that the date of termination of the windrow placement is recorded. Also, it should be noted that the raw material collected has not been sorted or crushed before. The windrows were deposited on the controlled fermentation platform in pyramidal form (L x W x H = 12 × 6 × 2.5 m) (**Figure 4**). Co-composting processes are commonly carried out with variants of organic residues such as straw, cutting and garden waste, and sludge stabilized by drying in a natural sunny bed. The straw was chosen because of its structure that can absorb a large amount of olive mill wastewater and it is for the same purpose that the cutting waste was chosen. As for the WWTP sludge, it was chosen with the aim of looking for an efficient variant of recovery of this type of environmentally harmful waste. Main parameters of the composting process will be monitored in situ or laboratory measurements. Daily monitoring of the temperature considered as a key parameter of the composting process will be carried out using a compost thermometer (probe). Thus, a total of 9 × 3 measurements will be taken: three at the mid-height of the windrow (50 cm), three others at 150 cm from the bottom and lastly three measurements at 230 cm from the top and at three different points A, B and C of the windrow surface mass. The temperature of the windrow at a specific point will be taken as the average value of the temperatures at the different measuring points. Windrow turning made necessary after the temperature elevation within the waste mass allows a heterogeneous waste at the start of the process to be progressively homogenized; the watering will maintain a suitable humidity for the development of the different macro and microorganisms.

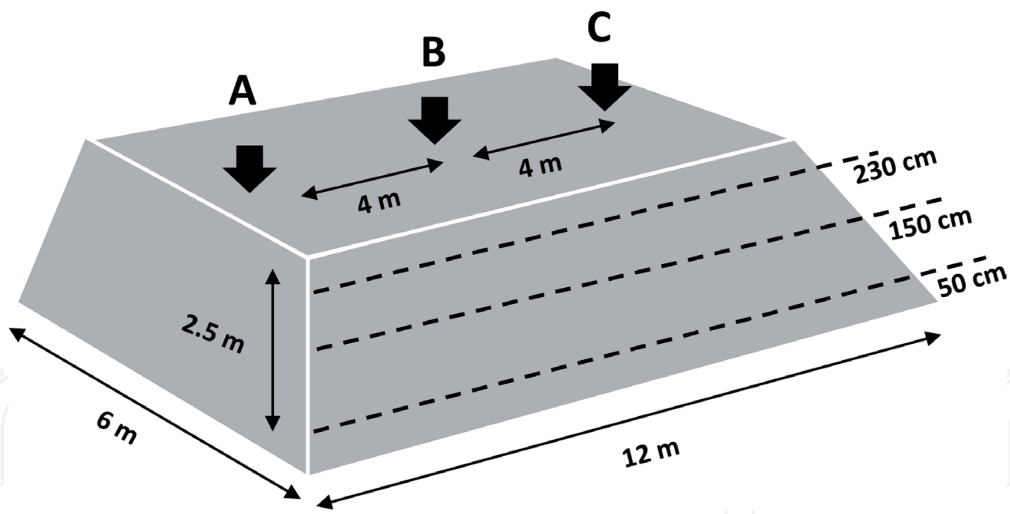

Figure 4.
Diagram showing the different levels of temperature measurement and waste sampling in a waste windrow.

The various possible treatment combinations could be conducted as follows: A1: Windrow composed of green waste without olive mill wastewater; A2: Windrow composed of green waste +15% olive mill wastewater; A3: Windrow composed of green waste +30% olive mill wastewater. A4: Windrow composed of premature compost without olive mill wastewater; A5: Windrow composed of premature compost +15% olive mill wastewater; A6: Windrow composed of premature compost +30% olive mill wastewater; A7: Windrow composed of straw + waste cuttings; A8: Windrow composed of straw + waste cuttings with 15% olive mill wastewater; A9: Windrow composed of straw + waste +30% olive mill wastewater. A10: WWTP sludge without olive mill wastewater; A11: WWTP sludge with 15% olive mill wastewater; A12: WWTP sludge with 30% olive mill wastewater, A13: Straws without olive mill wastewater; A14: Straws with 15% olive mill wastewater; A15: Straws with 30% olive mill wastewater; A16: Saturated straws. All these treatment combinations will be carried out in order to choose the right treatment for the different waste that goes with their rate and nature, and above all the quality of the finished product, i.e. the finished compost.

5.2 Quality of the finished products

It is important to mention that the olive mill wastewater addition to the sledges results in a less aerated compact waste structure of the windrow. This reduction of the interstitial space leads to a reduction in aeration at the level of the windrow, accompanied necessarily by a reduction in temperature at the level of the WWTP sludge-based windrows. At the level of these windrows, the temperature does not generally exceed 60°C. Therefore, monitoring of pathogens must be considered in order to ensure the sanitary quality of the finished product of compost.

However, the temperature changes in the straw-based windrows such A14, A15 and A16 showed high temperature values exceedingly largely 60°C, indicating active degradation. However, the windrow that has not received the olive mill wastewater, the temperature values to be recorded during the cycle of composting rates remains relatively low, this may be due to the fact that the straw has low enough moisture content for microbial growth, and an olive mill wastewater will be needed to correct the composition of the windrow in terms of moisture and nutrients.

Also, significant temperature increases will result in peaks between 50°C and 65°C. However, these thermophilic phases are interrupted by falls caused by overturning or naturally by precipitation. These waste turning is necessary to ensure aeration of the windrow and exudation of leachate from the windrows.

A global reading of the different temperature changes in the different variant of windrows could show that the composting cycle begins with a mesophilic phase where the temperature progresses rapidly from 40 to 45°C, just after a few days (5 to 6 days) of windrow implementation. Later and during the second thermophilic phase of composting, the temperature rise, which can last a month and a half, ensures pasteurization resulting in compost of good microbiological quality.

On the other hand, moisture is an essential factor in controlling the level of progress of the composting process. Here, humidity could vary between 20% and 85% with losses of water by evaporation and runoff or gains of water returned following rainfall in the absence of a cover. However, excessive humidity can interfere with the normal progress of the composting process, which may justify the aberrations that can sometimes be noted during temperature evolution.

Green waste and cutting windrows can have relatively higher moisture values of 65–88% than other straw windrows (A13, A14, A15 and A16). This may be attributed to their remarkable volumes that could create vacuums within the windrow.

However, moisture is less important for the sludge windrows. The small grain size of the sludge causes the windrows to become stacked. For straw windrows, low moisture values were recorded, suggesting that straw is a good absorbent, but significant leaching could be occurred throughout the composting cycle.

As mentioned earlier, the C/N ratio measures the relative proportions of carbon and nitrogen, nutrients essential to the life of microorganisms. Carbon and nitrogen measurements were taken at the beginning and end of the composting cycle. The highest ratios were recorded for straw swaths (A13, A14, A15 and A16) and cuttings (A7, A8, A9). This is because of their high carbon content, which is one molecule that is difficult to biodegrade. Hence its persistence in large proportion until the end of the composting cycle.

As for the windrows (A7, A8, A9, A13, A14, A15 and A16), respectively of cuttings and straw waste, relatively low nitrogen values of 0.30; 0.60; 1.00; 0.40; 0.80; 0.90 and 1.20% will be recorded at the end of the composting cycle.

As a result, C/N ratios remain fairly high, fluctuating between 124 and 139. This fairly high C/N ratio of the cuttings and straw waste windrows suggests that the resulting compost may be immature. It is well shown and known in the literature on this specific topic that the C/N ratio is considered an important indicator of maturity of organic matter in aerobic fermentation.

Green waste windrows represent the lowest final carbon values. This type of result automatically suggests compost stability, in terms of biodegradation speaking. In fact, green waste is essentially composed of cellulose, a component that is easily biodegradable. This specific composition means that the C/N ratios are always low. Indeed, a high initial C/N ratio favors nitrogen immobilization and a low ratio favors mineralization. This previous character is well confirmed by the general results obtained on this topic. In fact, the more the initial nitrogen content is increased by the addition of curbs, the more the mineral nitrogen will increase at the end of the composting cycle.

Thus, the contribution of olive mill wastewater to windrows rich in sludge considerably increases their nitrogen content. This nitrogen elements have the direct effect of increasing the general microbial activity and boosting the environment of the windrow.

Also, the application of olive mill wastewater has the effect of necessarily increasing the nitrogen content of the appropriate windrows. These nitrogenous elements reduce the C/N ratio and favor the stimulation of the biological activity.

As regards the co-composting of waste cuttings and straw, windrows with a large amount of straw and olive mill wastewater showed low C/N ratio values as compared to those obtained for windrows without olive mill wastewater; with respective C/N values for the windrows (A7: 0% margins, A8: 15% margins and A9: 30% margins) of 124, 63.5 and 40.3 will be recorded.

But we could notice that at the level of the finished product, a C/N ratio of 40.3 remains a rather high ratio indicating that the finished compost is not mature and an extension of the composting process is obligatorily essential because a non-mature compost might cause various important disturbances and an imbalance in the soil [19]. Thus, fertilizing substances and toxic substances such as ammonium are added to the soil in parallel. A similarity of the results would be observed in straw-based windrows where the respective values of C/N or windrows having received (0.15 and 30%) olive mill wastewater were 139; 54.38; 48.44 and 43.67.

Considering the organic components of the original waste, the addition of olive mill wastewater has increased the organic content in all the waste mass variants and this increase is proportional with the proportions of waste added for co-composting, 15% and 30%. Also, it is well known that the degradation of organic matter essentially corresponds to the mineralization of carbon and nitrogen. This result is confirmed by the fact that the smallest percentage of final residual organic matter would be recorded for windrows based on green waste. On the other hand, this percentage of residual final organic matter would be highest for straw and cuttings waste windrows, which would generally show low biodegradation.

The significant organic matter contents measured at the end of the composting cycle for sludge-based windrows could be explained by the richness of the sludge in easily metabolizable organic elements eliminated and rendered available during wastewater treatment by the complex biological flocculation-decantation-filtration phenomena.

Bacteriological analyses carried out on the various windrows at the beginning of the composting process often show great faecal bacteria contamination. Whereas an important abatement of these bacteria would be recorded at the end of the composting process. This result is certainly due to the inactivating effects of the thermophilic phase often known as the hygienization stage and exercising a significant influence on the composition of the macro and microbial flora, and consequently on the biological quality of the finished product.

These microbial inactivation effects during the thermophilic phase are very variable according to the nature of waste to be composted and the contents of the compost heap during the composting cycle. The addition of olive mill wastewater in the materials to be composted generally generates a stimulating effect of the organic biodegradation and an inhibiting and stressful effects concerning the growth of organisms presenting pathogenic or phytopathogenic characteristics [20].

The results relating to the analysis of polyphenols at the level of the windrows during the composting process (samples taken at the beginning and at the end of the composting cycle) show that the biodegradation or transformation of the polyphenols contained in the olive mill wastewater is possible by composting. Indeed, the polyphenol contents recorded at the beginning of the composting cycle are relatively higher than those obtained at the end of the composting cycle.

However, these polyphenol contents rise at the level of the windrows having received increasing quantity of 15 and 30% of the compost. At the end of the cycle, the polyphenol contents become very minimal and barely detectable (traces of the order of 0.3 mEq/g of dry matter of finished compost). The highest value is recorded at the level of the straw swath saturated with 0.55 mEq/g of finished compost dry matter.

This important result underlines the fact that the saturation of the waste windrows in the compost heap is not advisable and not recommended.

The application of a growing proportion of olive mill wastewater in the windrows does not affect the content and richness of the finished compost in mineral elements such as Zn, Cu, Ca and Cr, etc. The only exception is observed in case of the WWTPs sludge (A10, A11, and A12) with very high values of these last elements that are often proven conform to the common standards in vigor.

For the co-composting procedure treated with olive mill wastewater, we necessity assumes the improvement of the potassium and calcium contents of the finished product by assuming the great richness of the olive mill wastewater in these elements. A contrary result could be made and suggested that these nutrients have leaching with the rain in the case of processes conducted without shelter or during watering, especially in the case of potassium, which is the most soluble and therefore the most altered by leaching.

In the same manner, it is advisable to use straws (windrows: A16, A15 and A14) for composting on condition that more water or olive mill wastewater is used for watering and for avoiding low-slung water content at the start of the process that slows down the general process of composting.

Finally, industrial technology systems could therefore exploit the olive mill wastewater, which is considered as a precious raw material, very rich in organic matter and nutrients, in order to use them instead of water for watering the windrows during overall composting process.

6. Conclusion

Thus, the problem of the valorisation of the various organic residues, principally of the municipal wastes and olive mill wastewater, is currently worldwide worrying, and it is specially posed in terms of environmental preservation. The choice of the treatment technique must not be only from the point of view of monetary profitability, but above all must consider the efficiency of the treatment process. It is not possible to develop all the techniques currently being tested. Composting appeared as the main pathways for remediating this high and gigantic tonnage of wastes daily generated by modern societies. The processes of composting described above appeared very simple to be implemented, not expensive, and especially gave a finished product of good quality on average, but very consuming in space and in time. At last, I could clearly see that this kind of process might go well with an implantation especially in developing countries with a sunny and warm climate. The amendment of agricultural soil with organic matter is made very urgent by the flagrant lack of its substances on the market and the same demand for fertilisers from the increasingly demanding crops. Soil and the various bio-physico-chemical and especially biological processes of degradation and humification prevailing in the soil contribute intensively and could help in the solution of this thorny problem of accumulation of all organic residues in modern societies.

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