PRODUCTION OF COMPOST FOR MUSHROOM CULTIVATION: A LIFE CYCLE ASSESSMENT STUDY.

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ABSTRACT.

The composting process is an important part in the reuse of waste materials, especially those that are not recycled. Besides helping to reuse these products, the composting process significantly reduces air emissions and pollutants, compared to other processes. There are a wide variety of composting techniques. Windrow composting is the most used worldwide.

In this study the tunnel composting process with forced aeration for growing Agaricus Bisporus is studied. The composting process mainly consists of two phases, a tunnel composting phase and a pasteurisation phase in closed chambers. During the first phase a pile of compost with three turns, forced aeration, controlled temperature, humidity and CO_2 emission, is analyzed. In the second phase, the temperature, forced aeration, controlled temperature, humidity, CO_2 emission and the content of ammonia in the compost pile are controlled. The parameters for the entire process are constantly monitored and modified according to the needs of the process.

The results of this study indicate that the time required inside the composting tunnels and the weather conditions are directly related. A pile of compost needs more time inside tunnels in cold and wet seasons, as temperature and humidity are important parameters to control during the composting process.

Keywords: Compost, emissions, temperature, composting time, life cycle assessment.

1. INTRODUCTION

Mushroom cultivation in La Rioja has its origin in the early decades of the twentieth century. La Rioja region is well known by the red wine (Jimenez et al 2012) but it is actually the national leader in terms of production of mushrooms, presenting a strong production and marketing structure.

La Rioja has an output of 70,000 tons per year, with an income of 64.7 million Euros each year, a tenth of the total agricultural production. The biggest concentration of cultivation is in the municipalities of Pradejon, Ausejo and Calahorra. The growth capacity has increased with the Technology Mushroom Research Center created by the Government of La Rioja in the heart of the production area and built as a great reference point and support for the local sector.

Composting is based on the action of various aerobic microorganisms (Haug, 1993), which transform the original organic matter. This process produces elevated temperatures, reduces residues' volume and weight and causes humidification and darkening. During this process various factors which provide proper microbial growth and therefore adequate mineralization of organic matter (Cronje et al., 2003), must be controlled. Since these reactions are governed by microorganisms' biological cycles involved in the process, composting requires a long process to transform the organic matter (Nakasaki et al., 2005). Therefore, a composting process that seeks to obtain a useful final product, cannot be done spontaneously, since all required variables and parameters must be controlled to ensure the total completion of the process in as a short time period as possible and a minimum costs (Hedegaard and Krüger, 1996).

The type of waste that is suitable for the composting process is large. According to Haug (1993) these include urban and industrial waste, manure, logging and agriculture residues and organic waste (Garcia et al 2014).

The life cycle assessment (LCA) provides a framework and methods to analyze and assess the environmental aspects and the potential impact of a material, a product or a service during the entire period of its life cycle (Lorenz, 2014; Roy et al., 2009; Elduque et al, 2014). The scope of the evaluation covers the extraction and processing of raw materials, manufacturing and assembly processes, energy consumption (Martinez et al 2009a, 2009b, 2010; Azofra et al 2014) product distribution, use, reuse, maintenance, recycling and final disposal (Nash and Stoughton, 1994). It is an approach which reviews the environmental effect of the above processes in a holistic way (Barton, 1996). The LCA is now considered as a powerful tool for sustainability (Tsalidis et al., 2014).

This study proposes the integration of LCA in the production system as a tool for decision-making to identify any existing or potential impact during the composting process. Likewise, the life cycle inventory (LCI) is conducted to analyze the input and output of the process as well as any emission to study the environmental impact during composting.

2. MATERIALS AND METHODS.

2.1. Life cycle assessment.

An international standard for LCA developed by the International Organization for Standardization (ISO), has recently emerged and is under evaluation and review (Burgess and Brennan, 2001). The methodology framework used by the ISO is similar to the SETAC methodology. There are, however, some differences as it concerns the interpretation phase. The ISO include posterior as well as sensitivity analysis.

The LCA is used to determine the total impact of each product based on the resource consumption during the process This philosophy of life cycle approach, is also known as “cradle to grave”, (Jiménez et al., 2014).

The LCA methodology has been developed to consider a wide range of resources as well as their potential environmental impact (Tsalidis et al., 2014):

- Climate change.
- Acidification.
- Eutrophication.
- Ecosystems toxicity.
- Ozone depletion.
- Smoke formation.
- Habitat destruction and alteration.
- Loss of biodiversity.
- Resources depletion.
- Water consumption.
- Land use.

LCA methodology is the most widely used tool to consider the systematic environmental impact along the life cycle of a product, process or activity (Sarasa el al, 2009). It is also a methodology according to the ISO 14040 (Jiménez et al., 2014).

2.2. Modeling and analysis of the production process.

Modeling and analysis of a production process involves data collection and calculation procedures to quantify the input and output of a system. It is an iterative process that must be repeated or modified, if necessary, to obtain useful information during its execution.

The system under study must be modeled as a complete sequence of unit operations that communicates with each other via input and output. It is necessary to build a real model able to represent, as accurately as possible, all the changes between the operations of the studied system. Data collection will create an inventory for each individual process, quantifying the input and output associated with the flow of the final unit output.

For this modeling phase the following steps are defined:

- Construction of the flow diagram in accordance with the limits of the systems in the definition of the objectives and scope of the study.
- Data collection of all activities in the production system through field measurements or literature.
- Calculation of the environmental loads associated with the functional unit of the final product.
- Standardization of data to consistently work with the same units in reference to the functional unit.
- Mass balance to interrelate the input and output between the different tasks of the overall process.
- Create flowcharts for each task, quantifying and indicating the input and output for each task and sub process.
- Global inventory, both input and output, process and machinery used.

3. RESULTS AND DISCUSSION. CASE STUDY: A COMPOSTING FACILITY IN LA RIOJA.

In this article a case study is conducted in a composting facility in La Rioja region. The tunnel composting process investigated in this study, is based on a windrow composting system in a closed container. The process takes place in a rectangular concrete tunnel 30 meters long by 6 wide and by 5 high, with a single door in the front for input loading and unloading. On the ground, the tunnel has an aeration system, with a large quantity of blowing holes through which the air is injected into the compost pile.

Each tunnel is treated as a separate unit with its own control and air system.

Leachates produced during the composting process are also used and recirculated in places where they are needed to moisten the compost mixture, as it is done in the straw pre-wet process.

3.1. Modeling and analysis of the composting process.

3.1.1. Input mixing.

The composting process begins with the input and its storage in the company. Entries occur gradually throughout a campaign, from July to May to meet the requests of the farmers.

3.1.2. Straw pre-wet process.

The next phase begins with a pre-wet process. The wheat straw is moistened for 3-9 hours to reach the required moisture for a proper composting process. This step is important because the straw has a low humidity and the composting process requires high humidity to rot the raw material correctly (Haug, 1993). At the same time, the mixing of poultry litter, gypsum, ammonium sulphate, urea and calcium carbonate takes place. It is important to correctly adjust the properties of the substrate in this phase to make the mixture more homogenous and, thus, achieve the desired conditions of the substrate (Körner et al., 2003).

3.1.3. Filling the tunnels and building the compost pile.

Once the mixing phase is finished, the mixture is placed inside the tunnels. During the filling process water and leachates are introduced into the mixture to raise the moisture content and to allow the microorganisms to transform the organic matter (Jess et al., 2007).

3.1.4. Composting process inside the tunnels.

Once the filling phase is over, the composting process begins. Tunnel composting has 3 subphases (phase 1.1, 1.2 and 1.3), each lasting from 2 to 3 days, while the compost remains inside the tunnel. Once each subphase is completed the pile is turned to make the compost temperature homogeneous (Jess et al., 2007).

During composting, aeration times must be set, depending on the characteristics of the compost, since this will influence CO_2 concentration inside the tunnel. CO_2 concentrations will increase when the turbines are switched on. There are many odors that are emitted during composting. Therefore, the temperature of the compost should be kept elevated during this stage to avoid undesirable odors (Noble and Gaze, 1998) and to eliminate pathogens (Jess et al., 2007).

During composting, besides controlling the critical parameters such as temperature and humidity, other parameters such as pH, nitrogen, ash and C/N ratio as indicators of compost quality and productivity must be controlled (Noble and Gaze, 1996; Lyons et al., 2006).

3.1.5. Pasteurization phase.

Once composting is terminated, the compost pile is introduced into the pasteurization chamber using a filling machine. In agreement with the report of Noble and Gaze (1996) during pasteurization ammonia was found to be significantly removed from the compost pile. Ventilation during this process was continuous, in order for CO_2 concentrations to be homogenous.

3.1.6. Packaging and transportation of the final product.

After pasteurization, the pasteurized compost is taken to the packaging area. The final product is introduced in a packing machine with mycelium seeds to create the final product. All packets of compost are then palletized and transported to the growing areas.

3.1.7. Leachate collection.

During composting several wastes are generated in a liquid form, commonly known as leachates (Inbar et al., 1990; Krogmann and Woyczechowski, 2000). The leachate is a hazardous liquid because of its high concentration of pollutants. In some cases leachates contain heavy metals that must be first treated so they can be reused (Tabatabaei et al., 2012).

3.2. Results.

3.2.1. Composition of a standard compost pile.

The composition of a standard compost pile is shown in Table 1:

Table 1
Composition of a standard compost pile.

Material	Units	Quantity (kg)
Wheat straw	80 bales	32,180
Poultry litter	-	24,050
Urea	6 bags	240
Gypsum	-	375
Ammonium sulphate	100 bags	2,500
Calcium carbonate	-	600
Seeds	36 packets	632.16

3.2.2. Temperature.

Temperature is one of the critical parameters to control during composting. Temperature control is very important to destroy pathogens, to optimize breathing rates, to remove moisture and to stabilize the compost. In order to achieve this, a proper aeration control is essential (Ekinci et al., 2004).

Tunnel composting enables a high control during the process, particularly of the temperature. This is due to the fact that aeration can be easily controlled. During the process in the tunnel, temperature stabilizes at 80 °C, and this occur in the middle of each subphase shown in Fig. 1. The oscillations depend largely on the incidence of air in the pile of compost, the outdoor humidity and the characteristics of the material that compose the compost pile.

Table 2: Average compost temperature.

Composting phase		Pasteurization phase
Phase 1.1	71.21 ºC	48.69 ºC
Phase 1.2	73.5 ºC	
Phase 1.3	74.33 ºC	

3.2.3. CO_2 emissions.

CO_2 emissions are also measured throughout the process. During the first subphase, phase 1.1, the tunnel is closed so that the concentration, in ppm, of CO_2 is significantly higher than in other subphases, phase 1.2 and 1.3. Two different tendencies for each phase of the composting process can be distinguished in Fig.2. During the composting process the compost pile was aerated for a period of time previously established to maintain the temperature steady and to avoid the compost pile cool down. During periods of aeration the concentration of CO_2 is higher because it is released faster from the interior of the pile and, therefore, the concentration increases rapidly. During pasteurization emissions are more stable because the turbine is running continuously at a determined frequency.

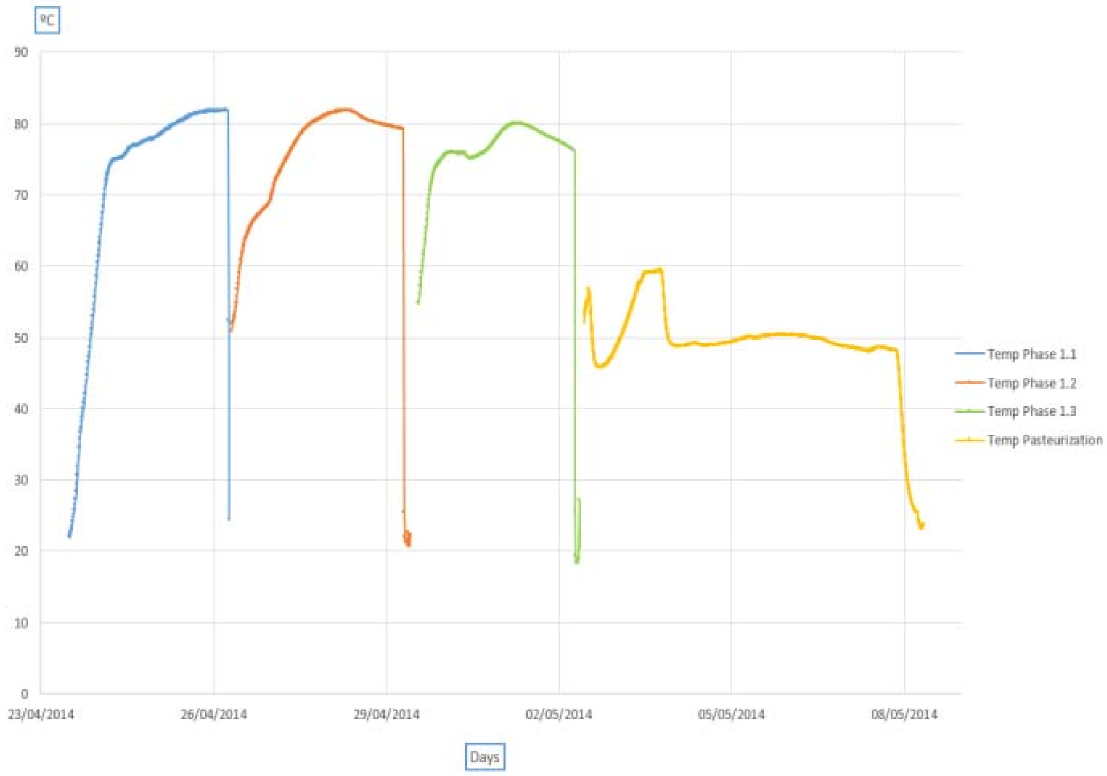

Fig 1. Compost temperature

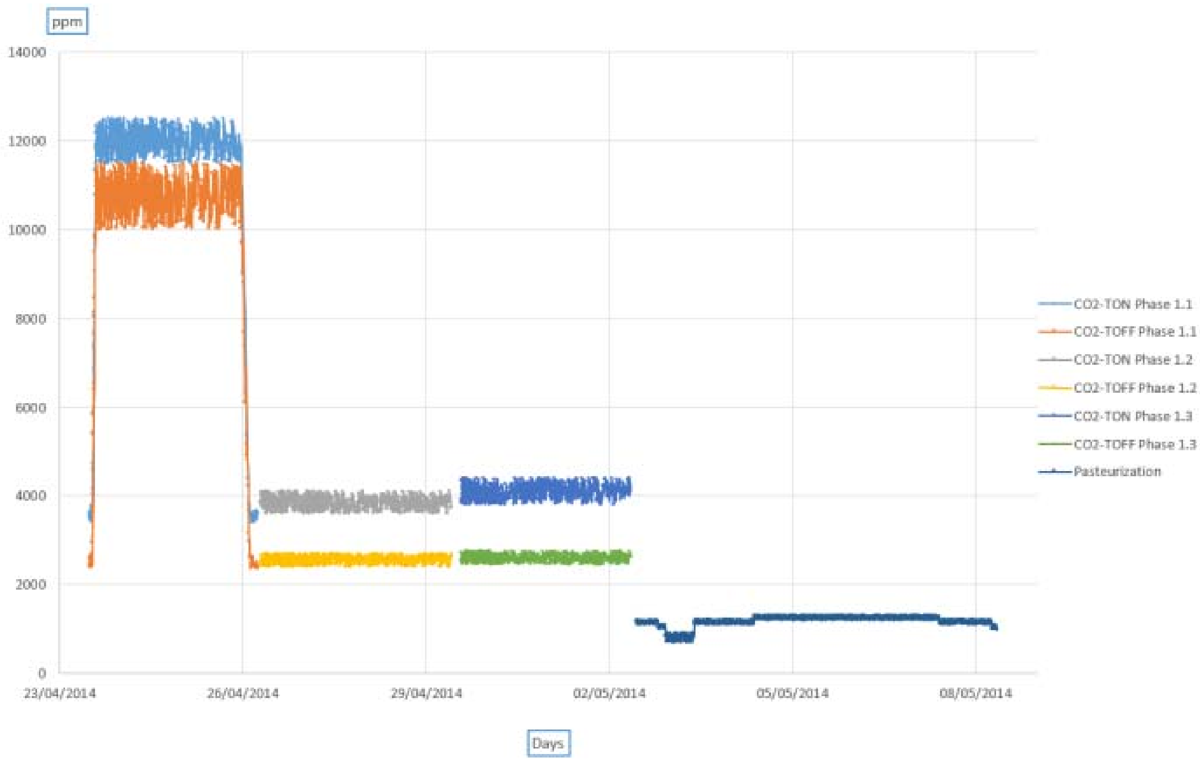

Fig. 2. CO_2 emissions.

Table 2.
Average CO_2 emissions.

Composting phase		Pasteurization phase
Phase 1.1	10562 ppm	1169 ppm
Phase 1.2	3199 ppm	
Phase 1.3	3348 ppm	

3.2.4. Time required inside the composting tunnels.

The time required inside tunnels of compost piles for a full year is analyzed. The average time required in tunnels is approximately 9 days through the year, substantial differences across seasons are noted as illustrated in Table 3.

Table 3.
Time required inside the composting tunnels according to season.

Season	Time (days)
Spring	8,92
Summer	8,59
Autumn	9,22
Winter	9,92

4. CONCLUSIONS

Tunnel composting offers great advantages over other systems. Among them:

- High odor control.
- High temperature control.
- High pathogens rate elimination.
- Reliable process.
- High reliability and consistency of the final product.
- Dramatically reduces the processing time (to 15-20 days).

The time required inside the composting tunnel, depends, among other parameters, on the external climatic conditions. The amount of time is higher in wet and low temperature seasons than in high temperature and dry seasons. Therefore, in winter days the required time inside the tunnel is higher, and conversely in summer the amount of time is lower.

To develop the composting process optimally, with the greatest pathogens rate elimination and optimal quality of the compost, temperature, humidity, C/N ratio and pH, among other parameters, must be monitored.

In this study, the temperature control through the aeration process is studied. This is relatively easy to accomplish in the first two composting subphases. However, in the third subphase the temperature is more difficult to control because of the reduction of organic matter.

The concentration of CO_2 is higher during periods of aeration in the tunnel composting phase than during the pasteurization phase because of the reduction of organic matter.

In future works, apart from studying the process, the facilities and machines will be analized in the life cycle assessment, taking into account the materials used (Aisa et al, 2006; Javierre et al 2006, 2013, 2014; Fernandez et al 2013), the way of fabrication, etc.

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