LIFE AGRISED, LIFE17 ENV/IT/000269

"Use of dredged sediments for creating innovative growing media and technosols for plant nursery and soil rehabilitation"

Guideline

The co-composting process

Index

The LIFE-AgriSed project: compost as a possible substitute for classic nursery substrates

Within the nursery sector, the substrate is of key importance in container cultivation. It is characterized by a double matrix: an organic fraction that mainly performs a support function and supply of nutrients and a mineral fraction that promotes the necessary aeration of the root system and the drainage of excess water. Currently, the most commonly used organic component in nurseries is peat. The term peat refers to various materials that derive from the incomplete decomposition of plant residues in marshy environments, also based on the availability of oxygen. It has been estimated (Kitir et al., 2018) that the European consumption of peat in the nursery sector is around 25-26 million m^3.

However, in recent years, there is an increasing difficulty in finding this resource due to an excessive and progressive depletion of the peat bogs and by laws, adopted by the main Northern European producing countries, which aim at their conservation and protection. In addition, the European Commission Decision 2001/688 / EC (CE. 2001) precluded the issue of the Community ecological quality label for substrates containing peat. Therefore, the need to use alternative substrates that are "peat-free" and, possibly, are obtained from waste materials is increasingly growing in order to significantly reduce the environmental impact of the nursery. With this in mind, a solution is offered by the use of compost, which is a product generated by the decomposition of multiple substances with an organic matrix thanks to a long and complex oxidation process operated by microorganisms in a particular environment characterized by well-defined parameters. The process can be accelerated by amassing the waste material in heaps in order to keep the heat developed by the metabolic processes which are speeded up, in turn, by the increase in temperature. Among the components that could find an application in the constitution of a compost suitable for the cultivation of plants in containers are the sediments found through the dredging of rivers, a resource that is little used and in excess which, generally, is disposed of in landfills as waste.

In Europe, the periodic dredging of rivers and ports produces about 200 million m^3 of sediments per year (Bortone et al. 2004) and, for this resulting material, it could be hypothesized a composting treatment together with green waste produced from local nursery companies. The latter also constitute, in fact, a waste that needs to be disposed of if it is not possible to use them in an alternative way (only in the Pistoia nursery district, 20,000 tons / year of plant residue are produced annually). The Life AGRISED project therefore sets itself the goal of carrying out an experimentation focused on these issues to establish whether, indeed, the resulting material deriving from the co-composting of green waste and dredged sediments can represent a valid alternative as a peat-free substrate.

The composting process

The term composting indicates a controlled aerobic fermentation process in which easily fermentable organic substances are degraded by oxidative actions implemented by thermophilic microorganisms. These microorganisms break down more complex substances into more stable humic molecules, mainly humine, humic acids and fulvic acids, while releasing heat and CO_2. The result of a correct composting process consists in a product similar to a homogeneous dark colored soil, without particular unpleasant odors, with a humidity content between 30 and 45% and a pH oscillating between neutral and slightly alkaline. According to Italian legislation (Legislative Decree 75/210, ex 217/06) (CE, 2010), compost is classified into two categories based on the original organic components from which it was obtained: if it derives only from green waste, such as for example vegetable waste from green maintenance or agricultural production, it takes the classification of Composted Green Soil Conditioner; if, on the other hand, these green waste are added to other organic matrices (sludge, wastewater from livestock farms, organic fractions of urban solid waste, and so on) it is classified as a Mixed Composted Soil Conditioner.

Essentially, the main phases that occur in a composting process are two: a first phase of bio-oxidation and a subsequent maturation phase of the compost. During the first phase, which is also the most intense, the various microorganisms that proliferate in the organic matrices rapidly begin to attack the more easily degradable compounds, therefore substances with simple molecular structures, such as sugars or free amino acids (Canditelli, 1996). These processes release large amounts of heat, carbon dioxide and, to a lesser extent, water. In the maturation phase, on the other hand, when the more easily degradable and more available substances are exhausted, less intense reactions from an oxidative point of view take place, with a consequent decrease in both temperature and CO_2 emissions. It is in this slower maturation phase that the synthesis of complex carbon-based compounds and the polymerization of molecules takes place, which leads to the stabilization of the composted material with the formation of humic substances (Meena et al., 2021).

Factors and parameters that influence composting

Given the microbiological nature of the composting process, it is obvious how all those factors capable of altering or influencing the processes of microorganisms consequently influence the progress of composting and the final result of this. Mainly the parameters of greatest interest to be kept under control during a composting process are the oxygen content, temperature, humidity, C / N ratio and pH.

Oxygen

As previously mentioned, composting is a strictly aerobic process; therefore, oxygen is one of the fundamental elements. In the initial phase of rapid bio-oxidation, the demand for O_2 is greater, with a demand ranging between 5 and 15%. In the subsequent ripening phase, given the slower and less aggressive nature of the processes in place, the oxygen content of the composting material can also drop to values between 1 and 5%. Obviously, both an excess and a lack of oxygen, therefore outside the optimal thresholds established for the two different phases, lead to different problems. A too low level of aeration can lead to a lowering of the evaporation rate, which, especially in the faster oxidation phase, where the production of water in the composting material is also greater, can lead to water stagnation and the consequent establishment of an anoxic environment. In this case both will have the consequent death of aerobic microorganisms and colonization by anaerobic organisms and the establishment of putrefactive processes, which will tend to break down and metabolize organic compounds, generating as secondary metabolites no longer the desirable humic acids, but reduced compounds such as acetic acid ($C_2H_4O_2$), hydrogen sulphide (H_2S) (Xu et al., 2020) and methane (CH_4) (Meena et al., 2021). This will cause, in addition to the emission of penetrating and unpleasant odors, also a loss of carbon, and therefore a worse final quality of the material obtained at the end of the composting period; moreover, most of these compounds are highly phytotoxic, severely limiting the subsequent possibilities of use of the compost produced in the agronomic field. In the opposite case, on the other hand, in the presence of excessive aeration, it will be possible to notice sudden drops in the temperature of the material being treated and an excessive rate of evaporation, with a consequent drop in humidity of the material, a factor that will limit the proliferation of aerobic bacteria and slow down consequently the whole composting process (Rynk et al. 1992). To ensure the right aeration rate inside the composted material there are basically three possible methods to be used:

- Forced ventilation: the air is forced into the compost heaps, through a system of pumps, fans and pipes previously set up. These are relatively complex and expensive systems, both from the point of view of construction and design, which consequently are usually used in large plants.

Being able to decide moment by moment the quantity of air blown in, it is possible, to a certain degree, to prescind the characteristics of the matrices used and the environmental conditions (Neklyudov et al., 2006).

- Passive ventilation: similar to the previous one, it is always based on pipes or ducts to circulate the air inside the material, the substantial difference is that instead of having an active pumping system for the air this is channeled through special vents oriented in the direction of the wind. Although having a management impact that is certainly less than active systems, the impossibility of correcting any excesses or shortages of air during construction implies the need for a more careful design of the system, from the choice of matrices to the study of climatic conditions/environmental conditions of the area where the composting takes place.

- Natural ventilation: without the aid of any structures such as those described in the two previous types, the air penetrates inside the heaps of material only as a function of the porosity of the latter. Even if with this system the costs related to the air distribution and circulation systems present in the active and passive aeration are ignored, a more accurate and constant control of the percentage of aeration in the heaps is necessary, as the only way to correct any scale hole values is to mechanically move the material, overturning it and remixing it to ensure that the matrices incorporate the right amount of oxygen.

Temperature

This is perhaps the most indicative parameter to take into account, as the various temperatures reached by the composting material during its treatment are important indicators of how the process is taking place, if there are problems or if the degradation of the organic substance is proceeding in the right way. In all composting processes, in optimal conditions, there are mainly three distinct phases, each characterized by well-defined temperature ranges.

- Mesophilic phase: in this phase the bacteria within the composting mass begin to adapt to the substrate in which they are located and to proliferate exponentially. After a period of standstill, in which the temperatures remain substantially the same as the external ones, the composted material quickly begins to heat up, due to the rapid degradation processes that the mesophilic microbial flora implements on the more easily attackable substances, such as monosaccharides, lipids, starches. and proteins (Tuomela et al., 2000). Temperatures rise within a few days until they reach a range between 40 ° C and 55 ° C; once these temperatures are reached, the mesophilic bacterial flora begins to die, while the colonization of thermophilic microorganisms begins.

- Thermophilic phase: during this phase there is the colonization of the substrate by thermophilic microorganisms such as fungi, capable of operating up to temperatures of 45 ° C - 50 ° C, and actinomycetes, capable of resisting up to temperatures close to almost 60 ° C. The temperature peak of this phase also corresponds to the exhaustion of the more easily degradable organic substances and to the beginning of the metabolization of more complex components, such as lignin, cellulose and hemicellulose, aromatic compounds (Mattei et al., 2016) and heavy metals (Whittle and Dyson, 2002). It is also in this phase, thanks to the high temperatures reached and maintained for a few days, that the self-sterilization process of the composted matrices takes place in which pathogenic organisms and microorganisms, phytopathogens, parasites and infesting seeds that could be present in the plant are brought to death. internal part of the plant components being treated. Figure 1 shows, for example, the temperatures and times for which these must be maintained to eliminate the most common human pathogens that can be found in sludge and solid fractions of municipal waste.

- Cooling phase: in conjunction with the exhaustion of the most readily available nutrients and at the beginning of the degradation of the more complex substances, the oxidative reactions become slower, with a consequent drop in temperatures. During this phase, fungi are mainly active, first the thermophilic ones again as soon as the temperature returns to around 60 ° C, then the mesophilic ones when it drops further below 50 ° C, capable of degrading even the most complex substances. When the temperatures reach the external ones, the composting process is considered concluded, as it is considered that there is no longer enough degradable organic substance to support the functions of the microorganisms.

Salmonella typhosa	Stops growth above 46 degrees; dies in 30 minutes at 55-60 degrees and within 20 minutes at 60 degrees; it is quickly destroyed in composting environments.
Salmonella sp.	It dies within an hour at 55 degrees and within 20 minutes at 60 degrees
Shigella sp.	He dies within an hour at 65
Escherichia coli	Most die within an hour at 55 degrees and within 15-20 minutes at 60 degrees
Entamoeba histolitica	It dies in a few minutes at 45 degrees and within seconds at 55 degrees
Taenia saginata	Dies within minutes at 55 degrees
Trichinella spiralis	It dies quickly at 55 degrees and instantly dies at 60 degrees
Brucella abortus and Brucella suis	They die in 3 minutes at 62-63 degrees and in an hour at 55 degrees
Micrococcus piogenes	It dies in 10 minutes at 50 degrees
Streptococcus piogenes	It dies in 10 minutes at 54 degrees
Mycobacterium tubercolosis var. hominis	It dies in 15-20 minutes at 66 degrees
Corynebacterium diphtheriae	It dies in 45 minutes at 55 degrees
Necator americanus	It dies in 50 minutes at 45 degrees
Ascaris lumbricoids	It dies in less than an hour at temperatures above 50 degrees

Figure 1 - Temperatures and timing necessary for the destruction of the most common pathogens and parasites contained in the waste (translated from Barazzetta, 1987).

Humidity

Given the fact that composting is an aerobic process, carried out by microorganisms, it is clear that humidity is also an important factor within this process. In fact, water is the medium in which the chemical reactions of degradation and creation of new compounds take place, in which nutrient exchanges between cell membranes and the outside take place and is a vehicle for the enzymes necessary for all these processes. It is therefore necessary that it be present in such quantities as to guarantee the optimal life conditions of the microorganisms, but not to generate phenomena of water stagnation such as to cause phenomena of anoxia; the optimal values are generally between 40 and 60% (Meena et al., 2021). A humidity rate of less than 40% begins to represent a limiting factor for the proliferation of microorganisms, which begin to slow down their metabolic activity, and consequently the degradation of the organic substance. This slowing down phenomenon is increasingly marked as the percentage of humidity decreases, until the microbial activity ceases almost completely, upon reaching a humidity level below 20% (Calabretta and Intrigliolo, 2007). On the contrary, a water content that is too high, higher than 65%, involves a rapid replacement of water by air in the interstitial spaces of the organic matrix, limiting the diffusion of oxygen and leading to a situation of anoxia in which putrefactive processes are established.

C/N balance

The relationship between the carbon (C) and nitrogen (N) content of the various organic matrices subjected to composting significantly influences the microbial population. The microorganisms active in composting processes, in fact, use carbon as an energy source and as the main constituent element for about 50% of their mass, while nitrogen is used for the synthesis of proteins, nucleic acids, enzymes and other necessary components. for operation and development; a good starting C / N ratio is around 30. This value will tend to decrease up to values between 10 and 15 in the finished product, as each time an organic compound is degraded by the bacterial flora about two thirds of its content carbon is released into the atmosphere in the form of CO_2. As for the previous parameters, a significant deviation, in excess as well as in defect, from the value considered optimal will cause problems during the composting phase. A carbon/nitrogen ratio greater than 35 indicates an organic material particularly rich in C: microorganisms would therefore have a wide range of carbon-based compounds available to be used as energy or as elements for cell growth, but they would not have enough nitrogen to synthesize proteins, enzymes, and all other components in order to support this rapid development. Composting therefore proceeds slowly, with a reduced oxidation rate of the organic material and with temperatures even significantly lower than processes that operate in the optimal range of the ratio between carbon and nitrogen. A ratio of less than 15, on the other hand, provides enough N to sustain a rapid growth of the microbial flora which, however, is not counterbalanced by a sufficient quantity of C. This, especially in the first phase of the process, the mesophilic one, where there is an abundance of easily oxidizable compounds, leads to an exponential increase in bio-oxidative processes, accompanied by a sudden increase in temperatures. However, once the easily degradable substances from which to obtain carbon are terminated and arrived at the lack of this with which to support exponential growth, the process suddenly slows down and the excess of free nitrogen, no longer used in the synthesis of molecules used by the bacterial flora, is lost in the form of volatile compounds such as ammonia (NH_3), especially in conjunction with alkaline pH and high temperatures.

pH

The pH, derived from the alkalinity or acidity of all organic materials present in the compost, influences the development of microorganisms and the fate of nitrogen-based behaviors. The optimal value for bacterial development is between 6.0 and 7.5, while for fungi the range is slightly wider, ranging from 5.5 to about 8 (Chen et al., 2011). However, pH control is not as important a factor, or at least not as important as the previous ones, during a composting process. This is because the pH values are not stable during the process: starting from values between neutral and basic (7.5-8), the pH in composting piles initially tends to decrease due to the rapid production of organic acids and CO_2 (Nakasaki et al., 1993); subsequently, the release of carbon dioxide from the heaps, the decomposition of complex proteins and the production of ammonia raise the values towards basicity. Finally, during the final stages of composting, the pH tends to stabilize on neutrality, also thanks to the proliferation of nitrifying microorganisms that degrade ammonium into nitrous or nitric acid (Calabretta and Intrigliolo, 2007).

Other characteristics

In addition to the characteristics listed so far, there are finally other properties to consider inherent to the matrices in composting. These are factors unrelated to the previous ones, but which can equally determine a better or worse outcome of the process. In this case it is mainly the physical aspects of the material that are taken into consideration; factors such as the weight of the material, its porosity, or its resistance to crushing. All these characteristics contribute to determining the "stability" of the compost heap and its behavior with regard to factors such as water or air. In fact, matrices with low porosity cause a poor circulation of these, leading to the risk of situations of anoxia or poor hydration of the material; a substrate that is too heavy, especially if added to materials with a low resistance to crushing, can cause a compaction of the heap, again causing problems for ventilation and humidity, but also making any overturning, homogenization, or management maneuvers more difficult of the composted material. A total density of the composted material considered optimal is between 150 and 250 Kg/m^3. Another key feature of the material to be used is its granulometry: the degradation processes of the organic substance operated by microorganisms take place on the surface of the various substances, therefore, for the same mass, there will be a greater degradation activity in those materials that present a greater attackable surface; smaller particles therefore determine a greater efficiency of the product compared to an equivalent mass divided into coarser elements. A particle size between 5 and 15 cm is considered the most suitable for the materials to be composted.

Compostable matrices

Considering what has been said so far, it seems obvious that a correct choice of the matrices to be sent to composting represents a first and fundamental step towards the creation of a quality material. Regarding the raw materials from which to obtain compost, there is no clear and unambiguous definition, simply due to the fact that, at least in theory, any organic material could be subjected to a composting process. However, it is highly unlikely, if not completely impossible, that a single organic component has all the correct characteristics, both physical and chemical, so that from the aerobic degradation of this material we obtain something that can be defined as compost pursuant to Legislative Decree 75/210. For this reason, it is advisable to add and mix different matrices, with different physio-chemical characteristics, to obtain a starting material as adherent as possible to all the characteristics of humidity, pH, C/N ratio and so on described above. Based on the contribution they make to the final compound the various matrices can be divided into:

- *Ammendants:* materials that modify one or more main characteristics (pH, humidity…).
- *Bulking agents:* they bring "structure" to the material, preventing it from collapsing under its own weight once piled up, crushing, and losing the porosity necessary to maintain optimal oxygenation and hydration levels.
- *Carbon sources:* mainly used to increase and correct the ratio between carbon and nitrogen, thus increasing the concentration of the former with respect to the latter, making compounds rich in C.

Below is a short list of the most common matrices that can be used in composting processes:

Animal breeding waste

They are mainly divided into solid substances, such as bovine and equine manure or the mass of excrements added to straw or sawdust that make up the bedding of the stables, and into sewage, when used in a liquid or semi-solid state. The first type has a good C / N ratio (15-25), thanks also to the litter material incorporated in the solid manure; liquid waste, on the other hand, almost totally missing the vegetable part of the litter, has a nitrogen content that is not balanced by a carbon source which therefore generates an extremely low C / N ratio (5-10). The high humidity also limits the possibilities of use: a drying period is very often necessary, which implies higher management costs and more extended times. Another problem related to the use of animal waste is the high number of pathogens and parasites that may be present in them and which, if not properly controlled, can also be found in the finished product, making it in fact unusable. Excellent to be used as soil improvers or as bulking agents.

Crop residues

A good starting material, mainly composed of easily degradable substances, with C / N ratios based on the type of waste that can vary between 20 and 40. They can also have very variable degrees of humidity based on the time elapsed before to be sent for composting, so from this point of view it is necessary to carefully evaluate how to use these matrices. They can have high levels of contamination from unwanted substances such as pesticides, so a preventive analysis of the material is usually recommended to ensure that it falls within the correct parameters. Usually used as soil improvers or as carbon sources in addition to matrices too rich in N.

Nursery residues

Composed mainly of dead plants, unsold specimens or material derived from pruning, for which they are used almost exclusively as a source of carbon; very often, if they come from pots, the plants still have the material used ad substrate. This can present a problem as the depleted substrate may contain pathogens, weed seeds or residues of fertilizers or control agents such as pesticides or fungicides. To date, therefore, it is still a material rarely used in composting.

Residues from urban green management

Leaves, grass clippings or pruning, also have very different characteristics. The leaves are a rather dry material, with a good carbon content, but which tend to have a poor resistance to compaction; moreover, often the collected masses contain foreign objects, stones, waste, plastics, which must be properly screened before using them. Pruning residues have a very high C / N ratio, even higher than 150 in some cases, but are difficult to degrade, especially in the first mesophilic phase of the process (Neklyudov et al., 2006); on the other hand, they are excellent, once shredded with chippers and shredders, as bulking agents, providing excellent resistance to crushing and good porosity to the resulting material. Finally, grass clippings are easily degradable, but often have a high nitrogen content, which lowers the C / N ratio around 10-15, a pH that is sometimes too high and even more than the leaves are subject to crushing and compaction in the heaps.

Organic fraction of urban solid waste (MSW)

Potentially a very large source of material to be used for composting, in Italy alone in 2019 about 1.7 million tons of organic waste were produced, of which only just under half (49.2%) was composted (ISPRA, 2020). The greatest limitations to the use of the organic fraction are due to its great heterogeneity, which makes it practically impossible to have a continuous supply of material with well-defined and constant characteristics, and to the possible contamination that this waste can undergo during the collection, selection and sorting prior to taking delivery of the material by the composting plant. Similarly, to cultivation residues they can be used both as soil improvers and as sources of easily degradable carbon.

Dredged sediments

As mentioned in the introduction, to date the resulting material from the periodic dredging to which ports and canals are subjected, both navigable and which does not represent a significant amount of material for which practically no use is foreseen, other than the consolidation of the embankments themselves of the channels from which these muds are dredged. Any use as a compostable matrix would therefore represent an effective method of disposal of these dredges which, otherwise, are destined to be disposed of as waste, with the costs and impacts associated with it. The biggest problem related to the use of these materials is the contamination by various substances that they may present, especially if the dredged mud comes from navigable canals, ports, or locations close to them. In fact, in several studies consistent accumulations of heavy metals have been found, especially zinc (Zn), copper (Cu) and lead (Pb), followed by chromium (Cr), nickel (Ni) arsenic (As) and cadmium (Cd), aromatic compounds (PAH), polychlorinated biphenyls (PCBs) and hydrocarbons with C> 12 (Kelderman, 2012), (Hashim et al., 2018). Although it has been demonstrated that the composting process can contribute to a certain degree to the phytoremediation of these sediments (Mattei et al., 2016), (Whittle and Dyson, 2002), it is not certain that the decrease in contaminant levels is such to determine a decrease in these values below the limits imposed by the legislation that regulates the use of fertilizers, compost or soil improvers; this is the case, for example, of metals that are difficult to mobilize, such as cadmium: in these cases even the final concentration of these elements can be even higher than the starting one, since at the end of the composting process the total volume of the composted mass undergoes a decrease compared to the initial value due to the degradation of the organic substance, thus increasing the concentration of any pollutants not disposed of. Another problem related to these materials, especially if they come from locations near the sea, is the high salinity, and therefore the high electrical conductivity of the dredged fish. This, in addition to representing a problem for the possible use as a cultivation substrate for plants sensitive to soil salinity, also presents problems from a legislative point of view, as, like heavy metals and other pollutants, also electrical conductivity is subject to limit values imposed by law.

Composting methods

The simplest composting method, as well as the most "primitive" one is the one that can also be observed in the classic home composters, that is a passive process where the organic material is accumulated in confined spaces and left to mature for long periods, sometimes even months, without any external intervention of overturning or homogenization of the material. It immediately becomes obvious that this can only be a "hobbyist" process, and that to produce quality compost it is necessary to resort to much more structured methods, among which the most commonly used are:

Composting in open windrow regularly turned

The starting material is arranged in heaps or in long lines (figure 2), with varying heights between 1 and 4 meters based on both the machinery subsequently used for overturning and based on the weight of the material: matrices with density high they cannot be stacked too much to avoid the risk of excessive compaction.

Figure 2 – open windrow composting.

These heaps are periodically subjected to turning, operated with specific machinery or even with the most common mechanical shovels; this guarantees to have a constant incorporation of air, to maintain homogeneous temperatures throughout the pile, as the colder material on the outside is cyclically replaced with the warmer one in the internal areas, and tends to gradually reduce the size of the material, making it more homogeneous and facilitating the degradation of microorganisms. The main disadvantages of this type of composting derive from the need to use heavy machinery for the management of the matrices (figure 3).

Figure 3 – machinery for turning heaps.

Composting in ventilated heaps

In this type of composting there is no overturning of the composted material, but the correct oxygenation rate is guaranteed by both passive and active air circulation systems (Figure 4). These are much lower structures than the piles subjected to overturning, usually no higher than 1 meter, 1 meter and 20 meters, since once the pile has been created it is no longer possible to intervene mechanically to solve any compaction problems. Again, due to the fact that no material handling interventions are foreseen, the choice and pre-treatment of these is a crucial element for the success of the composting process for ventilated heaps; the matrices must immediately be sufficiently homogeneous and present a size suitable for oxidative degradation processes. Porosity is also a determining factor, as the air must be able to reach all parts of the heap. The problem linked to this type of processes, and which can arise more easily, is the excessive drop in humidity in the heaps, dried by the continuous flow of air, which, however, can be easily remedied by wetting the processed material regularly.

Figure 3 - actively ventilated compost heaps.

Composting in bioreactors

System that differs from the previous ones in that the compostable material is inserted in large rotating cylinders (Figure 5), with diameters of about 3 meters and lengths up to 30/40 meters with a load capacity of around 50 tons. In these cylinders, slightly inclined and in which the air is circulated by means of pumps and fans, the material is subjected to continuous mixing and ventilation. Given the travel speed of the material inside the cylinders, about 3/4 days, and the temperatures that rarely exceed 55 ° C, these are systems used only for the activation of the microbial degradation processes of the matrices: the material at the outlet of these bioreactors, having in practice only carried out the mesophilic phase of the process, it must in any case be arranged in heaps as in the types described above in order to complete the two missing phases. This system, although complex in its implementation and management, allows to obtain excellent levels of homogenization in the compost, significantly facilitating the other phases carried out outside the bioreactor.

Figure 4- bioreactor for composting processes.

Life AgriSed: results obtained within the project

Within the Life AgriSed project, two tests were carried out on the composting of dredged sediments together with green waste from various sources. A first test was carried out in the Czech Republic, at the composting facility of the project partner "EPS Biotechnology, s.r.o", while the second was carried out in Italy, inside a space specially set up at the nursery "Fratelli Gorini plants "In Pistoia (PT).

Composting in the Czech Republic

Started on 29 October 2019 and collected on 14 July 2020, it was a composting in periodically overturned piles of 3 different ratios of green waste and dredged sediments: a first pile formed by 3 parts of sediment for each part of green waste, a second heap formed by a part of sediment for each part of green waste and a last heap composed of 1 part of sediment for every 3 parts of green waste (figure 6).

Figure 5 – the 3 compost heaps in the Czech Republic.

The components of the various mixtures were obtained as follows: the dredged sediment, resulting in a predominantly sandy texture material (66.08%), with poor electrical conductivity (0.92 dS/m) and slightly contaminated by PCBs and C> 12 hydrocarbons in a manner more marked, was collected by means of a small excavator from a canal located in an agricultural area about 50 km from Brno (figure 7), while the part of green waste was composed of green cuttings, crop residues of corn, residues woody chips and dry leaves (figure 8).

Figure 7 – sediments dredging

Figure 8 - A) grass clippings, B) corn crop residues, C) chipped woods, D) dry leaves.

During the duration of the composting, the temperatures of the piles were constantly measured to detect peaks in the microbial activity inside the piles: in correspondence with the lowering of these peaks, a sign of a decrease in activity due to oxygen depletion, it was prepared the overturning of the piles (figure 9).

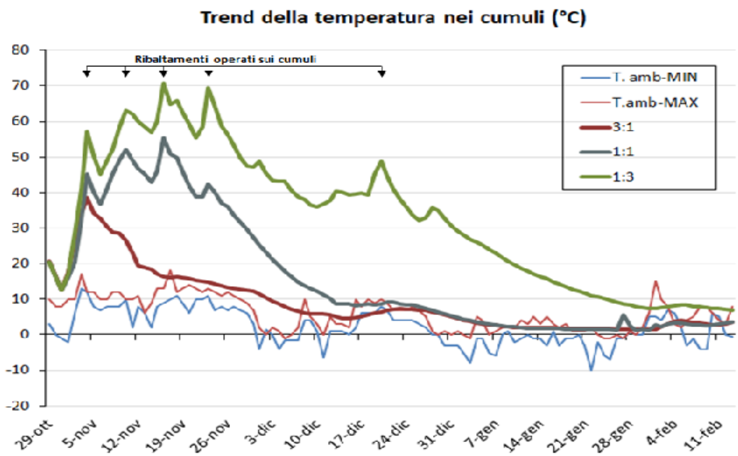

Figure 9 – temperatures trends in Czech composts.

As we can see, only the two heaps with the highest percentages of green waste compared to the sediments reached acceptable temperatures, while the heap containing 3 parts of sediment for each part of green substance not only did not even exceed the temperature of 40 ° C, but even in conjunction with the overturns, it did not show any recovery of microbial thermogenic activity. This would indicate a lack of carbon within the composted material that did not allow a substantial development of the bacterial flora. The main problems encountered by the final analyzes performed on the compost produced in the Czech Republic are due to the high pH (figure 10) and the presence of hydrocarbons with chain of C> 12 (figure 11) outside the Czech legislation regarding the use of materials such as compost.

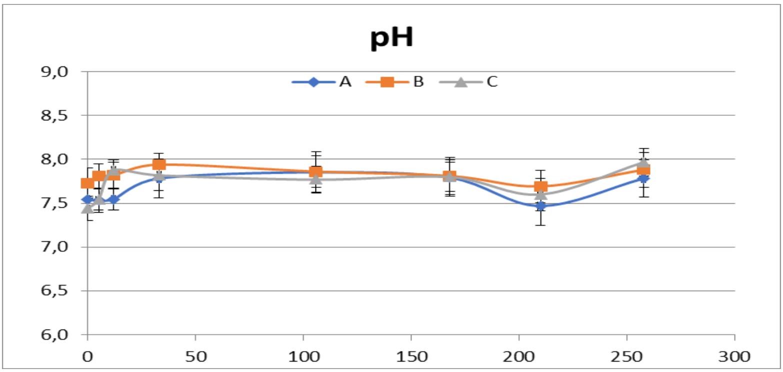

Figure 10 – pH trend on Czech compost. Sediment: green waste ***A****: 3:1,* ***B****: 1:1,* ***C****: 1:3.*

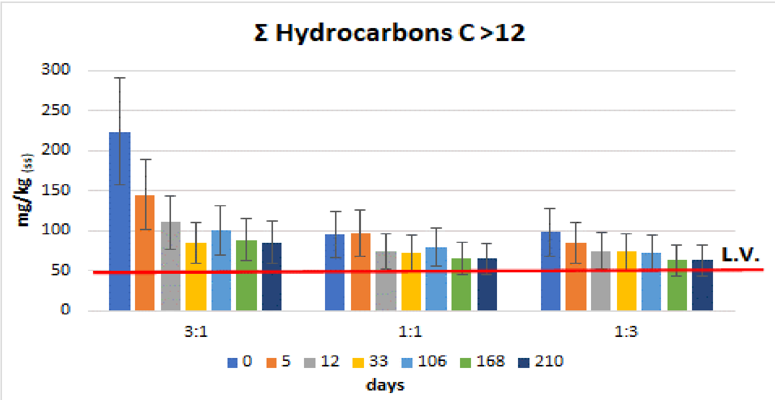

Figure 11 – degradation of C>12 hydrocarbons in Czech compost.

As far as the pH is concerned, the cause is probably to be found in the quantity of green cuttings and dry leaves, which have brought high pH values to the mass (> 8.5); this meant that although noting a decrease in the values in the final stages of composting, these never dropped below 7.5 Hydrocarbons C> 12 instead showed a sharp decrease, demonstrating that the composting of dredged sediments together with green waste can be seen as an effective method of phytoremediation; however, the very high initial concentrations prevented the material from falling within the limits imposed by Czech legislation. Furthermore, the concentration of the other pollutant detected in the Czech sediment, PCBs, also showed a clear decrease compared to the values present at the entry into the material in the composting process, where already after 12 days the concentration in all 3 piles was dropped below the detection threshold (Figure 12).

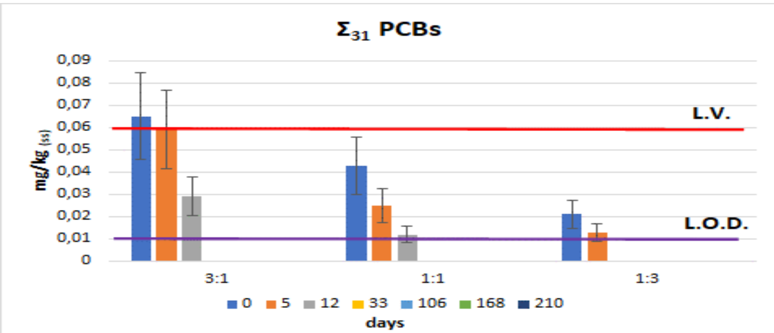

Figure 12 – PCBs degradation in Czech compost.

Composting in Italy

Started on 29 October 2020 and completed on 7 April 2021, it was always carried out on 3 heaps with the same ratios between dredged sediment and green waste (3: 1, 1: 1, 1: 3), but the origin and type of materials was substantially different: the sediment was dredged from the Navicelli canal of Pisa, a navigable waterway near the sea, resulting in a similar texture to the Czech sediment (mainly sandy), but presenting, due to its proximity to the sea, an electrical conductivity extremely high (4.20 dS / m), widely out of range for Italian legislation; furthermore, there was a slight contamination by PCBs, in any case below the limit values and hydrocarbon levels with C> 12 above the permitted threshold. As for the green waste, however, it was provided by a Pistoian company that deals with the recovery, treatment, and reuse of all green waste, mainly nursery, generated by the Pistoia district. Another substantial difference with the composting carried out in the Czech Republic consists in the fact that the composting authorization process at the "Fratelli Gorini plants" nursery required the construction of 3 composters designed ad hoc for this project, in which the material being treated was contained without the dangers of spillage or sewage percolation (figure 13), but which made the periodic overturning of the heaps much more complex and inefficient than expected, since the only way to carry out these movements was to use a small boom excavator (figure 14), not exactly the most efficient way to do these jobs.

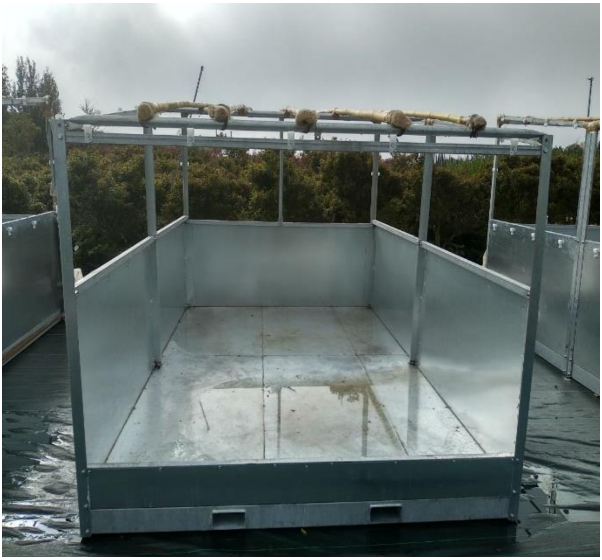

Figure 13 – one of the composters used in the project.

Figure 14 – the boon excavator use to turning the compost.

The difficulties encountered in homogenizing and mixing the matrices can be seen in the graph of the temperatures reached during composting in the 3 heaps (figure 15).

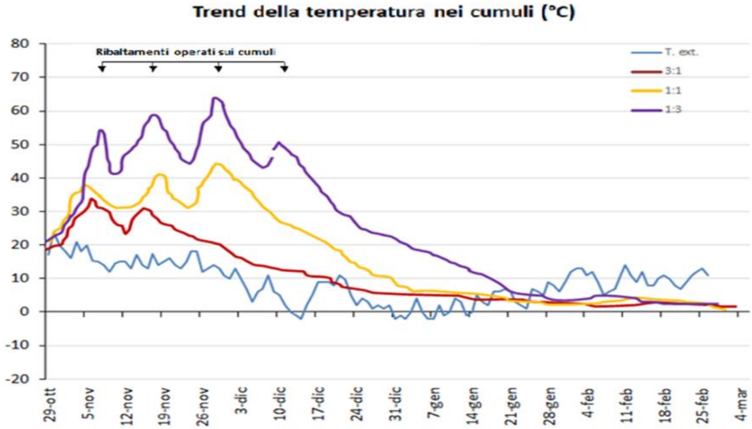

Figure 15 – temperatures trend in the Italian compost.

Compared to the temperatures reached in the Czech Republic there are differences in all 3 piles of about ten degrees ° C, and also the temperature peaks are more distant and less sudden. This is most likely because the green waste was not distributed in a sufficiently homogeneous manner within the mounds, so the microbial community did not have enough sources of nutrition to develop adequately. Another problem encountered in the Italian compost, not present in the Czech one, was the high rate of electrical conductivity obtained at the end of the process: even if the composting has shown the ability to lower this parameter, the high value in the dredged starting material has meant that according to the Italian legislation the final product obtained cannot be technically used as compost (figure 16).

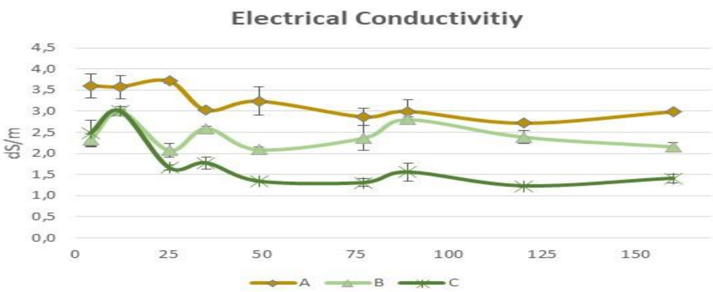

Figure 16 - trend of electrical conductivity during Italian composting. Sediment: green waste A: 3:1, B: 1:1, C: 1:3.

Similarly, to what has been seen in the Czech compost, moreover, also in the Italian one there was a degradation beyond the detection threshold level of PCBs (figure 17) and a significant, if not total, degradation of C> 12 hydrocarbons (figure 18).

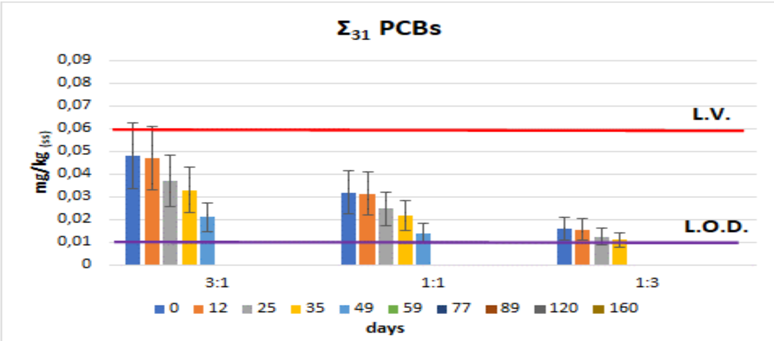

Figure 17 – PCBs degradation in Italian compost.

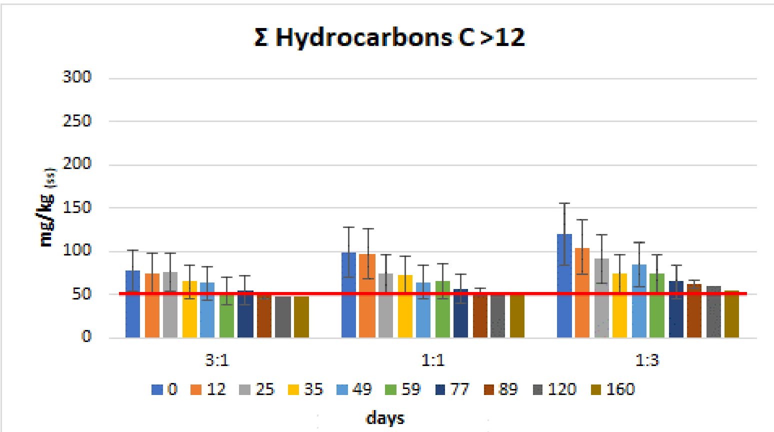

Figure 18 – *degradation of C>12 hydrocarbons in Italian compost.*

Conclusions

The two experiments carried out in the Czech Republic and in Italy confirmed, as per the objective of the Life AgriSed project, that composting dredged sediments and green waste could be a valid methodology for the creation of compost or alternative substrates, albeit with some reserves. In fact, although the composting process has obtained positive results, for example in the degradation of pollutants present in the dredged sediments, certain values, both in one product and in the other, have shown how these processes must be carefully studied and calibrated. in order to be able to fully comply with the limit values imposed by the laws of the various countries and to be able to produce compost of a quality that can be used beyond simple experimentation. However, combining the information obtained from this experimentation with an accurate knowledge of composting processes, it is easy to see how a process carried out in a rational and careful way can bring various benefits, including the reuse of materials otherwise destined to become waste to be disposed of.

Ultimately, a composting process that involves the use of green waste and sediments from river dredging is theoretically possible, but requires careful control of various factors:

- The physico-chemical characteristics of the incoming materials, especially as regards the humidity rate, salinity, and grain size of the dredged material; if these values are too far from the optimal ones, it may be advisable to think about a pre-treatment of this material, such as a series of washes to lower the electrical conductivity, or a drying period to decrease the humidity rate. As regards the green waste, on the other hand, it is advisable to ensure that the material to be used has a homogeneous size and, if it is made up of several different matrices, that characteristics such as pH, carbon content and structure of the material are suitable for the composting process.

- The trend of the moisture and oxygenation values of the matrices throughout the composting process, especially if carried out in heaps that are not actively ventilated. These, in fact, are among the most important parameters for monitoring the process, as they provide information on the proliferation and correct development of the aerobic microorganisms necessary for composting. The control of the oxygenation and humidity values inside the material is necessary to maintain an environment suitable for the development of aerobic microorganisms responsible for the degradation of the organic substance, avoiding on one hand the establishment of conditions of anoxia and water stagnation, and in another an excessive dehydration of the material, with a consequent decrease in the efficiency of the degradation.
- The temperature trend, as an index of the various phases into which a composting process is divided (mesophilic, thermophilic, ripening phase) and also,

together with the monitoring of oxygenation, as an indicator of the possible need to overturn the material, to aerate it and activate the degradation process again if this is limited by oxygen depletion when the material is still in the mesophilic or thermophilic phase.

- The correct homogenization of the material, to obtain a uniform matrix as much as possible, where the physico-chemical characteristics are similar in every point and avoid yield differences at the end of the process between one part of the pile and another. This is especially necessary in conjunction with the use of dredged sediments that are still rather humid, which tend to form compact agglomerates in which green waste is hardly incorporated, giving rise to masses with very different characteristics from the rest of the surrounding environment, especially as regards oxygenation, temperature and degradation rates of organic matter.

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