Agència de Gestió d'Ajuts Universitaris i de Recerca

UNIÓ EUROPEA
Fons Social Europeu

Memòria justificativa de recerca de les beques predoctorals per a la formació de personal investigador (FI)

La memòria justificativa consta de les dues parts que venen a continuació:
1.- Dades bàsiques i resums
2.- Memòria del treball (informe científic)

Tots els camps són obligatoris

1.- Dades bàsiques i resums

Títol del projecte ha de sintetitzar la temàtica científica del vostre document.
Estudi dels impactes ambientals del cicle de vida del compost, de la producció a l'aplicació.

Dades de l'investigador (benficiari de l'ajut)

Nom: Julia
Cognoms: Martínez Blanco
Correu electrònic: julia.martinez@uab.cat

Dades del director del projecte

Nom: **Joan**
Cognoms: Rieradevall
Correu electrònic: **joan.rieradevall@uab.cat**

Dades de la universitat / centre al que s'està vinculat

Universitat Autònoma de Barcelon
Institu de Ciència i Tecnologia Ambientals
Edifici CN, Campus UAB
08193 Cerdanyola del Vallès, Barcelona
T: 93.581.37.60
F: 935868008

Número d'expedient
JM017338

Paraules clau: cal que esmenteu cinc conceptes que defineixin el contingut de la vostra memòria.
fertilització orgànica, compost, anàlisis del cicle de vida, cultiu hortícola, hivernacle

Data de presentació de la justificació
juliol 09

Generalitat de Catalunya
Departament d'Innovació, Universitats i Empresa

Agència de Gestió d'Ajuts Universitaris i de Recerca

UNIÓ EUROPEA
Fons Social Europeu

Resum en la llengua del projecte (màxim 300 paraules)

La gran majoria d'hivernacles situats en clima mediterrLa gran majoria d'hivernacles situats en clima mediterrani són de cost relativament baix i de tecnologia senzilla. El cultiu en hivernacle te com a objectiu principal incrementar la producció agrícola per unitat de superfície mitjançant l'aïllament de les condicions del medi. Aquest projecte presenta inventaris detallats i de qualitat del cicle de vida complet del compost amb aplicació en aire lliure i en hivernacle, aportant informació dels impactes ambientals i avaluant la viabilitat agronómica del compost com a fertilitzant quan s'aplica en cultius hortícoles. S'han considerat quatre opcions de cultiu, depenent del tipus de fertilitzant utilitzat (fertilitzans minerals o compost) i de si el cultiu és a l'aire lliure o en hivernacle. Les dades s'han obtingut experimentalment en parceles pilot i en una planta de compostatge industrial, ambdos localitzats prop de Barcelona, en una àrea mediterrànea. Per al cultiu en hivernacle, s'han obtingut produccions de tomàquet superiors a les d'aire lliure en el cas d'aplicar fertilitzants minerals, mentre l'ús de compani són de cost relativament baix i de tecnologia senzilla. El cultiu en hivernacle te com a objectiu principal incrementar la producció agrícola per unitat de superfície mitjançant l'aïllament de les condicions del medi. Aquest projecte presenta inventaris detallats i de qualitat del cicle de vida complet del compost amb aplicació en aire lliure i en hivernacle, aportant informació dels impactes ambientals i avaluant

Generalitat de Catalunya
Departament d'Innovació, Universitats i Empresa

Resum en anglès(màxim 300 paraules)
The vast majority of greenhouses in Mediterranean climate are still of the low cost and technology type. Greenhouse cultivation aims to obtain the highest yield per area used through isolation from environmental conditions. This project presents detailed and quality inventories of the complete compost cycles in both open-field and greenhouse, providing information on the environmental impacts and assessing the agronomic viability of compost as a fertilizer when it is used for horticultural crops. Four cultivation options were considered, depending on the fertilizing option applied and the field location. The data were obtained experimentally in pilot fields and in an industrial composting facility, both located in the Mediterranean area. In greenhouse, major tomato productions than in open field were harvested using mineral fertilizer, while the use of compost as only fertilizer seems to not be able. Greenhouse options increased infrastructural materials requirements but water and pesticides were reduced. Considering the avoided burdens, the comparison of results for greenhouse and open field revealed that the former was more environmentally impacting than the latter for both options (C and M) and most of the impact categories when experimental harvests were considered. For the standard productions of the region, the impacts were nearly the same between greenhouse and open field crops considering mineral fertilizer treatment.

2.- Memòria del treball (informe científic sense limitació de paraules). Pot incloure altres fitxers de qualsevol mena, no més grans de 10 MB cadascun d'ells.

Agència de Gestió d'Ajuts Universitaris i de Recerca

UNIÓ EUROPEA
Fons Social Europeu

MEMÒRIA JUSTIFICATIVA DE RECERCA DE LES BEQUES PREDOCOTRALS PER A LA FORMACIÓ DE PERSONAL INVESTIGADOR (FI)

Estudi dels impactes ambientals del cicle de vida del compost, de la producció a l'aplicació.

Gener-Juliol 2009

Investigadora beneficiària: Julia Martínez Blanco

Tutor: Joan Rieradevall i Pons

Institut de Ciència i Tecnologia Ambientals

Institute of Environmental Science and Technology • UAB

Universitat Autònoma de Barcelona

INDEX

1. THE THESIS PROJECT

The thesis project, that is within the studies of Doctorat en Ciència i Tecnologia Ambientals of the Universitat Autònoma de Barceloa, is focused in two main areas. Firstly, the evaluation and comparation of the environmental impacts related to the use of compost or mineral fertilizer in several vegetable crops. Secondly, the evaluation of the environmental impacts of several types of compost production technologies.

1.1. Compost application

The focus of that thesis project is on the evaluation of the environmental impacts related to the production, transport and application of either compost obtained from the organic fraction of municipal solid waste (OFMSW) or mineral fertilizer in several vegetable crops. Such crops are located in open-field or in greenhouses. The previous results suggest environmental and economic improvement opportunities in the system.

In this project, it is considered a system that includes the OFMSW obtaining, the production and transport of compost and also the cultivation phase (Muñoz et al, 2007; Colón et al, 2009; Martínez-Blanco et al, 2009) that includes agricultural operations, irrigation, greenhouse and fertilizers and pesticides application.

Several crops have been grown and assessed in the experimental fields: tomatoes, chard, cauliflower, onion, zucchini and celery for open-fields; and tomatoes, pea, cucumber, lettuce, beans and radish for greenhouses.

The environmental impacts associated to three kinds of fertilizing treatment (only compost, compost and mineral fertilizer, and mineral fertilizer alone) are considered for all these crops. Life Cycle Assessment tool is used considering six impact categories and one flow indicator.

The use of compost for the fertilization of horticulture crops can be an interesting alternative for this by-product, although it would be necessary to propose some improvements for the reduction of the environmental impacts in the industrial composting process. On the other hand, the LCA methodology considers the compost only as a fertilizer, but there are also a series of local environmental indicators, such as soil quality (organic matter, water content and salinity) or erosion degree, that must also be taken into account.

The PhD student has adaptated the previous system design (Martínez-Blanco et al, 2009) to the other experimental fields and integrated the greenhouse cultivation. The results of that research are shown in the main body of the document.

1.2. Compost production technologies

Composting technologies have been extensively developed in recent decades in response to the increasing concern related to the management of solid wastes. Apart from the several advantages of composting processes, home composting considerably reduces the economic, material and energetic investment necessary for composting at industrial scale.

The aim of this study is to quantify the emissions and the environmental impacts associated to home composting and industrial composting and assessing its final compost quality. Regarding home composting, two typologies of organic waste were considered (leftovers of raw fruit and vegetables (LRFV) and organic fraction of municipal solid wastes (OFMSW)).

In this project, it is considered a system that includes: the OFMSW obtaining; the energy, water and infrastructure requirements for the compost production; and the waste, leachates and emissions generated. An exhaustive experimental data inventory is elaborated. Life Cycle Assessment tool is used considering six impact categories and one flow indicator.

During this period, the research developed by the PhD student was the environmental evaluation of the home composting performance in collaboration with the GICOM (Grup d'Investigació en compostatge, ETSE, UAB). This research was described in a paper named "Environmental assessment of home composting" that was accepted with major revisions in the journal Resources Conservation & Recycling. This paper has been enclosed at the appendix.

During this period, another paper based on previous research on that area were accepted and published, "Performance of an industrial biofilter from a composting plant in the removal of ammonia and VOCs after medium replacement".

1.3. Cientific publications

The PhD student has participated in two international conferences:

- CILCA International Conference of LCA in Latin America, April 2009, Pucón (Xile). "Emissions and environmental assessment of the home composting of two domestic organic wastes".

Posters and papers of the conferences have been enclosed at the appendix.

The PhD student has participated in the elaboration of two cientific papers:

- Joan Colón, Júlia Martínez-Blanco, Xavier Gabarrell, Joan Rieradevall, Xavier Font, Adriana Artola and Antoni Sánchez. Performance of an industrial biofilter from a composting plant in the removal of ammonia and VOCs after medium replacement. Journal of Chemical Technology &Biotechnology, DOI: 10.1002/jctb.2139 (2009).

- Joan Colón, Julia Martínez-Blanco, Xavier Gabarrell, Adriana Artola, Antoni Sánchez, Joan Rieradevall and Xavier Font. "Environmental assessment of home composting". Resources, Conservation & Recycling (Accepted with major revisions, June 2009).

Publicated paper has been enclosed at the appendix.

2. INTRODUCTION

Proliferation of unheated and plastic covered greenhouses in the Mediterranean basin began in the sixties, got established in the seventies, and became definitely generalised in the eighties (1). The mild climatic conditions, the increase of the demand of out of season vegetables, the reduction in the price of transports, the development of low-cost plastics greenhouses and the introduction of some simple technologies of microclimatic control were the major contributing factors for the latest expansion (2, 3). The present challenge is the environmental impacts reduction of such cultivation systems throughout the implementation of techniques with lower energy and resources consumption and the improvement of its surroundings incorporation, without compromising yields.

The total European protected area with greenhouses in 1997 were around 215.000 hectares (Antón tesis), with some Mediterranean countries in the top of the list, as Spain and Italy with 79.800 (en 2006) and 27.721 (2001) hectares in 2006, respectively (4). Similar to rest of Mediterranean region, in Spain the vast majority of greenhouses produced fresh vegetables (96 %) and the most common were tomato (25 % in area), melon, pepper and strawberry (4)

Greenhouse systems aim to obtain relevant productive advantages with respect to open field cultivations through control the environmental conditions of the crop. Greenhouse cultivation has been often perceived by consumers as an artificial technology, characterized by low nutritional quality of the final product and the intensive use of chemical inputs, linked with a heavy infrastructure and considered as a large visual impact practice. In contrast, open-field cultivation is generally perceived as a more environmentally respectful activity.

Actually, in spite of the trend of the last years towards the increase in greenhouse technology in Central and North European countries, the vast majority of greenhouses in Mediterranean climate are still of the low cost and technology type on account of the growers' investment possibilities and the lower thermal crop requirements. Currently, efforts are being made to improve their production by incorporating simple technology and using little external energy, water and chemicals (1, 5, 6).

Bradley et al. (7) defined the integrated crop management (ICM) as an environmentally sensitive and economically viable production system or process which uses the latest available techniques to produce high quality food in an efficient manner. For instance, farming practices including fallow, suitable rotations, the application of general hygiene measures, the use of insect traps among others act as significant barrier to the establishment and spread of diseases without the need of plant protection products, which are used when there are not another option (2). The ICM is a compromise between the consumer demand for more environmentally friendly farming, especially the reduced use of plant protection products,and the demand for food to be safe, affordable to all, widely available, fresh, blemish and insect-free (7).

Focusing on to reduce pollution from fertilizer runoff from agricultural systems, the most practical way would be to employ a production strategy based on optimal fertilizer input, especially N fertilizers (8). Compost application, it seems to be a good option for fertilizing the local setting as it involves an increase in the organic matter content of the soil and thus an increase in moisture content and in soil bulk density apart from other advantages (9). Moreover it gives the chance to closing metabolic cycles using the organic fraction of municipal solid waste (OFMSW) in crop production. The total annual arising of bio-waste in the EU is estimated at113-139 Mt that includes OFMSW and waste from the food and drink industry. The potential of compost production from most valuable inputs (bio-waste and green waste) is estimated at 35 to 40 Mt (10) that means a minimum of 131.000 t of available organic nitrogen (11).

Previous studies relative to environmental impacts of greenhouses had been developed in Northern and Central Europe installations, where glass as insulating material, heating and lighting are usual due to climatic conditions, and only few inventory items as water and energy were considered (12-14). Environmental performance of the aforementioned Mediterranean greenhouses had been studied by our research group (6, 15). In this project, Mediterranean greenhouses were featured in detail considering fertilization with compost or mineral fertilizers. the method of Life Cycle Assessment (LCA), well known in industrial processes, are being adapted to quantify the environmental impact of greenhouse production (5).

In relation to compost cycle, apart from Guerini et al. (16), Sharma and Campbell (17) and Martinez-Blanco et al. (9), the majority of previous scientific work had been focused only on one phase or an specific aspect of it. The gas emissions produced during the composting process or the use of compost as a fertilizer, organic amendment or growing medium, are examples (18-25).

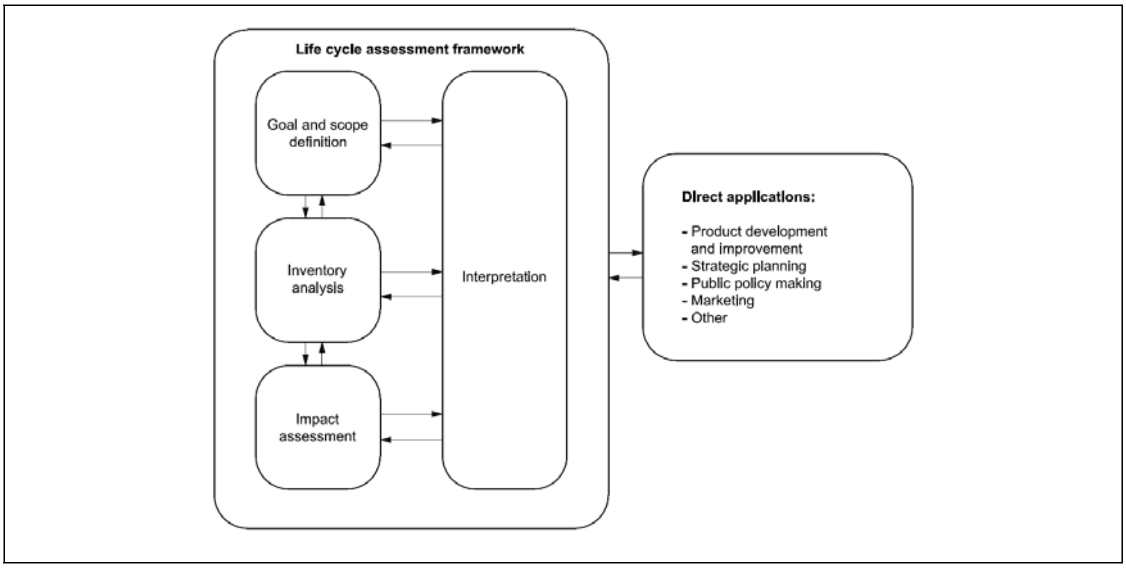


Figure 1. Diagram of an LCA (26).

The life cycle assessment (LCA) is a tool for assessing the potential environmental impact of a given product or a system considering its entire life cycle from resources extraction to waste disposal (26). An LCA is divided into four steps: the goal and scope definition of the system and the study; the inventory assessment, where all the extractions of resources and the emissions of substances attributable to the system are listed; the impact assessment that determines the potential impact of each individual substances within the impact categories considered; and, finally, the interpretation of the results obtained (Figure 1).

This project presents detailed and quality inventories on the comparison of two cultivation options, open-field and greenhouse, considering two fertilizing options, compost and mineral fertilizers, providing information on their environmental impacts and agronomic viability.

The plots studied are located in the county of Maresme, by the Mediterranean in the northeast of Spain, and declared a vulnerable region to nitrate contamination, according to the European Directive 91/676 (27). This traditionally agricultural area, close to the city of Barcelona, has major urban pressure and is one of the most important tomato producing areas in Catalonia.

3. ENVIRONMENTAL IMPACTS OF THE TOMATO PRODUCTION IN OPEN FIELD OR GREENHOUSE WITH COMPOST OR MINERAL FERTILIZER

3.1. Goal and scope definition

In the goal and scope definition section, the aim and the breadth, depth and detail of the present study were pointed.

3.1.1. Objectives of the study

The purposes of this LCA were to determine the differences between greenhouse and open field cultivation, between compost and mineral fertilizers and their several combinations, throughout three perspectives: the agricultural production and quality; the environmental inventory, assessing the energy and resources use and the emissions; and finally, the environmental impacts. Apart from the comparison between cultivation options, we determined the critical environmentally stages for each cultivation option which should be the focus of further measures.

3.1.2. Description of the system

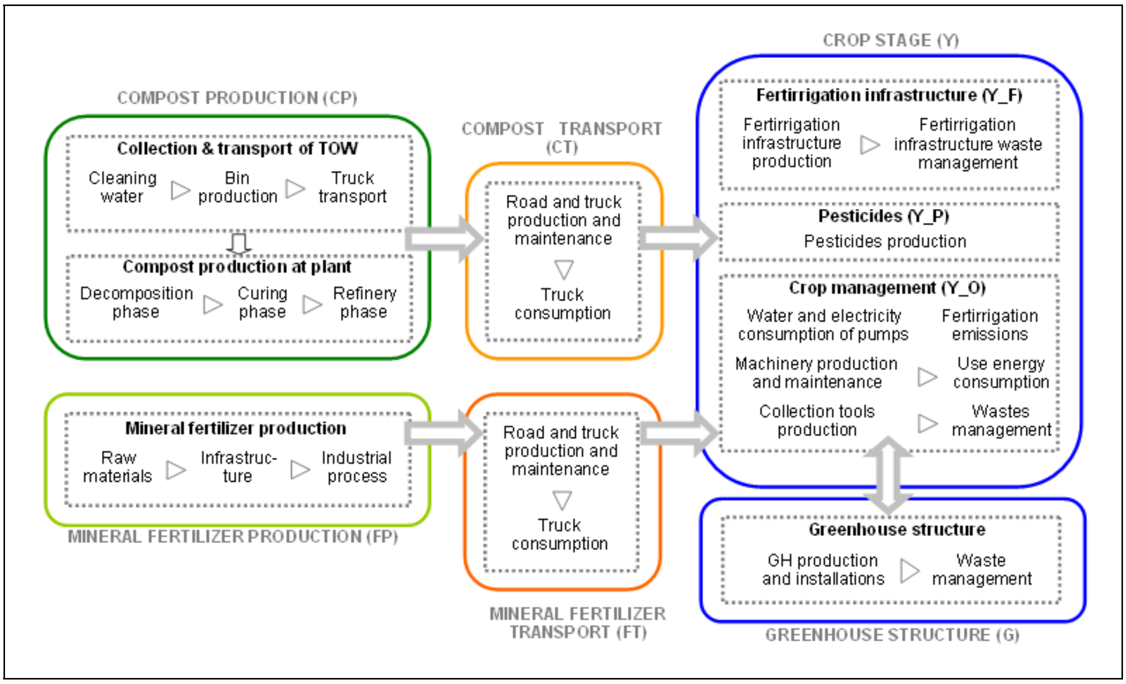


Figure 2. Diagram of the processes included in the four stages considered (mineral fertilizer and compost production, transports of them, cultivation stage and greenhouse structure) in the environmental impact assessment of cultivation options.

The whole process from raw materials, required for the manufacture of the different elements, to management of the generated waste was considered. Figure 2 shows the stages considered in the whole system: compost production (CP); mineral fertilizer production (FP); transport of compost (CT) and mineral fertilizer (FT) to the crops; greenhouse structure (G); and yield stage (Y), hat includes the sub-stages of field operations (Y_O), pesticides (Y_P), and the fertirrigation infrastructure (Y_F). The commercialization was not included because it was on local market, not involving significant environmental burdens, and with common characteristics for the four options considered.

Four cultivation options, characterised by the type of fertilization and location, were compared: cultivation inside greenhouse with comp ost as a fertilizer (GH_C) or with mineral fertilizers (GH_M); and cultivation at open field with compost (OF_C) or with mineral fertilizers (OF_M). The diagrams of each cultivation option are showed in Figure 2 and thus the stages of Figure 1 that were included on them.

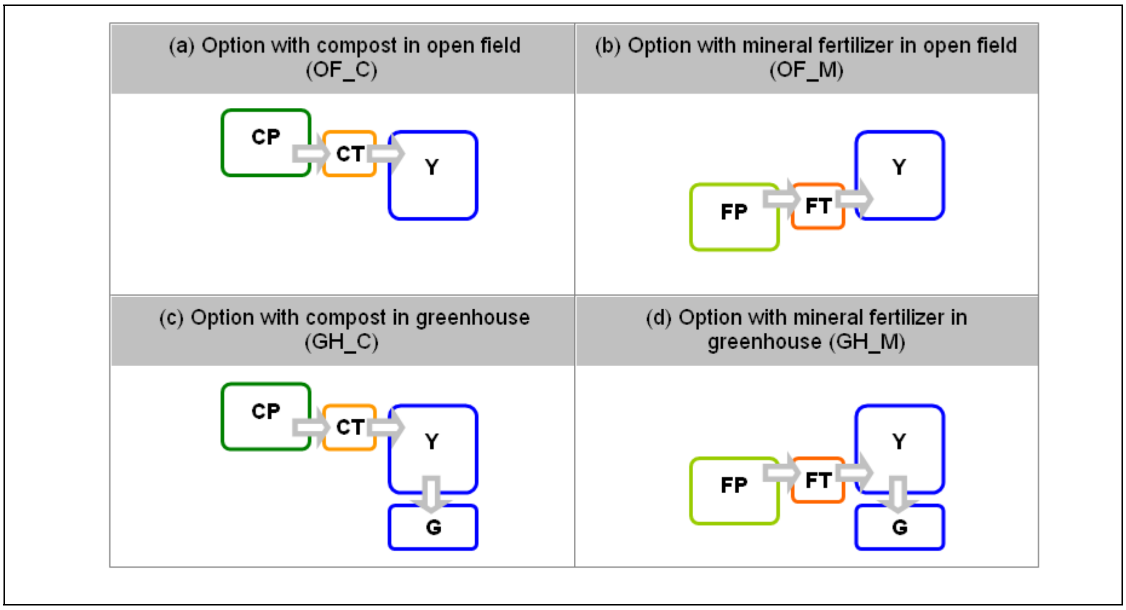


Figure 3. The four cultivation options considered and the stages included in each one. The four stages were represented in Figure 2. Cultivation options: (a) OF_C; (b) OF_M; (c) GH_C; (d) GH_M.

3.1.3. Functional unit

The functional unit (FU) provides a reference to which the inputs and outputs required to fulfil the intended function of the system are related. This reference is necessary to ensure comparability of LCA results. The FU chosen was the horticultural production of a ton of commercial tomato in Mediterranean region owing to the main function of an agricultural system is to produce (food or non-food) for human or animal use (Audsley). It provided a reference against which input and output flows were normalised in a mathematical sense (26).

Commercial fruit yield consisted of tomato fruit that showed no signs of disease or deformation, and were graded according to their diameter (8).

3.1.4. Quality and origin of the data in the inventory

The broaden system of study (Figure 1) required a detailed data-collection process. Most of this data was obtained experimentally by the authors for this paper or previous and by the research group.

The inventory of inputs and outputs of the industrial composting plant was provided by the managers (9) apart from gas emissions that were experimentally measured by Colon et al. (28) and theoretical determined by Martínez-Blanco et al. (9). In addition, experimental data from Muñoz et al. (29) on the physical and chemical characteristics of the compost obtained from the Castelldefels plant, were used. The composting plant was located at Castelldefels at the NE of Spain (41º17'18''N 1º58'16''E). It was selected because of its similar characteristics to those other Mediterranean plants.

The data relating to agricultural practices were obtained in experimental fields using the best available techniques for integrated cultivation management (7, 30). Information about the fertirrigation infrastructure, the greenhouse structure, building and consumption, the machinery production and hours used, the harvesting elements, the amounts of pesticides, compost and mineral fertilizer, and the water and energy consumption during irrigation was collected and processed (31).

a) Open field plot

b) Greenhouse plot

Figure 4. General views of the open field plot (Santa Susana, Catalunya, Spain) and greenhouse plot (Cabrils, Catalunya, Spain).

Tomato variety ElVirado® was cultivated during the spring and summer of 2007 in Santa Susana open fields (41º38'27''N 2º43'00''E, Spain), with sandy-loam soil, (Figure 4a) and tomato variety Caramba® in greenhouses of Cabrils (41º 31' 31'' N 2º 22' 07'' E, Spain), with loamy-sandy soil, during spring and summer of 2008 (Figure 4b), two common varieties for open field and greenhouse respectively. Planting was done at a plant density of 2.3 (OF) and

2.8 plants/m2 (GH), common rates for the two locations (8). Each option was replicated in four fields, with a whole area of 133 and 39 m2 for each option in open field and greenhouse, respectively.

To complete the life cycle inventory, few bibliographical sources and the Ecoinvent system process database v1.2 (32) were used.

3.1.5. Allocation procedure

Conflicts with assignation of environmental burdens are very common in waste options systems as a consequence of such systems usually provide one or more further functions in addition to waste option, as energy production or by-product obtaining.

Regarding the management of several waste generated between the burdens of the system, the method of "cut-off", which had been defined by Ekvall and Tillman (33), was used. According to this method, each system was assigned the burdens for which it was directly responsible. In the case of waste management, dumped materials were accounted for in the system being studied, while for recycled or reused waste, the burdens were attributed to the system using the waste as a raw material source.

When comparing the impacts of the four cultivation option systems (OF_C, OF_M, GH_C and GH_M), it could be remembered that composting, as well as providing a fertilizer product, was a form of waste management of OFMSW and vegetal fraction (VF), which was not the case in the production of mineral fertilizer. As proposed by Finnveden (34) and Ekvall and Weidema (35), to make these systems comparable and to include the extra function of composting, the boundaries of the system should be expanded, considering an alternative form of managing OFMSW and VF different from composting. The method selected was dumping, with its environmental burdens subtracted from those options that include composting, so that only the fertilizing function of the four cultivation options were compared. Until recently, dumping of organic and green MSW was common, but now is prohibited by Directive 1999/31/CE (36).

3.1.6. Categories of impact and LCA methodology

The computer tool used for the impact analysis was the SimaPro v. 7.1 program (37), performing the obligatory classification and characterization phases defined by the ISO 14040 regulation (26). Six impact categories, which had been defined by the CML (38), and an energy flow indicator were considered (Table 1). Owing to the lack of consensus in the international community, the toxicity categories were not assessed (31).

Table 1. Impact categories considered and their units.

Impact category		Units
Abiotic depletion	AD	kg Sb eq
Global warming potential	GWP	kg CO2 eq
Ozone layer depletion	ODP	kg CFC-11 eq
Photochemical oxidation	PO	kg C2H4
Acidification	A	kg SO2 eq
Eutrophication	E	kg PO4--- eq
Cumulative energy demand	CED	MJ eq

3.2. Life Cycle Inventory

The stages and sub-stages of the four cultivation options were developed in this section, most of the explanations are widely described in Martinez-Blanco et al. (31). Previously some general considerations were pointed.

3.2.1. Preliminary considerations

Three main commentaries had to be done previously to inventory stages description: tomato production and quality parameters, doses of mineral fertilizers and compost applied, some transport suppositions and finally, lifespan allocation and field dimensions.

a) Harvest productions and quality

The Table 2 shows the tomato harvests measured that were used to express the inventory results per functional unit. The Table 4 also contains two commercial parameters, the average diameter and the weight of the tomato fruit. Analysis of variance was by means of the General Linear Model, and the least significant difference (LSD, P = 0.05) was used to establish differences between options using the Enterprise Guide software package (39).

b) Doses of fertilizing products applied

The contribution of N for each option was calculated by taking into account nitrogen content of the irrigation water used, the nitrogen absorbed by the crops and the composition of the mineral fertilizer and the compost (Table 2). Nitrogen content of the irrigation water was considerably higher for open field (42.02 g/m^3) than for greenhouse (3.22 g/m^3), therefore nitrogen content was evened up among cultivation options because it was a local characteristics that did not depend on fertilization option neither on greenhouse or open field location. Accordingly, in the inventory and the impact assessment, a virtual concentration of 3.22 g/m^3 of HNO_3 was also considered for open field calculation and the real extra nitric acid contribution was accounted as a mineral fertilizer added (HNO_3), considering its production, transport and application.

Table 2. Mineral fertilizers and compost, nitrogen and irrigation water applied for each cultivation option.

Nitrogen sources	Open-field		Greenhouse	
	OF_C	OF_M	GH_C	GH_M
Fertilizers application (g/m^2)				
Compost [a]	1,931.0	0.0	1,861.1	0.0
HNO_3 [b]	166.3	161.6	0.0	176.5
KNO_3	0.0	146.2	0.0	99.9
KPO_4H_2	0.0	0.0	0.0	73.6
K_2SO_4	0.0	0.0	0.0	117.6
Nitrogen application (gN/m^2)				
N organic [c]	18.24	0.00	17.58	0.00
N mineral [d]	24.09	43.62	1.54	39.71
Nitrogen Total	42.33	43.62	19.12	39.71
Irrigation water (L/m^2) [e]				
Irrigation water	571	555	477	622

[a] Proportional part of the total compost dose for the 133/134 days of the tomato crop. The total doses for the 18/24 months were calculated as 7.8 kg/m2 for OF_C; 3.9 kg/m2 for C+OF_M; 10 kg/m2 for GH_C; and 5 kg/m2 for C+GH_M. The moisture content of the compost applied to the experimental plots was 27.7%, slightly lower than the 30 to 40% interval established by RD 824/2005 (11), and the organic matter content was 62% for dry material. In relation to heavy metals, this was class A compost (10). The complete analysis of the sample was included in Muñoz et al. (29).

[b] Acid nitric 60%. In open-field, high nitrogen water content was accounted as an addition of synthetic acid nitric.

[c] Total nitrogen added by compost. Nitrogen available the first year after spreading the compost.

[d] Total nitrogen added by mineral fertilizers, water irrigation and rainfall (for open field).

[e] A rainfall of 105 L/m2 must be added to open field options because rain was directly plunged on soil for open fields whereas in greenhouse it was stored and distributed with the fertirrigation system.

c) Transport suppositions

All transports were considered to be by road in the different stages and sub-stages, doubling the distance to calculate the associated environmental burdens to take into account a return trip for unloading, except in the case of FT. Furthermore average distances were accounted for transports to or from crops because they were also local characteristics, as nitrogen content.

d) Lifespan allocation and field dimensions

The proportional part of several materials, emissions and energy attributed per ton of OFMSW were designed taken into account the lifespan of them and the cultivation length. For the inventory data, a field of 5,000 m^2 was considered for each cultivation option with the aim to more realistic distribution of impacts, especially for those of fertirrigation infrastructure and greenhouse structure. The data were extrapolated from real field dimensions.

3.2.2. Stage of compost production (CP)

The composting plant studied treated about 14,500 t of organic waste a year -OFMSW and VF (Figure 5). Such waste was obtained by sorting at the origin in six nearby municipalities and the main supply centre of fresh products to Barcelona, both were located at 13 km of the composting plant, in average.

a) Obtaining organic MSW

The organic MSWfor the plantwas obtained by sorting at origin in six nearby municipalities and the main supply centre of fresh products to Barcelona. The pruning waste was from parks and gardens in these municipalities. OrganicMSW and pruningwaste were considered a mixture of homogeneous organic material for collection and transport to the plant in 16 t maximum authorised load (MAL) trucks. The average distance between collection points and the composting facility was 14 km, with the impacts of return trips made by the trucks also attributed. The remaining considerations were described by Martínez-Blanco et al (9).We added the energy needed for grinding pruning waste, which was done at a different facility to that studied.

b) Industrial composting process

The industrial composting process in the studied plant included four main phases:

- Pre-treatment: reception of the material, grinding to amaximum of 80mm and mixing at a ratio of 1:1 organic MSW and pruning waste.
- Composting or decomposition: this was in tunnels which had a forced aeration and irrigation system to optimise decomposition. The material remained there for a minimum of two weeks and the temperaturemust exceed 65 ◦C for two or three days to guarantee hygienization of the material. The temperature and oxygen concentration were automatically controlled.
- Curing: the decomposed material was put in piles periodically turnedmechanically to enable internal aeration, and which were watered when there was a need to increase humidity. The total maturation time was generally about eight weeks.
- Refining: screening to separate the mature compost, usually less than 15mm, from the other fractions. Such were the pruning waste that had not totally decomposed and was put back into the composting process, and the solid waste fraction which was dumped. The latter included non-organic material such as plastics and tins – inappropriate items introduced in the process with organic MSWand pruningwaste – and compostatedmaterial not correctly separated.

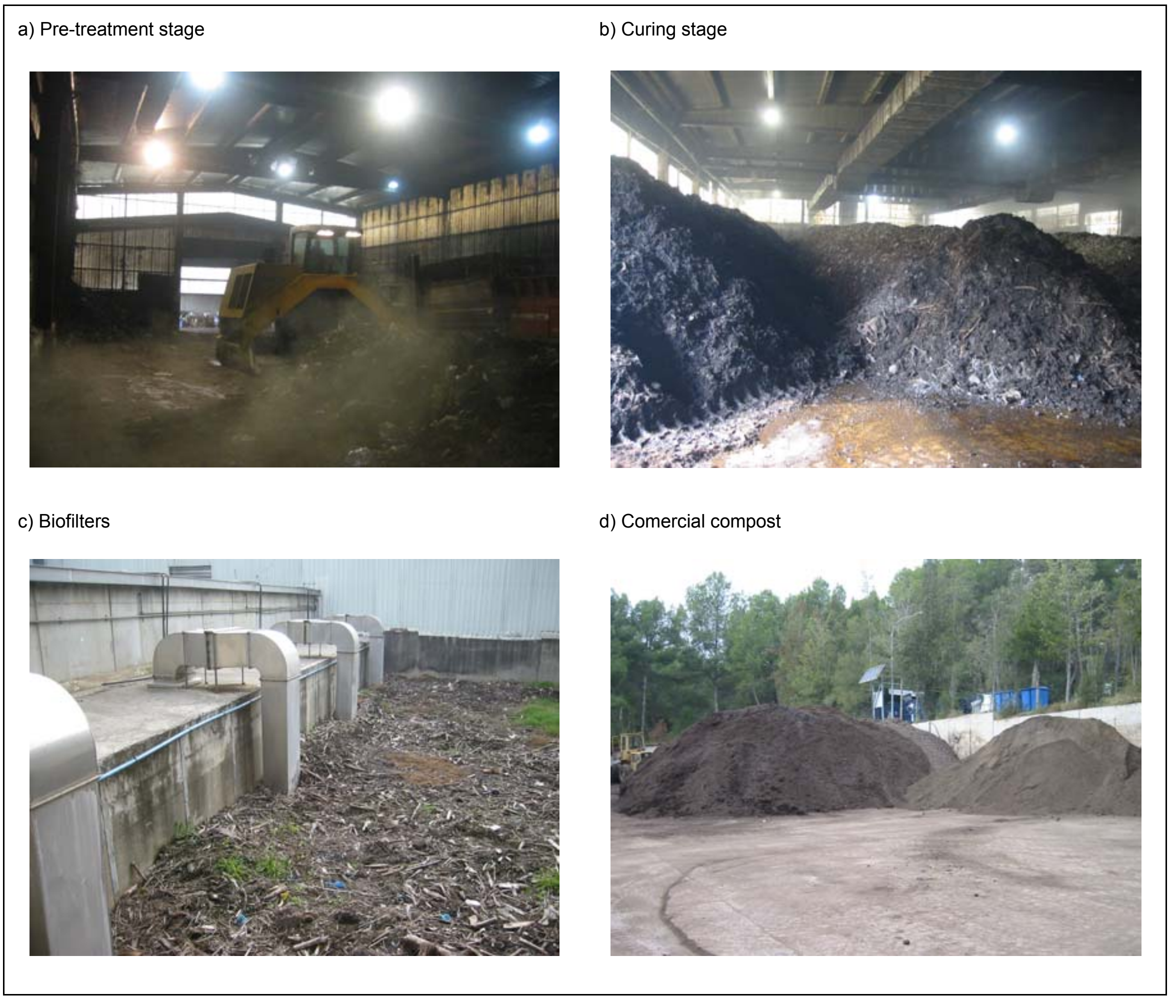


Figure 5. Four moments of the compost production at the Castelldefels composting facility (Castelldefels, Catalunya, Spain).

The complete process taken around 10 weeks, and then it was considered that the materialwas stable and could be applied to the soil without any problems associated to the incomplete decomposition of easily degradable materials.

To consider the plant's flows,we used values for the 2003–2006 period (Table 3), provided by the managers of the plant. We also accounted for the impact of the building and the main machinery, including production of the necessary construction materials, their transport and waste management (9).

c) Biofilter characteristics and gaseous emissions

The exhaust gases generated in the composting tunnels and in the pre-option and curing areas were treated using a biofilter before being released into the environment. This was a layer of organic material that was biologically enriched in which the contaminants were retained and metabolised by microorganisms. According to Colon et al. (28) the total amount of 0.08 kg of NH_3 and 0.84 kg of COV were emitted per ton of organic waste treated. For the other gases considered, CH_4 and N_2O, the emissions were estimated by Martínez-Blanco et al. (31) using bibliographic sources. An emission of 0.36 kg of CH_4 and 0.02 kg of N_2O per ton of organic waste treated were considered.

Table 3. Inventory of average input and output flows of materials and energy at the composting facility in Castelldefels (Barcelona) for the 2003-2006 period, and emission factors considered for the decomposition of organic waste (organic MSW and pruning waste)

Type of flow	Units	Annual flow
Input		
Electric supply	MWh/year	465.9
Diesel oil consumption [a]	m^3/year	64.3
Water consumption [b]	m^3/year	3,935
Total organic waste	t/year	14,461
organic MSW	t/year	10,022
pruning waste	t/year	4,439
Inappropriate items	%	20
Output		
Compost production	t/year	2,094
Solid waste dumped	t/year	2,823
Emissions		
CO_2 biogenic [c]	t/year	2,385.89
NH_3 [d]	t/year	1.59
CH_4 [c]	t/year	5.45
COV [d]	t/year	17.50
N_2O [c]	kg/year	0.30

[a] Diesel consumption includes the consumption by the organic MSW treatment plant and the fuel required to grind the pruning waste at an external plant.

[b] Water consumption includes the tap water supplied and rainwater collected in biofilters and reused.

[c] Bibliographic data on output from biofilters.

[d] Experimental data on output from biofilters.

3.2.3. Stage of mineral fertilizer production (FP)

The data on the manufacture of mineral fertilizer were from the processes inventoried in the Ecoinvent system process v. 1.2 (32) and described by Nemecek et al. (40),

3.2.4. Stages of mineral fertilizer (FT) and compost transports (CT)

In the European-Mediterranean area, the mineral fertilizer is produced in Germany and transported to the distributors in each country. Therefore, we considered transport over a distance of 1,950 km in 32 MAL trucks. Due to the efficiency of international transport platforms, the truck returned to Germany with another load and therefore only the outward journey was included.

The compost was transported from the composting facility in Castelldefels, a town located 66 km in average from the experimental plots, in 16 MAL trucks.

3.2.5. Cultivation stage (Y)

The management and design of the four cultivation options were under the integrated crop management guidelines (7) with the goal to compare efficient systems in resources and energy consumption.

a) Sub-stage of fertirrigation infrastructure (Y_F)

The system used in the experimental plots to supply water, fertilizers and phytosanitary products was a fertirrigation infrastructure with pumps and pipes for extracting and channeling the water, tanks, electrovalves for controlling dosage and a network of pipes supplying the plants. Integrated drip pipes were used as irrigation system. We considered the transport of these elements from the distribution point, in 3.5 t MAL vans, and the waste management.

b) Pesticides sub-stage (Y_P)

To determine the species of pesticides to apply, we turned to the Regulations for integrated crop management (7, 30). The doses applied, for each of them, were the minimums determined by the Spanish Ministry for Environment and Rural and Marine Affairs in its Registry of phytosanitary products (41). In open field the total amount of pesticide dosages applied were thirty seven for open field options and only two for greenhouses.

c) Field management sub-stage (Y_O)

In Y_O, we took into account the irrigation, the fertirrigation emissions the greenhouse management and the tractor and other agricultural machinery.

Irrigation water was pumped from a nearby well to the fields using two pumps, one to pump the water out of the wells and the other to spread it over the plots. For GH_C and GH_M rain water collected from the greenhouse covers was stored and used in the irrigation of crops inside them. The same rainfall was considered for open field and greenhouses during the cultivation period.

The total supply of water to the soils included rainfall (for open fields) and irrigation water. The latter, showed in Table 3, depended on the tensiometer reading that determines matric water potential evapotranspiration demands of the soil.

To calculate the fertirrigation emissions, we considered the nitrogen contributions made by each fertilizer and the nitrogen concentration absorbed by the crops, in accordance with Audsley's hypothesis for sandy soils (42). We accounted for emissions of NH3, N2O, NOx and N2 into the air and NO3 into the water.

For those options that considered greenhouse, its management only included the opening and closing of its windows, which had an electricity consumption associated.

The operations were the same for the four cultivation options apart from those operations related to compost application, which were not considered in the case of OF_M and GH_M. We also considered the burdens associated with the production and transport of the harvesting elements: the HDPE (High Density Polyethylene) crates and the steel handcarts.

Management of waste generated during the cultivation stage. As was aforementioned, the burdens of wastes with a recycling or recuperation option were not considered. Such wastes were non-yield biomass, non-commercial tomatoes and steel of harvesting handcarts. The waste dumped were the fertirrigation infrastructure and the fruit harvesting crates that were deposited in a landfill sited 48 km from the fields at the end of their useful life. The impact of their management consisted of transport to the landfill, in 16 t MAL trucks, plus the burdens of deposition, which depended on the material (32). The burdens of each waste were attributed to the sub-stage responsible of them.

3.2.6. Greenhouse structure stage (G)

A round arched greenhouse with vertical sidewalls or multi-tunnel greenhouse (3, 15) of 5.000 m2 was considered for each OF_C and GH_C cultivation option (Figure 6). The greenhouse was 104 m long, 8 m wide, 4 m high at the gutter and 5.5 m high at the ridge. It was made up of six span build with steel frames with concrete foundations and covered by a low density polyethylene (LDPE) film. The plastic film was fastened by means of a system of omegas that form part of the proper structure and was renewed every three years. The ventilation system was made up of six roof openings and two side-wall openings controlled by 0.75 HP engines that allowed air renovation and to modify the temperature. As was aforementioned, the rain water was collected by the greenhouse gutters and pipes and was used in the crop irrigation. Tomato plants were supported and guided by a prop ribbon made of raffia.

The phases of greenhouses production, transportation of materials, installation, management and waste management were included according to the criteria established by Audsley (42) and Antón (15).

Following the same suppositions that in previous section about management of waste generated, the cover film and the steel of the greenhouse frame were recycled since the rest of greenhouse structure was deposited in the landfill. Although cover film was made of LDPE that could be recycled, the high solar radiation degradation and the dirt and contamination present in the plastic waste, particularly mud remains, may constraint the amount of plastic really recycled.

Therefore, in the absence of specific data and following the indications of the cover film waste managers, it was supposed that a 75 % of the cover film was recycled and the rest, landfilled.

Figure 6. Four moments of the compost production at the Castelldefels composting facility (Castelldefels, Catalunya, Spain).

3.2.7. Avoided burdens of dumping organic and green municipal waste in landfill

The alternative organic and green MSW management method selected was dumping. There were not specific data on the impacts of depositing OFMSW in landfill (43). Therefore, such process was assimilated in that considered by Ecoinvent (32) for the management of municipal solid waste in landfill adding the collection and transport of waste to the landfill. The construction of the landfill and road accesses, the machinery and fuel used for operation, the combustion of methane without making use of the energy and the land used were all considered (32, 44) in a time limit of impact of one hundred years (44). Environmental burdens for dumping a similar amount of OFMSW and VF that used in the production of the compost used in OF_C and GH_C were subtracted from the total impact of these options.

3.3. Results and discussion

3.3.1. Harvest productions and parameters of agricultural quality

According to Enterprise Guide software package (39), commercial and non-commercial productions in greenhouse were significantly lower for C than M -40 % lower – because the high nitrogen demand of tomato plants in early stages of greenhouse cultivation. Such demand could not be satisfied by compost due to its slow nutrient release rates (23). Future studies with data for long periods applying compost in greenhouses could refute such negative result thanks to the improvement of the soil characteristics at long-term. Non-commercial productions were very similar between GH_C and GH_M (4-6 % of commercial production). The harvests obtained were within the minor normal levels expected in the area for GH_M but those for GH_C were very low (8, 45, 46).

No significant statistical differences were observed for commercial production in open field and between cultivation options (Table 4) as a result of the lower nitrogen demand and the extra nitrogen contribution with water irrigation. However, as Figure 4 shows, total tomato harvest -non-commercial plus commercial production- for C was slightly lower than that ones for M because non-commercial production for C was only 14 % (in weight) of the commercial tomato production whereas it is 23 % for option M. The harvests obtained were within the uppers normal levels expected for the commercial production of tomatoes in the area for open field (45). Results suggested that compost could be a suitable fertilizer in greenhouse with an additional dosage of nitrogen.

Table 4. Harvest production and parameters of agricultural quality.

Parameter	Units	Open-field			Greenhouse		
		C	M	LSD[a]	C	M	LSD[a]
Commercial production	t/ha	104	103	ns	96 a	159 b	-
Fruit average diameter	mm	79.1	78.7	ns	82.7 a	89.3 b	-
Fruit average weight	g	209.1	207.7	ns	236.64 a	283.93 b	-

[a] Analysis of variance was by means of the General Linear Model, and the least significant difference (LSD, P = 0.05) was used to establish differences between cultivation options (39). Different letters indicate significant effect and "ns" not significant effect at P = 0.05.

The Figure 7 illustrated the bigger production of GH_M compared with OF_M, a 35 % bigger, as a consequence of the benefits of protected horticulture as isolation of the inclemency of the weather with a relevantly rise of temperature, a better control of the crop variables or non-chemical measures of controlling the occurrence of diseases and pests. Whereas for compost option, GH_C was clearly lower than OF_C due to compost deficit in greenhouse. Non-commercial productions for greenhouse were clearly lower than percentages for open field.

Therefore the open field losses were considerably higher than greenhouse ones owing to the major protection of the inclemency of the weather and against plagues in the latter.

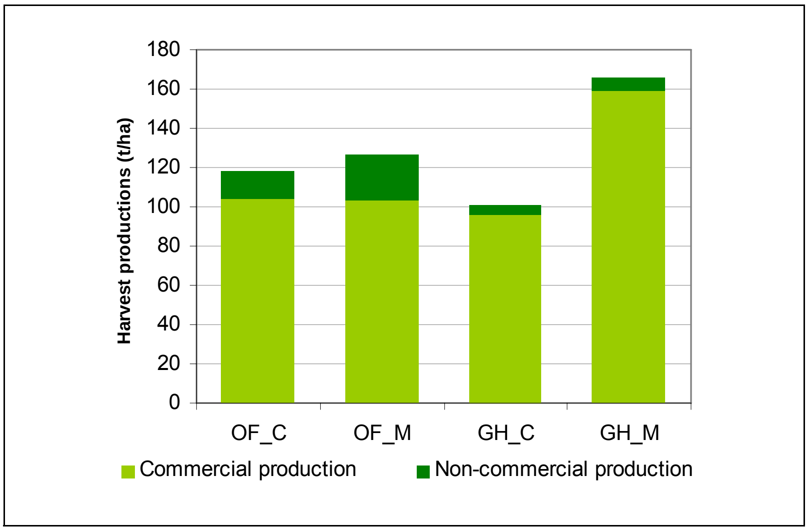


Figure 7. Four moments of the compost production at the Castelldefels composting facility (Castelldefels, Catalunya, Spain).

As Table 4 presented, for the two quality parameters analysed, namely the fruit average diameter and weight, no statistical differences were measured between open field fertilizing options. For greenhouse, these parameters were significantly smaller for C than M.

Although tomato varieties cultivated in open field and in greenhouse were different and therefore a carefully comparison can be done, not only harvest production but also quality parameters had a better performance in greenhouses than in open field apart from GH_C production.

The aforementioned results indicate that compost application as a fertilizer for tomato crops did not appear to have a negative affect on production or product quality in open field as a result of the lower nitrogen demand and the extra nitrogen contribution with water irrigation. It suggested that compost could be a suitable fertilizer in greenhouse with an additional dosage of nitrogen.

3.3.2. Environmental inventory

Table 5 presented the inventories of water, energy, pesticides and infrastructural materials consumed, amounts of waste generated and landfilled and transport required for open-field and greenhouse cultivation options. Such inventory included only the stages of mineral fertilizer transport, compost transport and crop stage, excluding mineral fertilizer and compost production stages due to the absence of an own inventory for mineral fertilizers production. Results were given per functional unit, i.e. ton of commercial tomato.

Table 5. Energy, transport and material inventories for the four cultivation options including the stages of fertilizer transport and the crop stage. Units per functional unit, i.e. ton of commercial tomato.

Input or output	Units	Open-field		Greenhouse	
		C	M	C	M
Water [e]	m^3/UF	64.89	64.09	49.49	39.13
Energy	MJ/UF	83.53	73.55	101.39	72.56
Pesticides	kg/UF	0.504	0.51	0.004	0.003
Infrastructural materials	kg/UF	8.97	9.09	60.87	36.94
Waste	kg/UF	8.79	8.93	14.55	8.84
Transport	tkm/UF	58.28	61.78	49.37	72.56

[a] It included rain and irrigation water.

[b] The infrastructural materials input includes the fertirrigation infrastructure, the tractor and other agricultural machinery, the crates and steel handcarts for the harvesting and the greenhouse structure and the machinery for its construction (for options in greenhouse).

In relation to water, only irrigation was considered. As was aforementioned the water applied per square meter to each option depended on the reading of the tensiometer. From the Table 2 no relevant differences were observed between total water supplied to OF_C, OF_M and GH_M, they were lower than 10 %. Regarding greenhouse, the water consumption per square meter for M is 30 % major than that for C (Table 2). This would appear to be consequence of the greater biomass production in option M that had a major demand (8) and of the improvement in the water holding capacity of the soil due to compost application, particularly in sandy soils (23). In Table 5 water consumption was referred to functional unit. For open field the water applied remained nearly equal between options and for greenhouse the high consumption per square meter for GH_M lost importance against the higher commercial tomato production. Moreover, greenhouse options had a more conservative use of water than open field options, between 0.1 (C) and 0.4 more (M), regarding production (Table 5) because evaporation and evapotranspiration were limited due to air circulation being considerably reduced in a closed environment (1) which is of primary importance in the regions with arid climate.

The direct energy consumed as electricity or fossil fuels was not very different, less than 15 %, among the cultivation options apart from GH_C, due to functional unit selected. The major energy consumers were the irrigation pumps and the tractor, both considered in all the options, and the opening of the greenhouse windows.

Considerably more pesticides were applied to options in open-field than in greenhouse ones, between 125 and 170 times more, owing to greenhouse is an isolated and closed unit and, according to Integrated Crop Management, a pest management program based on biological control and other practices that lead to the suppression of pests were suitable.

The element with most material requirements of the system was greenhouse structure, with cover film and structure transport as the major responsible, so options in GH needed between 28 and 52 kilos of materials more than OF per FU. The material requirements were particularly higher for option GH_C due to its smaller production of tomato. Nevertheless greenhouse protection allowed the managers to control the microclimatic conditions and use non-chemical practices that lead to the suppression of pests and diseases resulting in an important reduction of the pesticides and irrigation water necessities.

Waste generation was very similar between options with the exception of GH_C also as a consequence of FU differences.

Regarding transport OF_C and OF_M had nearly the same necessities. Comparing options in greenhouse, GH_M required a 47 % more transport than GH_C due to the large amounts of mineral fertilizers applied in the former. In addition for mineral fertilizer options, GH needed 17 % more transport than OF.

3.3.3. Environmental assessment by stages and sub-stages

Figure 8 contains the results broken down by stages and sub-stages, without taken into consideration the avoided burdens for C on depositing composted organic and green MSW in landfill.

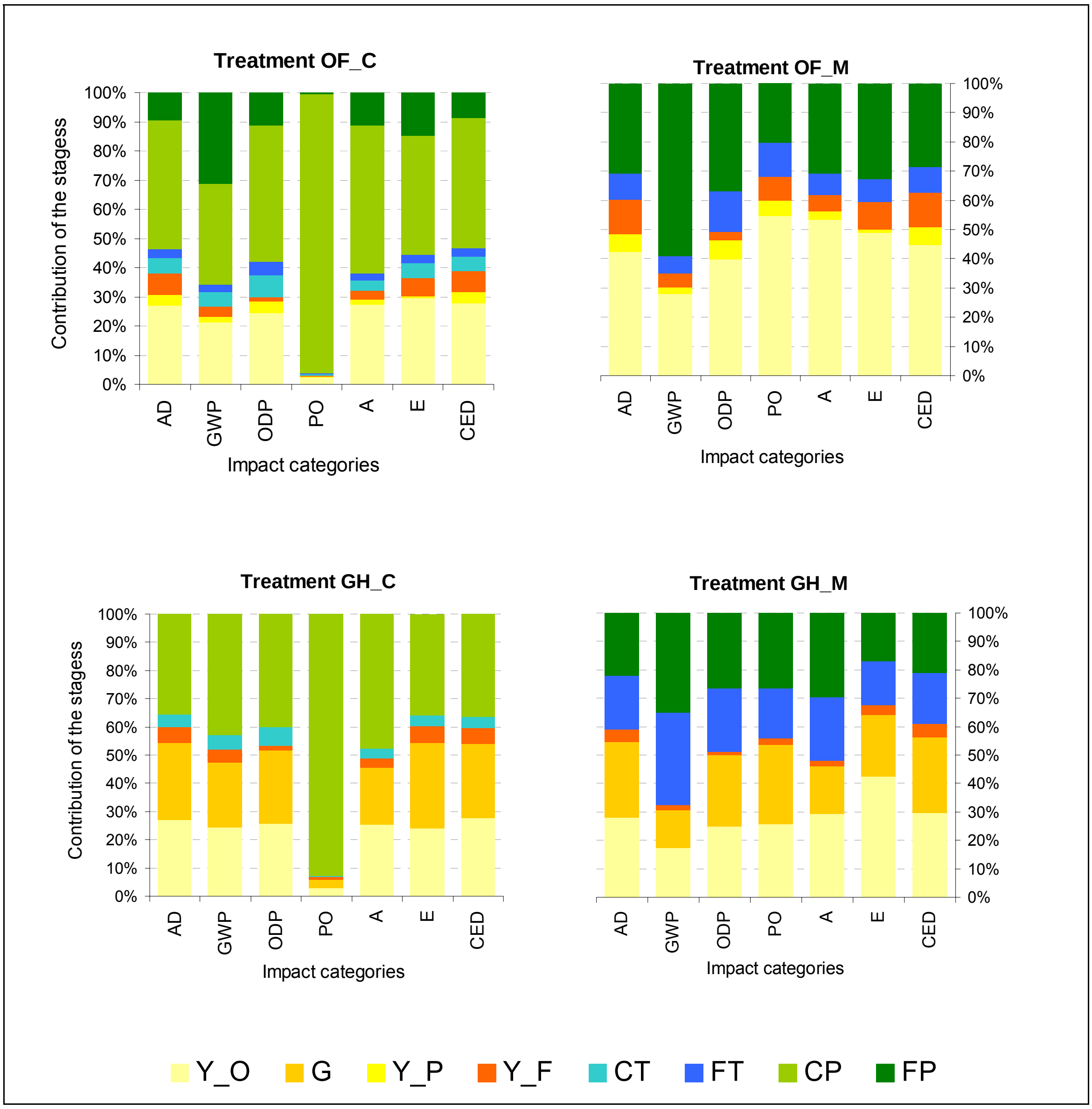
a) Cultivation options in open field

For OF_C the biggest impact responsibility was for the compost production stage (CP), which had 36-96 % of the total impact depending on the impact category considered. Such stage was followed by field operations sub-stage (Y_O), with an impact at least 21 % of the total for all categories except photochemical oxidation (PO). For PO the compost production stage was responsible for 96 % of the total impact due to the emission of volatile organic compounds.

Regarding option M in open field, the field operations sub-stage (Y_O) had the biggest burden achieving between 28 and 54 % of the total impact, except for global warming potential (GWP), although the absolute value for field operations impact was very similar to OF_C ones. Such stage was followed by fertilizer production (FP) that supposed between 20 and 59 % of the total impact, depending on the category.

b) Cultivation options in greenhouse

Compost production (CP) was also the most impacting stage for option C in greenhouse representing between 36 and 93 % of the total impact depending on the category. Such stage was followed by greenhouse structure (G) and field operations (Y_O), which represented arround 25 % (each one) of the total impact for all categories apart from PO.



Stages: FP, Mineral fertilizer production stage; CP, Compost production stage; FT, Transport of mineral fertilizer stage; CT, Transport of compost stage; Y, Crop stage; Y_F, Sub-stage of fertirrigation infrastructure; Y_P, Sub-stage of pesticides; Y_O, Sub-stage of crop management; G, Greenhouse structure stage.

Impact categories: AD, abiotic depletion; GWP, global warming potential; ODP, ozone layer depletion potential; PO, photochemical oxidation; A, acidification; E, eutrophication; CED, cumulative energy demand.

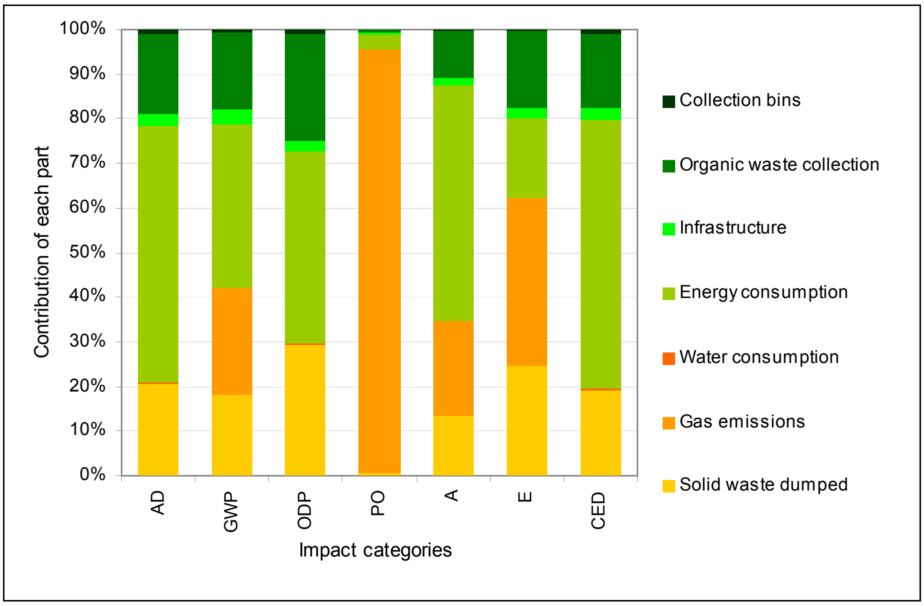
Figure 8. Contribution to total environmental impact of the stages of the system for the four cultivation options.

For GH_M there were two main responsible stages: field operations (Y_O), which represented 17-42 % of the total impact for M for all the categories; and greenhouse structure (G) with an impact at least 13 % of the total. Mineral fertilizer production (FP) represented between 17 and 35 % of the impact and its transport (FT) between 17 and 33 %.

As a consequence of the high difference between the amounts of pesticides needed, the pesticides sub-stages (Y_P) for greenhouse options were one hundred times smaller than open field ones. Even though, such stage did not have a relevant influence on the total impact for any of the locations.

c) Impacts of compost production stage

Figure 9 illustrates the contributions to the total impact of the composting production stage (CP). The energy consumption of the facility, and mainly the electricity, had the highest impact for abiotic depletion (AD), global warming potential (GWP), ozone layer depletion (ODP), acidification (A) and cumulative energy demand (CED), representing between 37-61% of the impact of CP stage for these categories. For the other categories, photochemical oxidation (PO) and eutrophication (E), the emission of volatile organic compounds and ammonium were the maximum contributors to the total impact of CP, respectively. Apart from the intensive energy consumption and the large emissions of the composting process, the compost nitrogen concentration was certainly lower than mineral fertilizers ones and therefore the amounts applied of such organic fertilizer were higher.

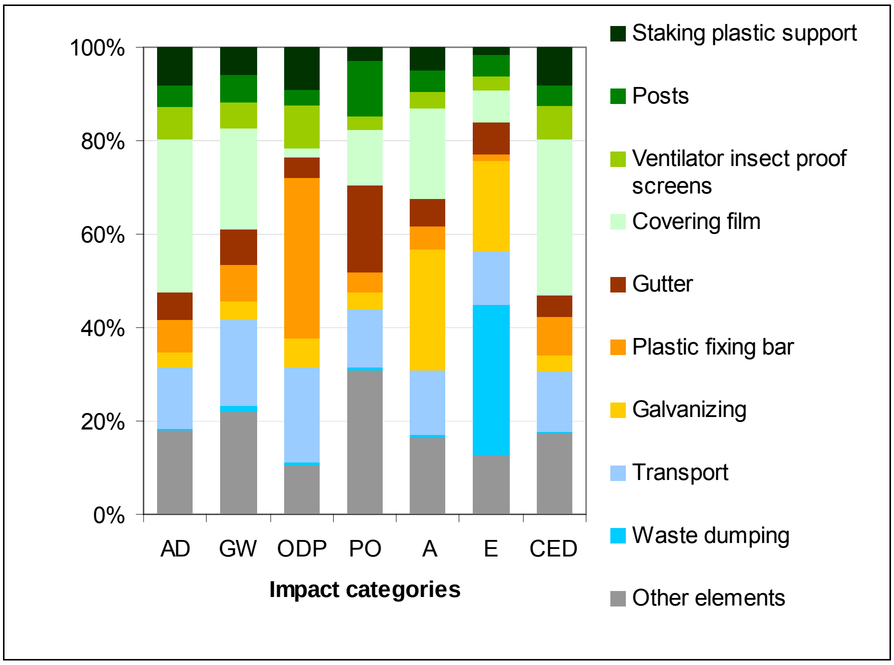


Impact categories: AD, abiotic depletion; GWP, global warming potential; ODP, ozone layer depletion potential; PO, photochemical oxidation; A, acidification; E, eutrophication; CED, cumulative energy demand.

Figure 9. Contribution to total environmental impact of the compost production stage (CP) for the items considered in.

d) Impacts of greenhouse structure stage

As can be seen from Figure 10 and according to Antón et al. (6) the cover film had the highest impact of the whole greenhouse structure (G) for AD, GWP and CED, mainly due to its relatively short lifespan, it contributed between 2-34 % depending on the impact category. Furthermore for ozone layer depletion (ODP), PO, A and E categories, the fixing rod, the gutter, the galvanizing and the waste dumping were the most impacting elements, respectively. Transport of all the elements from the production facility to the fields was also a relevant impacting element for all the categories.



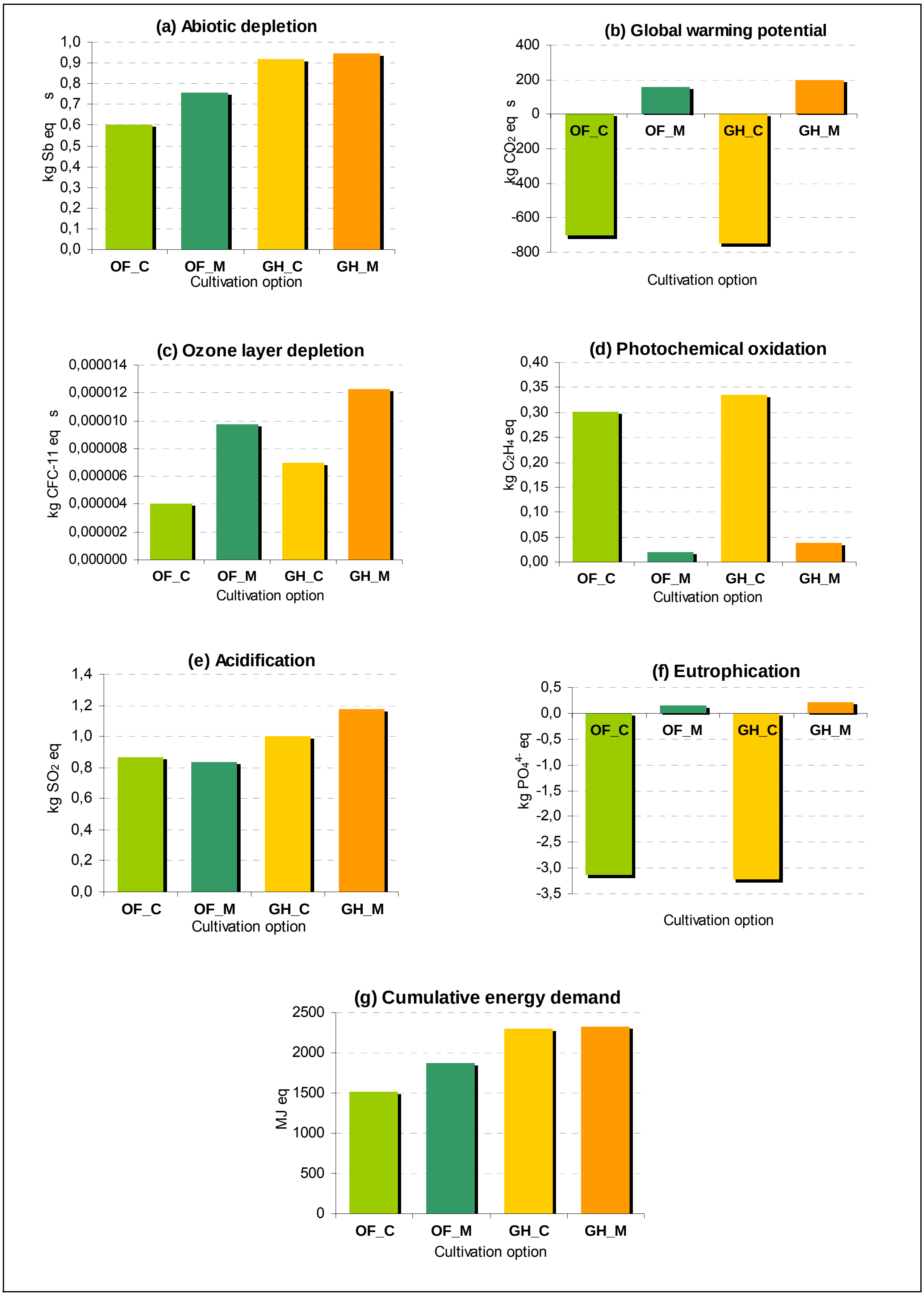
Impact categories: AD, abiotic depletion; GWP, global warming potential; ODP, ozone layer depletion potential; PO, photochemical oxidation; A, acidification; E, eutrophication; CED, cumulative energy demand.

Figure 10. Contribution to total environmental impact of the compost production stage (CP) for the items considered in.

3.3.4. Environmental assessment of the total impacts for each cultivation option

Figure 11 represents the total impacts associated to the four cultivation options considering and without considering the widening of the system borders. Such expansion dealt with the subtraction of the burdens avoided through composting by not dumping organic and green MSW. The total amounts of organic and green MSW were 1.28 and 1.33 tons of OFMSW used per ton of tomatoes produced for OF_C and GH_C, respectively.

For most of categories and without considering subtracted burdens, GH_C option was the most impacting ones and OF_M was the least. Such is due to the high impact of compost production and greenhouse structure stages.



Cultivation options: OF_C, cultivation with compost in open-field; OF_M, cultivation with mineral fertilizers in open-field; GH_C, cultivation with compost in greenhouse; GH_M, cultivation with mineral fertilizers in greenhouse.

Figure 11. Total impact assessment for the four cultivation options considered subtracting the avoided burdens.

a) Comparison of fertilizing options

Concerning the avoided burdens and for open field, compost option had less impact than M for the categories of AD, GWP, ODP, E and CED. For these categories, the burdens of landfill were higher than composting ones and it reversed the order of impact. For AD and CED, OF_M was around a quarter more impacting than OF_C and for ODP it contributes a 139 % more. Regarding GWP and E, OF_C was 5 and 21 times less impacting than M, respectively, and had negative impacts, which mean that such options saved impacts. For A, impacts were very similar between open field options, differences were below 4%; and for PO the option C was fourteen times more impacting than M as a consequence of VOC emissions in compost facility. Cultivation option OF_C saved the emission of 705 kg CO_2 eq/t tomatoes and involved the consumption of 1,511 MJ eq/t tomatoes.

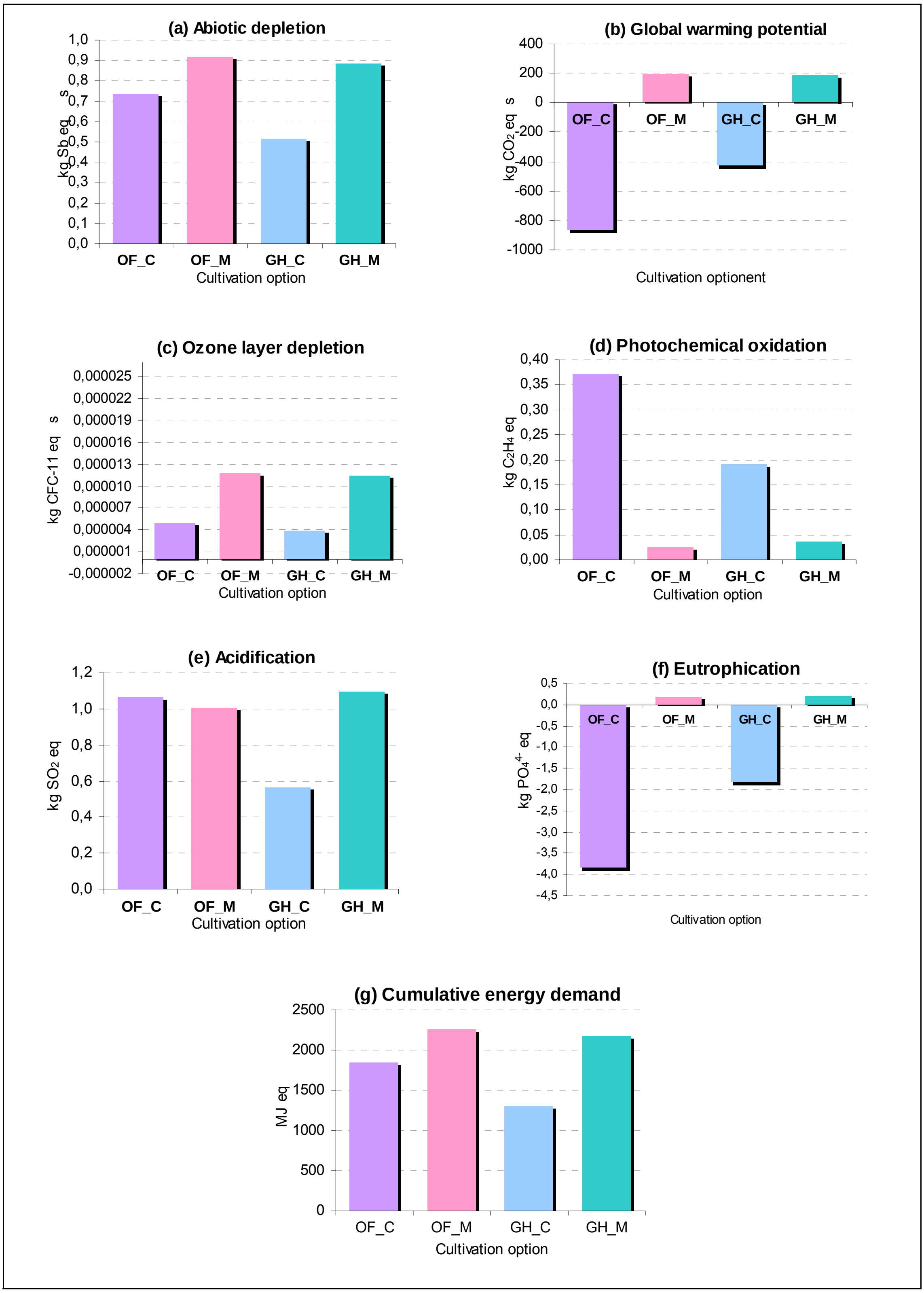
According to Figure 8 and considering the avoided burdens and for greenhouses, C had a smaller contribution than M for GWP, ODP, A and E. The GH_C option generated a 17 and 75 % more impact than GH_M for ODP and A, respectively. For the categories of GWP and E, OF_C had negative impacts and was 5 and 16 times less impacting than OF_M, respectively. Regarding AD and CED, the two options in greenhouse had nearly the same impacts. Only for PO, GH_M was the best option being 8 times smaller than GH_C, due to the high volatile organic compound emissions during composting process. Cultivation option GH_C saved the emission of 750 kg CO_2 eq/t tomatoes and involved the consumption of 2,298 MJ eq/t tomatoes.

b) Comparison of locations

Considering the avoided burdens, the comparison of results for greenhouse and open field revealed that the former was more impacting than the latter for both options (C and M) and most of the impact categories. Such order was reversed for option C in GWP and E categories, given that total amount of organic and green MSW considered was slightly bigger for GH than OF and therefore the avoided impacts was higher too. The location factor did not entail highest differences to 84 % between GH and OF. The biggest differences in the environmental performance among cultivation options were consequence of treatment variable.

c) Harvest production sensitivity assessment

The tomato productions obtained at open field were slightly higher than the values expected for Maresme region, whereas greenhouse production was quiet lower than the normal. According to previous studies on this area the normal production of tomatoes at open field was around 85 t/ha and that in greenhouses was between 150 and 200 t/ha (8, 45). Impact assessment were recalculated with productions of 85 and 170 t/ha, respectively. For the new distribution of impacts and regarding C options, OF_C was more harmful than GH_C from an environmental point of view for vast majority of the categories (Figure 9), apart from GWP and E. The OF_M and GH_M options had similar impacts for all categories except PO.



Cultivation options: OF_C, cultivation with compost in open-field; OF_M, cultivation with mineral fertilizers in open-field; GH_C, cultivation with compost in greenhouse; GH_M, cultivation with mineral fertilizers in greenhouse.

Figure 12. Total impact assessment of the four cultivation options considering that functional unit was 85 t tomatoes per ha in open fields and 170 t/ha in greenhouse. Avoided burdens were considered.

Greenhouse structure must be associated with relevantly large productions to justify the relevant expenses in energy and resources. Therefore compost used alone was not the better option in greenhouses as harvests were significantly lower.

Since Mediterranean greenhouses were light structures of protection, they could be the better environmental option if high productions were obtained. Even though new impact categories specific for this region, as water use and erosion rate, and functional units different from tomato production, as quality parameters, must be more extensively developed.

3.4. Conclusions and future perspectives

The harvest obtained for greenhouse using mineral fertilizers was 35 % higher than M_OF on account of the benefits of protected horticulture as the control of climatic conditions and the possibility to apply measures of controlling the occurrence of diseases and pests among others. Whereas production for C_GH was 8 % lower than C_OF due to the high nitrogen demand of tomato plants in early stages of greenhouse cultivation that could not be covered with only compost. Future studies with data for long periods applying compost in greenhouses could refute such negative result thanks to the slow nutrients release and the improvement of the rest of soil characteristics of compost. The open field losses, measured as the non-commercial production, were considerably higher than greenhouse ones owing to the major protection of the inclemency of the weather and against plagues in the latter.

The results indicate that compost application as a fertilizer for tomato crops did not appear to have a negative affect on production or product quality in open field as a result of the lower nitrogen demand and the extra nitrogen contribution with water irrigation. It suggested that compost could be a suitable fertilizer in greenhouse with an additional dosage of nitrogen.

The infrastructural material requirements in greenhouse options were between 3 and 6 times those of open field due to the high investment in the steel frame and the plastic over among other structural elements. However such protection allowed the managers to control the microclimatic conditions and use non-chemical practices that lead to the suppression of pests and diseases. Such were resulted in an important reduction of the pesticides and irrigation water necessities.

Among the stages considered for the cultivation options with compost (OF_C and GH_C), compost production was the major contributor – representing more than 30 % of the total impact for all the categories, and achieving the ninety for photochemical oxidation due to volatile organic compound emissions. Such stage was followed by field operations sub-stage and, for GH_C, greenhouse structure stage.

Regarding mineral fertilizer options (OF_M and GH_M), field operations sub-stage and fertilizer production were the major contributors – accounting around 18-54 % and 17-59 % of the impact, respectively –, and were followed by greenhouse structure stage for GH_M.

The high impacts of compost production stage were consequence of the intensive energy consumption, the large emissions and the big amounts of such organic fertilizer needed.

The considerable impacts of the greenhouse structure stage were mainly caused by the cover film made of LDPE, mainly due to its relatively short lifespan, the fixing rod, the gutter, the galvanizing, the waste dumping and the transport.

For most of categories and without considering subtracted burdens, GH_C option was the most impacting ones and OF_M was the least. Such is due to the high impact of compost production and greenhouse structure stages.

Considering the subtraction of the burdens avoided through composting by not dumping organic and green MSW, compost options were less harmful than M ones for most of impact categories apart from photochemical oxidation.

Considering the avoided burdens, the comparison of results for greenhouse and open field revealed that the former was more impacting than the latter for both options (C and M) and most of the impact categories. The location factor did not entail highest differences to 84 % between GH and OF. The biggest differences in the environmental performance among cultivation options were consequence of treatment variable.

Greenhouse structure must be associated with relevantly large productions to justify the bigger expenses in energy and resources. Therefore compost used alone was not the better option in greenhouses as harvests were significantly lower.

Since Mediterranean greenhouses were light structures of protection, they could be the better environmental option if high productions were obtained. Even though new impact categories specific for this region, as water use and erosion rate, and functional units different from tomato production, as quality parameters, must be more extensively developed.

4. BIBLIOGRAPHY

(1) Diaz Alvarez, J. R., Modeling of greenhouse structure and characteristics for an ideal economic structure for growing vegetables, flowers or fruit crops. In Protected cultivation in the Mediterranean region = Cultures protégées dans la région méditerranéenne (Cahiers Options Méditerranéennes ; v. 31). Colloque sur les Cultures Protégées dans la Région Méditerranéenne, Morocco 1996, Choukr-Allah, R., Ed. Paris : CIHEAM ; Agadir : Institut Agronomique et Vétérinaire Hassan II, 1999.

(2) Papasolomontos, A., Integrated production and protection in the Mediterranean region under protected cultivation. In Protected cultivation in the Mediterranean region = Cultures protégées dans la région méditerranéenne (Cahiers Options Méditerranéennes ; v. 31). Colloque sur les Cultures Protégées dans la Région Méditerranéenne, Morocco 1996, Choukr-Allah, R., Ed. Paris : CIHEAM ; Agadir : Institut Agronomique et Vétérinaire Hassan II, 1999.

(3) Grafiadellis, M., The greenhouse structures in Mediterranean regions - problems and trends. In Protected cultivation in the Mediterranean region = Cultures protégées dans la région méditerranéenne (Cahiers Options Méditerranéennes ; v. 31). Colloque sur les Cultures Protégées dans la Région Méditerranéenne, Morocco 1996, Choukr-Allah, R., Ed. Paris : CIHEAM ; Agadir : Institut Agronomique et Vétérinaire Hassan II, 1999.

(4) MMAMRM Anuario de estadística agroalimentaria y pesquera 2007; Ministerio de Medio Ambiente y Medio Rural y Marino: Madrid, 2008.

(5) Montero, J. I.; Antón, A. In Greenhouse Characteristics and Microclimatic Conditions, VI International Symposium on Protected Cultivation in Mild Winter Climate: Product and Process Innovation, Italy, 2003; ISHS Acta Horticulturae, Ed. 2003.

(6) Antón, A.; Montero, J. I.; Muñoz, P.; Castells, F., LCA and tomato production in Mediterranean greenhouses. Int. J. Agricultural Resources Governance and Ecology 2005, 4, (2), 102-112.

(7) Bradley, D.; Christodoulou, M.; Caspari, C.; Di Luca, P. Integrated crop management systems in the EU; European Commission DG Environment. Agra CEAS Consulting: 2002.

(8) Muñoz, P.; Antón, A.; Paranjpe, A.; Ariño, J.; Montero, J., High decrease in nitrate leaching by lower N input without reducing greenhouse tomato yield Agronomy for Sustainable Development 2008, 28, (4), 489.

(9) Martínez-Blanco, J.; Muñoz, P.; Antón, A.; Rieradevall, A., Life cycle assessment of the use of compost from municipal organic waste for fertilization of tomato crops. Resources, Conservation and Recycling 2009. In press, 53, (6), 340-351.

(10) European Commission, Green paper on the management of bio-waste in the European Union. In Official Journal of the European Communities: 2008.

(11) MP, Real Decreto 824/2005 sobre productos fertilizantes (in Spanish). In Ministerio de la Presidencia. Boletín Oficial del Estado Español: 2005.

(12) Jolliet, O., Bilan écologique de la production de tomates en serre. Revue S. Vitic. Arboric. Hortic 1993, 25, (4), 261-267.

(13) Nienhuis, J. K.; Vreede, P. J. A. d. In Utility of the environmental life cycle assessment method in horticulture, Proceedings of the XIIIth International Symposium on Horticultural Economics, New Brunswick, New Jersey, USA, 1996; 1996; pp 531-538.

(14) Van Woerden, S. In The application of Life Cycle Analysis in glasshouse horticulture, Proc. International Conference LCA in Foods, Gothenburg, 2001; 2001; pp 136-140.

(15) Antón, A., Utilización del análisis del ciclo de vida en la evaluación del impacto ambiental del cultivo bajo invernadero mediterráneo. Thesis. Barcelona, 2004; p 235.

(16) Guerini, G.; Maffeis, P.; Allievi, L.; Gigliotti, C., Integrated waste management in a zone of northern Italy: compost production and use, and analytical control of compost, soil, and crop. Journal of Environmental Science and Health Part B-Pesticides Food Contaminants and Agricultural Wastes 2006, 41, (7), 1203-1219.

(17) Sharma, G.; Campbell, A. Life cycle inventory and life cycle assessment for windrow composting systems; Department of Environment and Conservation (University of New South Wales). Recycled Organics Unit: Sydney, pp. 16, 2003.

(18) Lundie, S.; Peters, G. M., Life cycle assessment of food waste management options. Journal of Cleaner Production 2005, 13, (3), 275-286.

(19) Sonesson, U.; Björklund, A.; Carlsson, M.; Dalemo, M., Environmental and economic analysis of management systems for biodegradable waste. Resources, Conservation and Recycling 2000, 28, (1-2), 29-53.

(20) Amlinger, F.; Peyr, S.; Cuhls, C., Green house gas emissions from composting and mechanical biological treatment. Waste Management & Research 2008, 26, (1), 47-60.

(21) Dimambro, M. E.; Lillywhite, R. D.; Rahn, C. R., The physical, chemical and microbial characteristics of biodegradable municipal waste derived composts. Compost Science & Utilization 2007, 15, (4), 243-252.

(22) Elherradi, E.; Soudi, B.; Chiang, C.; Elkacemi, K., Evaluation of nitrogen fertilizing value of composted household solid waste under greenhouse conditions. Agronomy for Sustainable Development 2005, 25, (2), 169-175.

(23) Hargreaves, J. C.; Adl, M. S.; Warman, P. R., A review of the use of composted municipal solid waste in agriculture. Agriculture Ecosystems & Environment 2008, 123, (1-3), 1-14.

(24) Blengini, G. A., Using LCA to evaluate impacts and resources conservation potential of composting: A case study of the Asti District in Italy. Resources, Conservation and Recycling 2008, 52, (12), 1373-1381.

(25) Hansen, T. L.; Christensen, T. H.; Schmidt, S., Environmental modelling of use of treated organic waste on agricultural land: a comparison of existing models for life cycle assessment of waste systems. Waste Management & Research 2006, 24, (2), 141-152.

(26) International Organisation for Standardisation, ISO 14040. Environmental Management, Life Cycle Assessment-Principles and framework. In 2006.

(27) European Economic Community, Directive 91/676/ECC, of 12 December 1991concerning the protection of waters against pollution caused by nitrates from agricultural sources. In Official Journal of the European Communities: 1991.

(28) Colon, J.; Artola, A.; Font, X.; Sánchez, A., Emissions de gasos contaminants en un procés de compostatge industrial: eficàcia de biofiltració i influència del canvi de material biofiltrant (in Catalan). In Universidad Autónoma de Barcelona (UAB): 2008.

(29) Muñoz, P.; Antón, A.; López, M.; Huerta, O.; Núñez, M.; Rieradevall, J.; Ariño, J., Aplicación de compost de fracción orgánica de residuos sólidos municipales en la fertilización de cultivos hortícolas en la comarca del Maresme (in Spanish). In Subvenciones de I+D+i en el ámbito de la prevención de la contaminación. Balance 2004-2007, DGCEA, Ed. Ministerio de Medio Ambiente: pp. 45-51, 2008.

(30) MAPA, Real Decreto 1201/2002, de 20 de noviembre, por el que se regula la producción integrada de productos agrícolas (in Spanish). In Ministerio español de Agricultura Pesca y Alimentación. Boletín Oficial del Estado: 2002.

(31) Martínez-Blanco, J.; Muñoz, P.; Antón, A.; Rieradevall, A., Life cycle assessment of the use of compost from municipal organic waste for fertilization of tomato crops. Resources, Conservation and Recycling 2009. In press.

(32) SCLCI Ecoinvent Data v1.2., Dübendorf, 2005.

(33) Ekvall, T.; Tillman, A., Open-Loop Recycling, Criteria for allocation procedures. Int J LCA 1997, 2 (3), (3), 155-162.

(34) Finnveden, G., Methodological aspects of life cycle assessment of integrated solid waste management systems. Resources, Conservation and Recycling 1999, 26, (3-4), 173-187.

(35) Ekvall, T.; Weidema, B. P., System boundaries and input data in consequential life cycle inventory analysis. International Journal of Life Cycle Assessment 2004, 9, (3), 161-171.

(36) The Council of the European Union, Directive 1999/31/EC, of 26 April 1999 on the landfill of waste. In Official Journal of the European Communities: 1999.

(37) PRé Consultants SimaPro software versión 7.1, The Netherlands, 2006.

(38) Guinée, J. B. Life cycle assessment: An operational guide to the ISO standars. Part 1 and 2; Ministry of Housing. Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML): The Netherlands, 2001.

(39) SAS institute Inc. SAS Enterprise Guide, Cary, North Carolina, USA, 2006.

(40) Nemecek, T.; Heil, A.; Huguenin, O.; Meier, S.; Erzinger, S.; Blaser, S.; Dux, D.; Zimmermann, A. Life Cycle Inventories of Agricultural Production Systems. Final report, ecoinvent 2000 No. 15.; Agroscope FAL Reckenholz and FAT Taenikon, Swiss Centre for Life Cycle Inventories: Dübendorf, pp. 289, 2004.

(41) MMAMRM Registro de Productos Fitosanitarios (in Spanish). www.mma.es/portal/secciones

(42) Audsley, E. Harmonisation of environmental life cycle assessment for agriculture. Final Report Concerted Action AIR 3-CT94-2028; European Commission DG VI Agriculture: UK, pp. 101, 1997; p 101.

(43) Finnveden, G.; Bjorklund, A.; Moberg, A.; Ekvall, T.; Moberg, A., Environmental and economic assessment methods for waste management decision-support: possibilities and limitations. Waste Management & Research 2007, 25, (3), 263-269.

(44) Doka, G. Life Cycle Inventories of Waste Treatment Services. Ecoinvent report No. 13; Swiss Centre for Life Cycle Inventories: Dübendorf, pp. 444, December, 2003, 2003.

(45) Muñoz, P.; Antón, A.; Nuñez, M.; Vijay, A.; Ariño, J.; Castells, X.; Montero, J.; Rieradevall, J., Comparing the environmental impacts of greenhouse versus open-field tomato production in the Mediterranean region. Acta Horticulturae 2007, 801, 1591-1596.

(46) Muñoz, P.; Ariño, J.; Montero, J. I.; Antón, A. In Cascade crops: A method proposed for increasing sustainability in El Maresme, International Conference by Innovation by Life Cycle Management LCM2005, Barcelona, 2005; Castells, F.; Rieradevall, J., Eds. 2005.

MEMÒRIA JUSTIFICATIVA DE RECERCA DE LES BEQUES PREDOCOTRALS PER A LA FORMACIÓ DE PERSONAL INVESTIGADOR (FI)

Estudi dels impactes ambientals del cicle de vida del compost, de la producció a l'aplicació.

ANNEXES

Gener-Juliol 2009. Investigadora beneficiària: Julia Martínez Blanco. Tutor: Joan Rieradevall i Pons.

Institut de Ciència i Tecnologia Ambientals. Universitat Autònoma de Barcelona

APPENDIX

1. Joan Colón, Julia Martínez-Blanco, Xavier Gabarrell, Adriana Artola, Antoni Sánchez, Joan Rieradevall and Xavier Font. “Environmental assessment of home composting”. Resources, Conservation & Recycling (Accepted with major revisions, June 2009)

2. CILCA International Conference of LCA in Latin America, April 2009, Pucón (Xile). “Emissions and environmental assessment of the home composting of two domestic organic wastes”.

3. Joan Colón, Júlia Martínez-Blanco, Xavier Gabarrell, Joan Rieradevall, Xavier Font, Adriana Artola and Antoni Sánchez. Performance of an industrial biofilter from a composting plant in the removal of ammonia and VOCs after medium replacement. Journal of Chemical Technology &Biotechnology, DOI: 10.1002/jctb.2139 (2009).