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Environmental and agronomical assessment of three fertilization treatments applied in horticultural open field crops

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ABSTRACT

In 2010, the generation of municipal solid waste (MSW) by the European Unión (EU-27) was 252 million tons, with an estimated organic content of 30–40% by weight. Composting this organic matter would significantly improve waste reduction and mineral fertilizer substitution. We present a Life Cycle Analysis (LCA) and agronomical assessment of the following three fertilization treatments: industrial compost (IC), home compost (HC) and mineral fertilizer (MF), applied to horticultural cauliflower crops. For the IC and HC treatments, we evaluated the entire cycle of the organic matter, starting from the moment it becomes MSW and including collection, production of compost, transportation and application in open field cauliflower crops. For the MF treatment, the analysis includes the raw material extraction, production, transportation and the application of the compost material to crops via irrigation.

A higher crop yield was achieved with MF treatment, which was 26% and 91% higher than HC and IC treatment, respectively. However, the application of HC treatment resulted in larger, heavier cauliflowers. No significant differences were found in the nutritional analysis, which included the quantification of the total phenols, glucosilonates and flavonoids. The HC treatment had the best environmental performance with the lowest impact in all categories assessed except for its abiotic depletion potential and eutrophication potential (which was the lowest for IC). The IC treatment had the highest environmental impact in five of the seven categories assessed, whereas the MF treatment had the highest eutrophication and global warming potentials.

1. Introduction

The use of manufactured fertilizers has been increasingly incorporated into regular farming practice in the EU since its introduction in the mid to late nineteenth century. In 2010, the mineral fertilizer consumption in the EU was 18 million tons (Eurostat, 2012).

Fertilizers are essential to sustaining agricultural production, increasing the yield and improving soil characteristics. However, when the quantity of the nutrients applied exceeds the plant's nutritional requirements, there is a higher risk of nutrient losses from agricultural soils into the ground and surface water. The resulting higher concentration of nutrients can severely deplete the ecosystems (such eutrophication). Some forms of nitrogen (N) can also volatilize into the air as ammonia, contributing to acidification, atmospheric pollution with micro particles, or emissions of nitric oxide (NO_x) and nitrous oxide (N_2O), a potential greenhouse gas that contributes to climate change. In addition, fertilizers may also have adverse environmental effects that result from their production process.

Fertilizers application is also responsible for ground water pollution and eutrophication.

Fertirrigation, a technique used to apply fertilizers that are dissolved in water to crops (CREA, 2005), is commonly practiced in the Mediterranean region and involves excessive nutrient usage, contributing to ground water pollution and eutrophication (Muñoz et al., 2008).

Compost results from the biological degradation and stabilization of organic substrates under controlled thermophilic and aerobic conditions. In addition to its fertilizing effects, compost improves the physical properties of soil and increases the water retention capacity and supply of organic nutrients (McConnell et al., 1993; Jakobsen, 1995; Hargreaves et al., 2008). Compost application

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is an effective fertilizer substitute and/or complement (Martínez-Blanco et al., 2009). Compost has the advantage of a slower rate of nitrogen release in the soil (Hargreaves et al., 2008). Compost can also be used for partial or total integration of substrates for ornamental plants (Russo et al., 2011).

Furthermore, when home compost production is near the application sites, the need to transport the product is reduced, further reducing environmental impact (Fragkou et al., 2010). The production of compost near the application site is also known as proximity composting. The management practices for composting take into account the processing of organic scrap in local or on-site composting, as well as collective composting, community composting and neighborhood composting.

The potential of quality compost production in EU is estimated at 35–40 million tons year^{-1} (European Commission, 2009), equivalent to 131,000 tons of available of organic nitrogen (3.5%) (MP, 2005). Additionally, the European Union Landfill Directive 1999/31/CE (Council of the European Union, 1999) requires member states to reduce the amount of biodegradable waste being dumped. The goal is to minimize the environmental impacts and loss of the organic resources by adopting measures that increase and improve waste reduction, recovery and recycling.

There is concern about the massive generation of organic waste by human activities and as well as interrelated soil environmental problems, such as soil degradation, desertification, erosion and loss of fertility (European Commission, 2009). These concerns have led to the proposal of several alternatives to avoid landfilling and promote recycling. Following the EU landfill directive to reduce landfill waste and associated problems, the aim of this study is to research alternative methods for treating organic waste from municipal solid waste. The production of compost from organic waste is a great opportunity for the sustainable use of waste from municipal solid waste. Additionally, our research focuses not only on the production of compost by two well-known techniques (industrial and home compost) but also on the application of the compost to open-field crops, and we evaluated agronomical parameters such as the yield and bioactive substance content in fruits. The use of organic waste has many societal benefits. As discussed by Martínez-blanco and Lazcano (2013), the following nine benefits to using compost have been identified: nutrient supply; carbon sequestration source; weed, pest and disease suppression; increased crop yield; compost prevents soil erosion and thereby avoids losses of arable land; compost increases the capacity of the soil to retain waste; compost improves the soil workability, decreasing the energy requirements for agricultural operations; compost can lead to changes in the soil biological properties and biodiversity; and compost improves the nutritional quality of crops.

Barcelona offers conditions for the production and application of compost. Currently, Barcelona, with three composting facilities, is considered an intensive compost production region in the EU. The metropolitan area alone has an estimated compost production of 150,000 tons per year. Additionally, Barcelona has four plants for mechanical-biological treatment (MTB), with a total processing waste capacity of 120,200 tons of waste per year. These MBT facilities include aerobic and anaerobic digestion for the organic fraction resulting from the sorting process. Likewise, there are an estimated more than 20,700 home composters in the Catalonia country (Agència de Residus de Catalunya, 2012).

The compost was applied in the experimental fields of IRTA, near Barcelona in the county of Maresme, by the Mediterranean in the northeast of Spain. The Maresme is a suitable area for applying compost because it is substantially involved in the production of horticultural products for the Barcelona city.

The aim of this study is to quantitatively assess the environmental and agricultural performance of the following three fertilization treatments as applied to open field cauliflower crops: industrial compost (IC), home compost (HC) and mineral fertilizers (MF). The cauliflowers were grown in a sandy loam. The soil was Typic Xerothent and exposed to the Mediterranean climate with annual evapotranspiration (ET0) and rainfall of 955 and 618 mm, respectively. We used Life Cycle Assessment (LCA) to quantify the burdens such as mineral extraction, soil enrichment and transportation as well as the benefits of reducing organic waste in landfills. Furthermore, we differentiate between home compost that is produced individually at home using leftover fruits and vegetables (LRFV) and compost produced in a plant that is fed by the organic fraction of municipal solid waste (OFMSW).

2. Materials and methods

This research was developed according to Life Cycle Assessment (LCA) methodology from ISO 14044. LCA is a methodology for determining the environmental impacts associated with a product, process or service from cradle to grave (ISO, 2006). The SimaPro v. 7.3.3 software (PRé Consultant, 2012) was used to determine the environmental impacts for the three fertilization treatments. The CML 2001 methodology developed by the Centre of Environmental Science of Leiden University (Guinée, 2001) was used for the impact assessment. According to this methodology, the impact categories selected for this study were the following: abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (OLDP), photochemical oxidation potential (POP) and an energy flow indicator, cumulative energy demand (CED).

2.1. Goal and functional unit

The aim of this LCA is to compare the yield, quality and environmental impact of three fertilization treatments applied in an open-field for cauliflower crops. The functional unit (FU) selected for this study was the total number of tons per hectare of horticultural crops of cauliflower.

2.2. Description of the system boundaries

The stages and processes of each fertilization treatment included in the study are presented in Fig. 1.

2.2.1. Industrial compost

The IC treatment group was taken from a full-scale facility that manages the waste of the twelve municipalities that make up Mancomunitat La Plana, located in the province of Catalonia, Spain. The facility uses a confined windrows technology (CCW). This facility is a low cost, small-scale plant lacking complex equipment and a bio-filter for gaseous emissions treatment. The plant produces compost from OFMSW from waste collected through a "door to door" management system. The processing at this plant consists of a decomposition phase in confined windrows with controlled aeration and watering over a period of 4 weeks followed by 6–8 weeks in the turned windrow (curing phase). More details of this facility and a full description of the process can be found in Colón et al. (2012).

2.2.2. Home compost

For the fertilization treatment with HC, which was applied to crops, we evaluated the production of compost by a typical family in a Barcelona city neighborhood. The organic matter used for composting in the HC treatment group was LRFV with pruning waste (PW) as the bulking agent. The bulking agent for carrying out the process was applied in a proportion of 1:1 (organic matter: bulk