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EARTHWORMS FOR FEED PRODUCTION FROM VEGETABLE WASTE: ENVIRONMENTAL IMPACT ASSESSMENT

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Abstract

In the European Union, 88 million tons of food is wasted annually, 30% of which comes from the production and processing sectors. Among the different food waste, vegetable ones represent a remarkable share and their management is complicated by the usually high-water content and the difficult storage.In this context, the earthworms are an interesting solution because transform vegetable waste into valuable products: the vermicompost, that can be sold as organic fertilizer, and the earthworms that, thanks to their high protein content can be used for feed and food production.This study aims to evaluate the environmental impact related to the production of vermicompost and dry earthworm meal. LCA approach was applied, 1 kg of dry meal for feed production was selected as functional unit. Inventory data were collected during experimental tests carried out in 2017 in a composting plant located in Northern Italy where earthworms were fed with vegetable waste. Secondary data were used about emissions during earthworms. 1 kg of fresh earthworms (16% of dry matter with 67% of protein content) and 13 kg of vermicompost were produced from 45 kg of vegetable wastes. Between earthworm rearing and processing, the first one is the main responsible for the environmental impact for all the evaluated impact categories except than for freshwater eutrophication and ecotoxicity. GHG emissions during composting are the main hotspots for Climate Change.

Key words: feed, protein source, vermicompost, waste valorisation

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1. Introduction

Food loss and waste have a negative environmental impact due to the natural resources used for food production as well as for their management and disposal. In the European Union, 88 million tons of food is wasted annually, 30% of which comes from the production and processing sectors. In particular, the fruit and vegetable retail sector generates large amounts of waste. In industrialized countries, fruit and vegetable waste (FVW) are mainly generated before reaching consumers, during all phases of the supply and handling chain, such as market oversupply or nonfulfillment of aesthetic and quality standards (Plazzotta et al., 2017). Even without official quality standards, food retailers generally do not offer food with abnormal appearance, based on the assumption that consumers do not purchase or consume foods that deviate from regular products, which can mean yielding lower profits (Loebnitz et al., 2015). For this reason, related to not reflecting aesthetic standards (shape, color or size), many products are discarded, even if they were produced for human consumption, they are still healthy, safe, and edible and could still reach the consumers (Stuart, 2009). FVW poses environmental problems due to the squandering of environmental, human and economic resources used to produce it and represents also a loss of valuable biomass (Plazzotta et al., 2017).

In order to reduce the impacts associated with food waste and to avoid the squandering of valuable resources, the search for sustainable solutions to the valorisation of food waste is highly necessary and encouraged. A possible strategy is the utilization of

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FVW as feeding substrate for the rearing of terrestrial invertebrates to be used as potential protein source for feed and/or food supply chains. Among terrestrial invertebrates, earthworms could be an interesting solution. Earthworms grown on FVW can contribute to the waste disposal efficiency and bio-transform FVW into valuable products: the vermicompost, that can be sold as organic fertilizer, and the earthworms themselves that, thanks to their high protein content, can be a new food/feed source. Earthworms are rich in proteins, particularly in essential amino acids and they can contribute to human and animal nutrition (Yadav and Garg, 2011; Zhejun and Jiang, 2017). Currently, earthworms are just employed to convert food waste (FW) in a bioconversion process to mitigate the FW problem as a sustainable, cost-effective and ecological approach in dealing with FW management (Huang et al., 2016). Up to now, the attention on alternative protein sources has regarded mainly the insects both as human food (Halloran et al., 2016; Oonincx and De Boer, 2012; San Martin et al., 2016) and as animal feed (Smetana et al., 2016; Salomone et al., 2017). No studies addressed the environmental performances of dried meal production from earthworms.

In this context, this study aims to evaluate the environmental impact of the earthworms' dried meal production for feed purposes using fruit and vegetable waste (FVW) as feedstock. Primary data collected during field trials were combined with secondary data coming from literature; the environmental impact was quantified, and the environmental hotspots identified.

2. Methodology

Life Cycle Assessment (LCA) is a holistic approach, structured and recognized worldwide that consists of a systematic set of procedures to convert inputs and outputs of the studied system into its related environmental impact (ISO 14040, 2006; ISO 14044, 2006).

In details, there are 4 steps in LCA:

(i) goal of the study definition that foresees the selection of the functional unit, the definition of the system boundary and the solving of multifunctionality;

(ii) Life Cycle Inventory (LCI) data collection, in which the flow of materials and energy from the studied systems and the environment are identified and quantified;

(iii) Life Cycle Impact Assessment; during which, thanks to specific characterization factors, the inventory data are converted in few numeric indicators of environmental impact;

(iv) interpretation of the results and identification of the process hotspots.

Over the last years, although originally developed for industrial processes, LCA has been more and more applied also to agricultural systems (Moudry et al., 2018; Schmidt Rivera et al., 2017) and waste to energy processes (Bacenetti and Fiala, 2015; Lijó et al., 2015; Vida and Tedesco, 2015) and waste treatment solutions (Bacenetti et al., 2016; Bjelic et al., 2017; Lijó et al 2017; Salomone et al., 2017; Smetana et al., 2016).

2.1. Goal and scope definition

The goal of the present study is to evaluate the environmental impacts of the earthworms' (*Eisenia foetida*) production system reared on a low-quality substrate made of fruit and vegetable waste (FVW).

Concerning the functional unit, in this study, to avoid allocation between vermicompost and earthworms dried meal, a mixed functional unit was selected. According to ISO standards for LCA (ISO, 2006), the functional unit is defined as the quantified performance of a product system, and is used as a reference unit in an LCA. In this study, the FU is the production of 1 kg of dried earthworm meal and 80 kg of vermicompost.

Concerning the system boundary, a "from cradle to gate" approach was applied. Fig. 1 reports the system boundary for the evaluated process; two different subsystems were identified:

- Subsystem 1 (SS1), a mix of young-non-clitellum and adult-clitellate earthworms was reared on a feeding substrate consisting of FVW and straw. FVW, constituted mainly by tropical fruits, was ground and then used as feed for earthworms three times a month. Besides earthworms, during the decomposition of FVW also an odour-free and hummus-like substance is produced: the vermicompost. Vermicompost is the co-product of the production system, it can be used as organic fertilizers. After 3 months of earthworms rearing, the vermicompost and the earthworms were collected through mechanical separation;

- Subsystem 2 (SS2), the collected earthworms were processed to produce meal. First, they were repeatedly washed, then kill by cooling and, finally, dried. During the experimental trials, the dry meal was produced in a laboratory by drying earthworms in an oven at 50°C and then proceeding with grinding.

The following activities were included: raw materials extraction (e.g., fossil fuels, metals and minerals), manufacture of the different inputs (e.g., diesel, electricity, water and trucks for FVW transport), use of the inputs (diesel fuel emissions), maintenance and final disposal of capital goods (e.g., the trucks used for the FVW transport). The emissions of methane, dinitrogen monoxide and ammonia related to the vermicomposting of FVW were included too.

The packaging, the distribution as well as use and end-of-life of the produced meal were excluded from the system boundary.

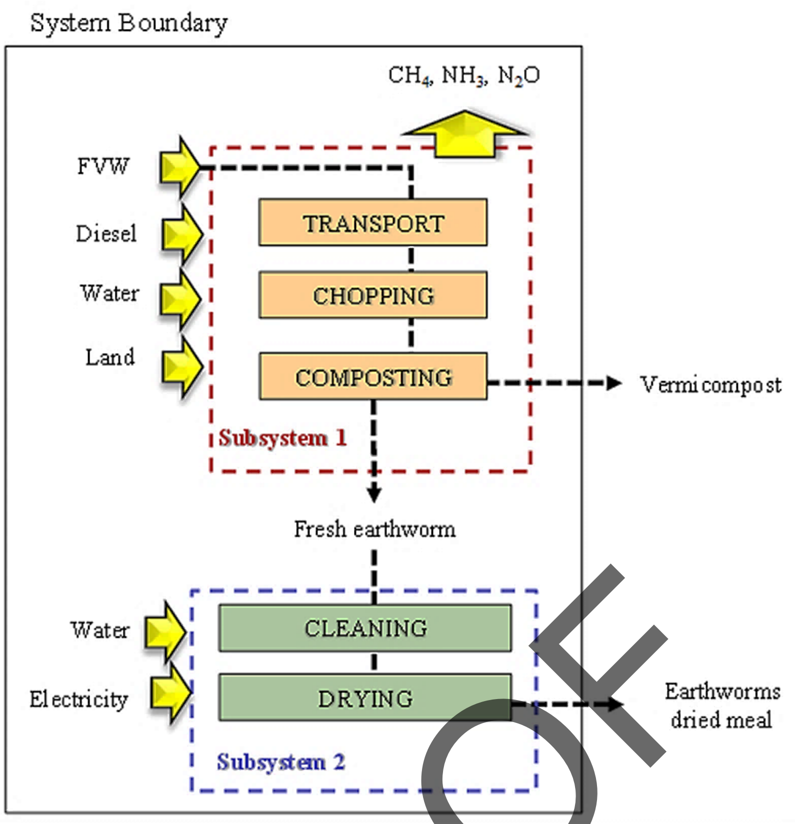

Fig. 1. System boundary

2.2. Description of the process

Earthworms were provided by a small-scale production system, located in the province of Lecco (North Italy). Earthworms were reared on an area of about 30 m^2 made up of FVW (growth substrate), placed above a non-woven textile sheet and covered with a net. During the rearing phase, moisture, temperature, and pH of the growth substrate were kept under control in order to guarantee optimal living conditions.

After 3 months, samples of *Eisenia foetida* at the adult stage of development were collected. The first cleaning procedure consisted of a mechanical separation from the growth substrate with the use of a trommel.

As the material rolls, anything smaller than the holes in the screen falls through, and the rest continues until it comes out the output end. Subsequently, they were washed with running tap water and soaked for some hours, to remove the residual particles of waste and to clear their gut. Finally, to produce the meal, after being frozen at -28°C, they were dried at 65°C and ground.

2.3. Life Cycle Inventory

Inventory data concerning inputs and outputs relevant to the production of earthworms' biomass were collected over a three-month experimental test performed in year 2017. Primary data were collected with questionnaires during interviews with the farmer and during surveys to the experimental site. More in detail the following data were directly collected: amount of FVW used as feed, fossil energy for preparing the feed substrate, water volumes and land occupation for earthworms breeding. The main secondary data refers to the emissions during vermicomposting. These emissions were retrieved from literature (Yang et al., 2017). Table 1 reports the main inventory data for the analyzed production process.

Background data was retrieved from the Ecoinvent Database v.3.5 (Moreno Ruiz et al., 2018; Weidema et al., 2013).

Table 1. Inventory data

Subsystem	*Inputs/Outputs*	*Amount*
1	Fruit and vegetable waste	285.8 kg
1	Transport of FVW	25 km
1	Diesel	1.2 kg
1	Water	22.9 kg
1	Land	2.6 m^2
1	Ammonia	99.03 g
1	Dinitrogen oxide	9.56 g
1	Methane	31.60 g
2	Electricity	2.0 kWh
2	Water	22.4 kg
2	Vermicompost	80.0 kg
2	Dried meal	1.00 kg

2.4. Life Cycle Impact Assessment

The systems considered here have been modeled using SimaPro LCA software 8.05 and the impacts estimated according to the ReCiPe method (Goedkoop et al., 2009). The following 10 impacts are considered: *Climate change* (CC), *Ozone depletion* (OD), *Terrestrial acidification* (TA), *Freshwater eutrophication* (FE), *Marine eutrophication* (ME), *Human toxicity* (HT), *Photochemical oxidant formation* (POF), *Particulate matter formation* (PM), *Metal depletion* (MD) and *Fossil depletion* (FD).

3. Results and discussions

Table 2 reports the environmental results for the different evaluated impact categories while Fig. 2 shows the environmental hotspots (i.e. the inputs or emissions mainly responsible for the total impact).

The main environmental hotspots are:

- Diesel production: the consumption of diesel fuel for grinding a share of the FVW (e.g., pineapple leaves) is the main contributor for OD (72%) and FD (69%) while for the other evaluated impact categories it is responsible of a share of the total impact ranging from 10% in CC to 31% in POF;
- Transport of the FVW to the composting plant is the main responsible for HT and POF (51% and 52%, respectively, mainly due to the emissions of pollutants related to the diesel combustion) and MD (54%, mainly due to the manufacturing of the truck). Similarly, to the diesel production, the transport plays a non-negligible role for all the other evaluated impact categories (from 2% for TA to 21% in TE);
- Electricity consumption during earthworm processing in SS2 is the main contributor of TE (57%) and it is responsible for about one-third of HT. For the other evaluate impact categories the role of electricity ranges from 1.8% in ME and 18% in MD. For CC, the consumption of electricity; is responsible for 13% of the total impact;
- Ammonia emission during vermicomposting is the main contributor to TA (94%), ME (94%) and PM (85%, due to the formation of secondary particulate);
- Dinitrogen oxide emission deeply affects CC with 45% of the total impact.

With regard to the other inputs or emissions:

- The consumption of water in SS1 (for rearing humidity maintenance) as well as during SS2 (for cleaning) is responsible for a small impact (<2% for all the evaluated impact categories);
- The emissions of methane only slightly contribute to CC (about 12%) and POF (2.6%, due to the emission of CH_4).

Table 2. Environmental impact for the selected FU

Impact category	*Acronym*	*Unit*	*Score*
Climate change	CC	kg CO_2 eq	6.327
Ozone depletion	OD	mg CFC-11 eq	1.142
Terrestrial acidification	TA	kg SO_2 eq	0.257
Freshwater eutrophication	TE	g P eq	0.429
Marine eutrophication	ME	g N eq	9.637
Human toxicity	HT	kg 1,4-DB eq	0.618
Photochemical oxidant formation	POF	g NMVOC	12.332
Particulate matter formation	PM	g PM10 eq	36.997
Metal depletion	MD	g Fe eq	72.318
Fossil depletion	FD	kg oil eq	2.212

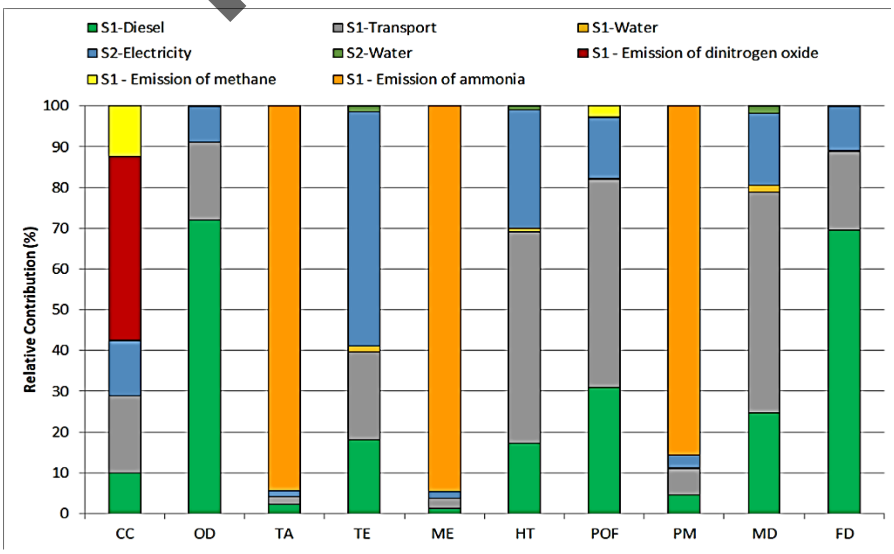

Fig. 2. Identification of the environmental hotspots (S1 = subsystem 1, S2 = subsystem 2)

Between the two subsystems, SS1, with a share of the total impact ranging from 70% in HT to 98% in TA and ME, is the main contributor for all the evaluated impact categories except than for TE. For this last impact category, 59% of the impact is related to SS2.

The environmental impact of the earthworms' dried meal production for feed purposes using fruit and vegetable waste (FVW) as growth substrate showed a higher CC value associated with its production; this was caused by the considerable energy input for FVW transport and drying process. This could be reduced if the vermicomposting process takes place at the FVW production site. Moreover, Europe's reliance on imported protein, particularly soybeans, to feed livestock is inconsistent with sustainability objectives because soybean is associated with deforestation and impacts from pesticide use and transportation (Tallentire et al., 2018). The environmental burden for soybean meal is 3.05 kg CO_2 eq kg^{-1} (Tallentire et al., 2017). This means that improvements of the earthworms' dried meal production for feed purpose using FVW could be a promising research field how even the necessity of alternative protein sources in terms of minor warming potential and reduction of food waste (Conti et al., 2018).

4. Conclusions

By means of the Life Cycle Assessment (LCA) method, the environmental impact of the production of earthworm-dried meal was quantified. The feed substrate for earthworms is made of fruit and vegetable waste (FVW) that, therefore, is highly valorised respect to wasting. Given the increasing importance worldwide of issues related to food waste, the transformation into feed and/or food meal is very promising. Besides the not negligible environmental impact, this production system brought benefits such as the recovery of FVW as feeding substrate, the earthworm production as a food/feed source with high nutritional profile, and the availability of vermicompost as an organic fertilizer that allows reducing the use of mineral fertilizers in other production systems.

Similarly, to other protein sources, earthworm dried meal currently has high environmental impacts mostly due to the transport of FVW for fresh earthworm production and energy use during processing. To make earthworm meal sustainable and competitive on the market, enhancing earthworm productivity and reducing energy costs of the processing stages by shifting towards renewable energy sources is essential.

Additional research and integration with innovations among different sectors are the key drivers for the near future. However, the outcomes of this study can be useful for the development of a subsidy framework supporting the earthworm dried meal production chain thanks to the identification of the hotspot stages and their possible mitigations.

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