Environmental impact of strawberry production in Italy and Switzerland with different cultivation practices

Daniele Valiante[1], Ilaria Sirtori[1], Stefano Cossa[1], Luca Corengia[1], Martina Pedretti[1], Luca Cavallaro[1], Lorenzo Vignoli[1], Andrea Galvagni[1], Stefano Gomarasca[1], Gaetano Roberto Pesce[4], Alessandro Boccardelli[1], Luigi Orsi[2], Daniela Lovarelli[3], Davide Facchinettii[3], Domenico Pessina[3], Jacopo Bacenetti[2*]

[1] Faculty of Agricultural and Food Science. Università degli Studi di Milano, via Celoria 2, 20133, Milan, Italy.

[2] Department of Environmental and Policy Science. Università degli Studi di Milano, via Celoria 2, 20133, Milan, Italy.

[3] Department of Agricultural and Environmental Science. Università degli Studi di Milano, via Celoria 2, 20133, Milan, Italy.

[4] Department of Agricultural, Food and Environment, Università degli Studi di Catania, Via Valdisavoia 5, I-95123 Catania, Italy.

* jacopo.bacenetti@unimi.it;

Abstract

In this study, the environmental impact of strawberry production in Italy and Switzerland was evaluated using the Life Cycle Assessment (LCA) approach. The main differences between the two countries are the cultivation practices: crop cycle duration (1 year in Switzerland and 2 or 3 years in Italy), soil management and cultivation in open and protected fields.

For all the environmental impact categories evaluated with LCA, strawberry production in Switzerland shows higher impacts respect to the Italian production. The impact reduction related to the Italian production in open fields without soil sterilisation ranges from 96% (for photochemical oxidant formation) to 35% (for freshwater eutrophication). For Swiss production, soil sterilisation is by far the main environmental hotspot for all the evaluated environmental effects except for toxicity-related impact categories and for resources consumption (i.e. manufacturing, maintenance and disposal of tunnel). Conversely, the main hotspot in Italy differs depending on the considered categories. Moreover, the 3-years cycle duration has a higher impact respect to the 2-years one because of the low yield in the third year that worsens the outcomes.

Finally, sensitivity and uncertainty analysis were performed. The environmental results are deeply affected by yield variation and only slightly by changes in the life span of the tunnels while the uncertainty related to the selection of the data source, the model imprecision, and the variability of data does not affect significantly the results, except for the toxicity-related impact categories.

Keywords

Environmental assessment, open field, protected field, strawberry, soil sterilisation

1. Introduction

Agriculture and climate change are closely linked (FAO, 2016; Lijó et al., 2017). Often, the environmental impact of agricultural activities depends on the cultivation practices adopted by farmers. For many years, these practices focused only on the maximisation of profits, but in recent years their effect on the environment is gaining importance and cultivation practices are becoming a strategic asset for farmers and agri-food firms (FAO, 2016).

Moreover, the consumers' behaviour is more and more influenced by environmental aspects of food through the entire life cycle from production to disposal (European Commission, 2014). In fact, consumers play nowadays an important role with their choices during the whole purchase process, since they may reward or penalise a product (or a firm) based on sustainability and ethics in business (Grunert, 2011).

The conditions for an "aware" purchase depend on the information provided by food labels (Erskine and Collins, 1997). In fact, labelling is a fundamental tool to communicate the characteristics of products to consumers, including their sustainability (Banterle et al., 2013). However, the amount of information that can be placed on the label is limited and this impacts negatively on the effectiveness of the social and environmental communication (Wansink et al., 2004; Banterle et al., 2013).

The environmental approach is becoming a relevant strategic asset for a sustainable management of an ample class of food products, because this type of approach requires a thorough understanding of complex issues relating to sustainability such as the development of proper indicators and metrics for each product, the ability to anticipate future trends, an in-depth knowledge of the food supply chain and the purchase responses of consumers.

Along time, different methods have been proposed to assess the environmental performances of agricultural activities. Among these, the Life Cycle Assessment (LCA) approach is one of the most widely used. It is a standardised method designed for assessing, with a holistic approach, the environmental impacts by considering all resources, inputs and outputs associated to a product or a service throughout the entire life cycle. Although ecosystem services, biodiversity and soil fertility (Pavan et al., 2018; Jeswani et al., 2018) are not yet fully considered, applying LCA, the potential environmental impacts of products (processes or services) can be evaluated (ISO 14040-14044, 2006).

Taking into account the fruit and vegetable market, an important market niche is attributable to the cultivation and marketing of small fruits. Of them, strawberry is certainly the leading product. During the last 20 years, the production of strawberries cultivated globally has grown 2.4 times (FAOSTAT, 2015). In China and USA, that are currently the biggest world producers, open field cultivation prevails (Herrick, 2012; The Protected Agriculture Project, 2009). Strawberry production in Europe represents only a small portion of the global production, but both open field and protected cropping methods are used. Strawberries are also suitable for conventional and organic cultivation (Kahu et al., 2010).

Some studies (Gunady et al., 2012; Stoessel et al., 2012; Khoshnevisan et al., 2013) evaluated the environmental impact of strawberries showing contradictory conclusions on their impact, but this depending on the cultivation practice, the crop cycle duration and the cultivation in open or protected fields. Up to now, the environmental impact of strawberry production is rarely thoroughly analysed and information about the impact of different crop cycle durations as well as different cultivation practices is missing.

This study aims to assess the environmental impact of strawberry production in different European countries considering different cultivation practices. More in details, strawberry production is studied in Italy in open field with a crop cycle of 2 and 3 years and in Switzerland in tunnels with an annual crop cycle. Using the LCA approach the environmental impact of the different strawberry cultivation practices was quantified and the main environmental hotspots were identified.

2. Material and Methods

This study is performed in accordance with ISO Standards (ISO 14040-14044 series) for LCA, hence next sections follow the standardised approach. More in details, goal and scope (section 2.1), functional unit (section 2.2), system description (section 2.3), system boundary (section 2.4), life cycle inventory (section 2.5), and life cycle impact assessment (section 2.6) are explained.

2.1 Goal and Scope

The goal of this study is to assess the environmental impact of integrated strawberry production in Northern Italy (Lombardy region) and in Southern Switzerland (Canton Ticino) considering different cultivation practices. Information about the integrated cultivation practice was collected during surveys at two farms, one located in Italy and one in Switzerland. In these areas, strawberry represents a high-income crop and its cultivation is performed in open fields or tunnels and can have different crop duration cycles. In both the countries, integrated strawberry production is by far the most applied (Blando et al., 2010; Girgenti et al., 2015).

The geographical scope was central and southern Europe while the temporal scope was 2017.

In Switzerland, from 1961 to 2016, strawberry production has increased from about 2,500 tons to 8,800 tons. The cultivated area has fallen from the early 60s to the early 70s from 900 ha to 270 ha, followed by a slow and steady growth until the current 500 ha. In the same period, the average yield per hectare increased from about 2.8 tonnes/ha to around 18.4 tonnes/ha (FAOSTAT, 2015).

In Italy, in the same years, strawberry production increased from about 46,320 tons to 131,430 tons. The cultivated area has grown from the early 60s to the end of the 70s from 7230 ha to 15000 ha, and then decreased until reaching the minimum of 2600 ha in 2011. Nowadays, the area dedicated to strawberry is around 5000 ha. The average yield raised from about 6.4 tonnes/ha to about 26.5 tonnes/ha (FAOSTAT, 2015).

The four main specific goals of this study are:

- To quantify the environmental impact related of 1 kg of strawberry in two different European countries (Italy and Switzerland);
- To identify the processes mainly responsible for the environmental impact (namely the environmental hotspots);

- To discuss the relation between the environmental impact and the different cultivation practices in term of crop cycle duration and indoor or open field cultivation;
- To compare the results with those of studies previously carried out.

2.2 Functional Unit

In accordance with ISO 14040 (ISO 14040, 2006) and with previous performed LCA studies focused on fruit production (i Canalis et al., 2006; De Menna, 2013; Nikkhah et al., 2017), 1 kg of fresh strawberry was chosen as functional unit (FU).

2.3 System Description

In both of the considered farms, strawberry is cultivated according to the guidelines for integrated agriculture (Schweizer Obstverband, 2013; Regione Lombardia, 2018). Nevertheless, the cultivation practice in the two Countries differs in the crop cycle durations and in the cultivation in open or protected fields.

2.3.1 Cultivation in Italy

For Italy, the selected farm is located in Cassina de' Pecchi (45.513094 N, 9.393304 E, average yearly temperature 12.8°C, average yearly rainfall 981 mm), Milan district, Northern Italy. On this farm, strawberry is cultivated with 2-years or 3-years crop cycle in open fields for a total area of 3.5 ha.

The cultivation technique can be summarised as follows:

- In the first year, few days before ploughing, mature cow manure is spread on field using a manure spreader. After ploughing with a 3-furrow plough at 30 cm depth, secondary tillage is carried out with a rotary harrow at 10 cm depth, followed by hoeing and bedforming. During this latter, a plastic film is placed on the soil, while an irrigation drip system is buried below the soil surface (10 cm depth). Transplanting of strawberry seedlings is carried out by hand;
- During the second and third year, besides the harvesting (made by hands, from 10 to 15 times), the following operations are performed:

- Weed and pest control, carried out using a sprayer coupled with a tractor,
- Mechanical weed control and plant spacing (by hands) during the winter season (mainly to control the plants spacing long the row),
- Mulching, carried out manually by spreading wheat straw between the rows.

Irrigation and fertirrigation are performed several times during the growing season using the drip irrigation system. The fertilizer amount applied depends on climatic conditions and crop productivity.

Between the two crop durations of 2 and 3 years, the cultivation practice is the same for the first two years. The difference is limited only to the third year for the longer crop cycle.

2.3.2 Cultivation in Switzerland

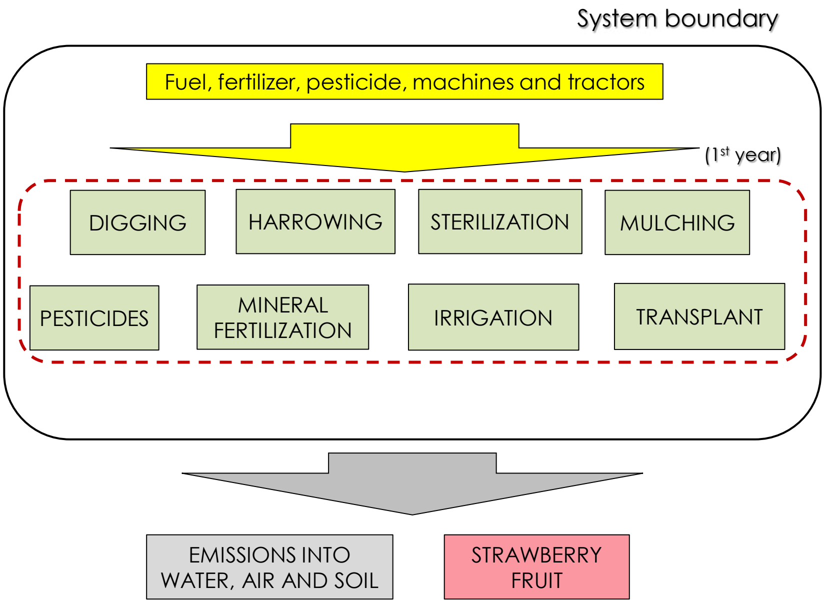
The selected farm is located in Coldrerio (45.853105 N, 8.998087 E, average yearly temperature 11.2°C, average yearly rainfall 1302 mm), Mendrisio district, Ticino Canton. In this farm, strawberry is cultivated with 1-year crop cycle in tunnels for a total area of 0.41 ha.

Soil tillage is performed using a subsoiler at 25 cm depth and a rotary harrow working at 15 cm depth. Afterwards, soil sterilisation takes place with a steam machine coupled with a tractor. Steam is an effective non-fumigant way for soil disinfestation. In particular, this soil sterilisation permits to control effectively nematodes, soil pathogens and, depending on the raised temperature, also weed propagules. Thanks to soil sterilisation, strawberry can be cultivated in the same tunnels for several years. However, steam application is very slow and energy intensive. The machine, towed by the tractor, is constituted by a frame over which is installed a generator fuelled by diesel and a fuel tank. The produced heat is used to generate steam that is kept on the soil surface using a plastic film previously located in the tunnel. After sterilisation, the drip irrigation system is placed into the soil, while a plastic film is placed on the soil surface. Once these operations are carried out, the seedlings are planted manually.

Crop management involves several treatments against pests (5 per year) and diseases (5 per year) that are carried out by operators equipped with a portable sprayer. Fertilisation is performed using ammonium nitrate, superphosphate and potassium sulphate. Finally, strawberries are harvested manually.

2.4 System boundary definition

In this study, a "*cradle-to-farm gate*" approach was applied. Consequently, the life cycle of each agricultural process was included within the system boundary. More in details, the following activities were considered: raw materials extraction (e.g., fossil fuels, metals, minerals, nutrients), manufacture of the agricultural production factors (e.g., diesel, fertilisers, pesticides, plastic films, and agricultural machines), use of the agricultural inputs (fertilisers emissions, diesel fuel emissions, and tire abrasion emissions), maintenance and final disposal of tractors, operative machines and infrastructure (e.g., tunnel). **Figure 1** shows the system boundary for strawberry production in Italy and in Switzerland.



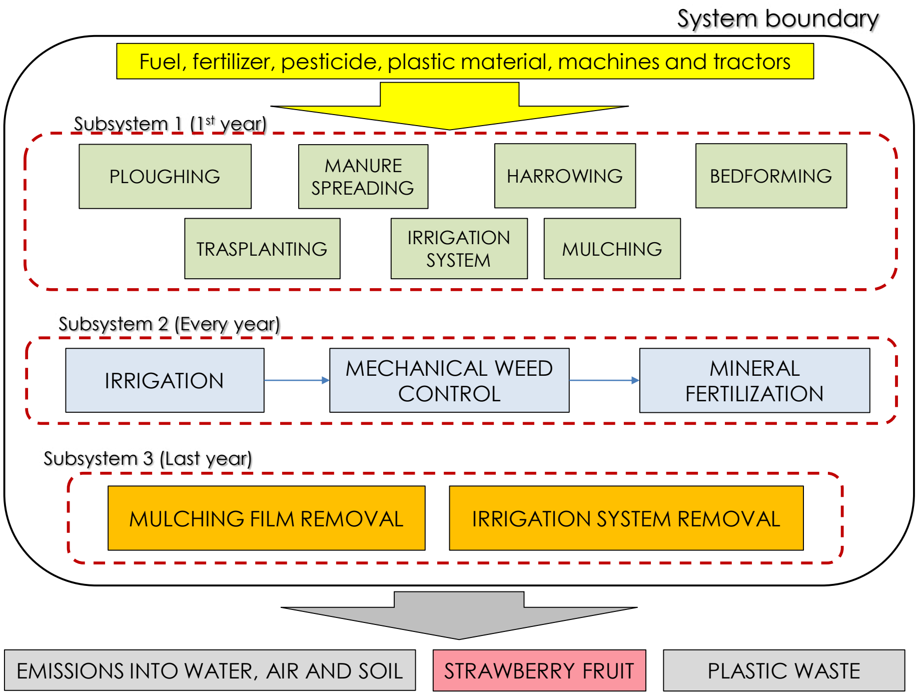


Figure 1 – System boundary for strawberry production. On the top for Switzerland, on the bottom for Italy.

The following emission sources were considered: emissions of N and P compounds related to ammonia volatilisation, denitrification, nitrogen leaching and phosphate run-off, emissions from pesticides application and emissions related to fuel combustion.

According to the PCR for "arable crops" (Environdec, 2014) and to previously carried out studies on agricultural systems (Nikkhah et al., 2017; Lovarelli et al., 2018), no change in the soil organic carbon content was considered (Pavan et al., 2018).

2.5 Inventory data collection

Primary inventory data regarding the crop cultivation in Italy and Switzerland were collected during surveys at the farms and with questionnaires to the farmers. More in details, the following information was retrieved:

- Sequence of the field operations, timing and number of repetitions over the crop cycle;

- For each operation, the size, mass, length and width, engine power needed for carrying out the operation, age, annual average working time and life span of the operative machines and the engine power, mass, stage for exhaust gases emissions to which the engine belongs, age, annual working time and life span of the tractors;
- production factors consumed (e.g., fuels, pesticides, fertilisers, plastic film).

The "virtual" consumption of tractors and agricultural implements during the field operations was calculated considering the total working time of the operation and the annual working time (hours worked/year), the physical (hours) and the economic life span (years). Physical life span (h) was considered equal to 12000 h for tractors, 2000 h for plough, harrow and other machines for soil tillage and 3000 h for fertilisers and pesticide spreaders. Concerning the economic life span (years), 12 years were taken into account for tractors, farm trailers, plough and harrow, and 8 years for fertiliser spreader, sprayer and other equipment (Bodria et al., 2006; Lovarelli and Bacenetti, 2017). In more details, this calculation was performed to quantify the mass of machinery consumed during every operation of the crop cycle. It is named "virtual" mainly because it is not effectively "consumed/depleted" during every single operation but is split over the life span of the machinery. **Tables 1** and **2** report the main inventory data for strawberry cultivation in Italy and in Switzerland.

Table 1 and **2** around here

Background data about the production of seedlings, diesel fuel, fertilisers, pesticides, plastic film, tunnel, pipes, tractors and agricultural machines was retrieved from the Ecoinvent database Database v.3 (Weidema et al., 2013). **Tables 3** reports the list of the main processes retrieved from the Ecoinvnet® database.

The environmental impact of the plastic film used in Italy to cover the flowerbeds was assessed considering the consumption of LDPE polyethylene granules and their extrusion (97.6% of extrusion yield, equal to 1.0246 g of granules for 1 g of plastic film). The plastic tunnel used in Switzerland is made of a structure of galvanised steel, covered with an EVA (ethylene vinyl acetate) copolymer sheet. The plastic cover is replaced every 4 years while the tunnel lifetime is typically 25 years. Additionally, for the life span of the tunnel, a sensitivity analysis was done.

Tables 3 – Processes retrieved from database.

Process	Ecoinvent® 3.5 Process	Modifications
Manure spreading in Italian cultivation	Solid manure loading and spreading, by hydraulic loader and spreader {GLO}| market for | APOS, U	n/a
	Manure, solid, cattle {RoW}| market for| APOS, U	n/a
Planting	Strawberry seedling, for planting {GLO}| market for strawberry seedling, for planting | APOS, U	n/a
Plastic film used in Italian cultivation for mulching	Polyethylene, linear low density, granulate {RER}| production | APOS, U	n/a
	Extrusion, plastic film {GLO}| market for | APOS, U	1 kg of this process equals 0.976 kg of extruded plastic film
Plastic tunnel for cultivation in Switzerland	Plastic tunnel {GLO}| market for plastic tunnel | APOS, U	Modified considering 20 years of lifespan
Fertilizer consumed during crop cultivation	Nitrogen fertiliser, as N {GLO}| market for | APOS, U Phosphate fertiliser, as P2O5 {GLO}| market for | APOS, U Potassium fertiliser, as K2O {GLO}| market for | APOS, S	n/a
Pesticides applied for pest control	Pesticide, unspecified {RER}| production | APOS, U	With regard to the emissions into the soil the different active ingredient were considered.
Manufacturing of irrigation system	Polyethylene, high density, granulate {GLO}| market for | APOS, U	n/a
Diesel fuel consumed during field operations	Diesel {RER}| market group for | APOS, U	n/a
Tractors used during field operations	Tractor, 4-wheel, agricultural {GLO}| market for | APOS, U	A life span of 12 years was considered[1]
For ploughing and harrowing	Agricultural machinery, tillage {GLO}| market for | APOS, U	A life span of 8 years was considered for the machinery used for soil tillage[1]
For field operations excluding soil tillage	Agricultural machinery, unspecified {GLO}| market for | APOS, U	The following life span were considered: 6 years for manual sprayer, 8 years for bed-maker and rototiller[2]
For all the field operations	Shed {CH}| construction | APOS, U	n/a

[1] Lovarelli and Bacenetti, 2017; [2] Lovarelli et al., 2017

The emissions of ammonia and dinitrogen oxides into air, and of nitrate and phosphate into water were estimated considering the models proposed by Brentrup et al. (2000) (for NH_3, NO_3 and N_2O) and from Prahsun (2006) (for PO_4). The active ingredients applied with the different pesticides were considered released completely into the soil (Environdec, 2013). PestLCI 2.0 (Fantin et al., 2019) was not applied due to the lack of site-specific data concerning the soil physic and chemical characteristics.

2.6 Impact assessment

The conversion of the inventory data in environmental impact was performed using the characterisation factors provided by the International Reference Life Cycle Data System midpoint method (ILCD, 2012; EC-JRC, 2011). Twelve impact categories (namely environmental effects) were considered: climate change (CC), ozone depletion (OD), particulate matter formation (PM), human toxicity-no cancer effect (HTnoc) and cancer effect (HTC), photochemical ozone formation (POF), terrestrial acidification (TA), eutrophication of terrestrial ecosystems (TE), freshwater (FE), and marine water (ME), freshwater ecotoxicity (FEx) and mineral and fossil resource depletion (MFRD).

The ILCD 2011 Midpoint method was selected because it was endorsed by the European Commission, Joint Research Centre in 2012 (EC-JRC, 2011)

3. Results and discussion

Figure 2 shows the environmental hotspots for strawberry production in Switzerland and in Italy (3-years crop cycle duration). The label "prod. of prod. factors" includes the production of fertilisers, pesticides and wheat straw, while "Plastic materials" includes the production of the plastic film as well as the pipes for the irrigation system.

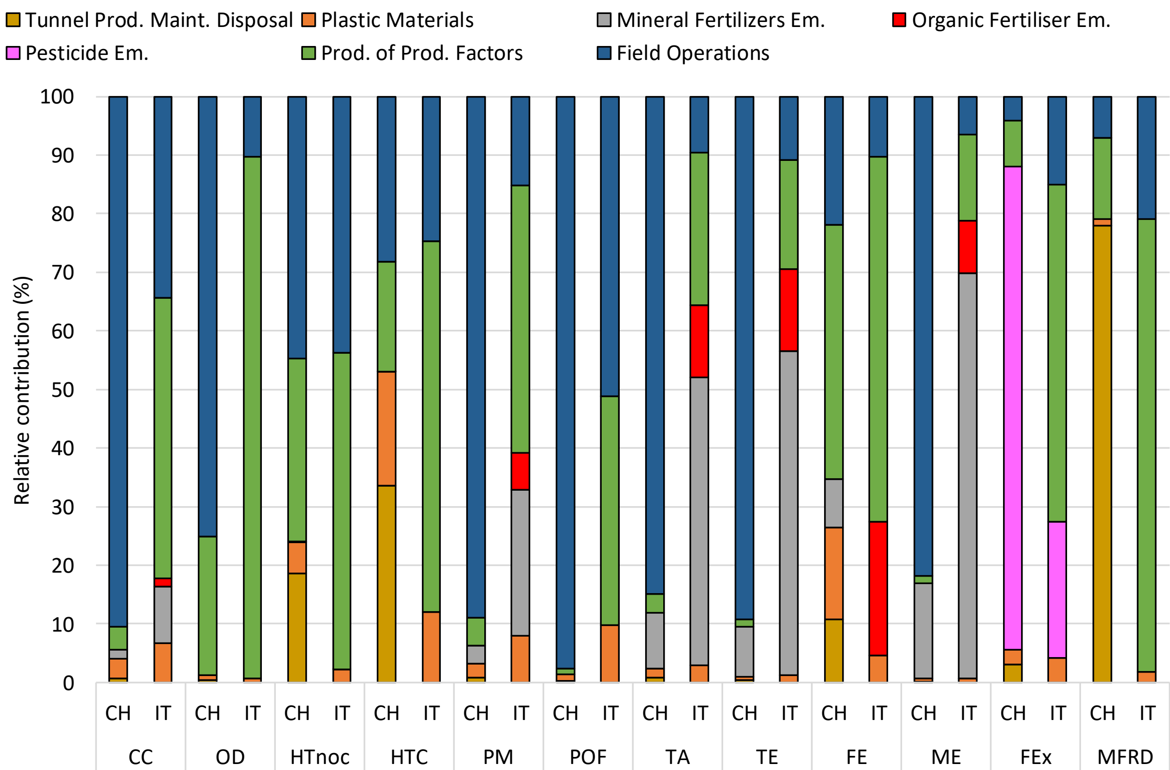


Figure 2 – Hotspots identification for strawberry production in Switzerland and Italy (3-years crop cycle) (note: the label "field operation" includes the impact of machines manufacturing, maintenance and disposal, diesel production and related combustion emissions).

Regarding the Swiss case, the field operations, mainly due to soil sterilisation, are the main hotspot for all the evaluated impact categories except for the toxicity-related impact categories and for MFRD. More in detail, the field operations are the main responsible, counting more than 80%, for CC, PM, POF, TA, TE and ME. On FEx, the greater impact (82.4%) is due to the emissions related to pesticides application; on MFRD, the production of the tunnel plastic coverage impacts for 77.9%.

In the Italian case, field operations do not play a predominant role as in Switzerland because the soil is not sterilised; in this scenario, the main hotspot varies among the different impact categories, and more in details:

- the impact related to the production of the production factors contributes for 47.9% in CC (mainly due to the production of mineral fertilisers), 89.1% in OD (mainly due to the production of fertilisers and pesticides), for 54.1% in HT-noc and for 63.2% in HTC (mainly due to pesticides production), for 39.1% in POF (mainly due to the production of seedlings), for 57.6% in FEx (due to the production of mineral fertilisers, seedlings and pesticides) and for 77.4% in MFRD (mainly due to the production of mineral fertilisers);

- mineral fertilisers emissions are the main responsible (> 50%) for TA, TE and ME mainly because of the emissions of N-compounds, and in particular of NH_3 due to ammonia volatilisation in the atmosphere;
- organic fertiliser emissions play a minor role due to the low amount applied; nevertheless, they are responsible for 6% of PM and 13% of TA (due to the emissions of NH_3) and for 15% of TE and 22% of FE due to nitrate leaching;
- the production of plastic materials (plastic film for mulching) impacts in a non-negligible way: except for OD, TA, TE and ME, for which its contribution is very low, for the other impact categories it has a relative contribution greater than 5%, with a maximum of 12% for HTC.

Table 4 reports the absolute environmental impact for 1 kg of strawberry cultivated in Italy (ITA) and in Switzerland (CH). **Figure 3** shows their relative comparison.

Table 4 – Environmental impact for the FU in the two considered countries

Impact Category	Unit	CH	ITA (3-years)
CC	kg CO_2 eq	1.868	0.212
OD	mg CFC-11 eq	0.140	0.021
HTnoc	CTUh	7.34×10^{-08}	3.75×10^{-08}
HTC	CTUh	1.34×10^{-09}	4.58×10^{-09}
PM	g PM2.5 eq	1.282	0.108
POF	g NMVOC eq	21.882	0.579
TA	molc H+ eq	0.0185	0.0025
TE	molc N eq	0.092	0.010
FE	g P eq	0.048	0.031
ME	g N eq	9.170	1.501
FEx	CTUe	7.599	0.943
MFRD	g Sb eq	0.059	0.008

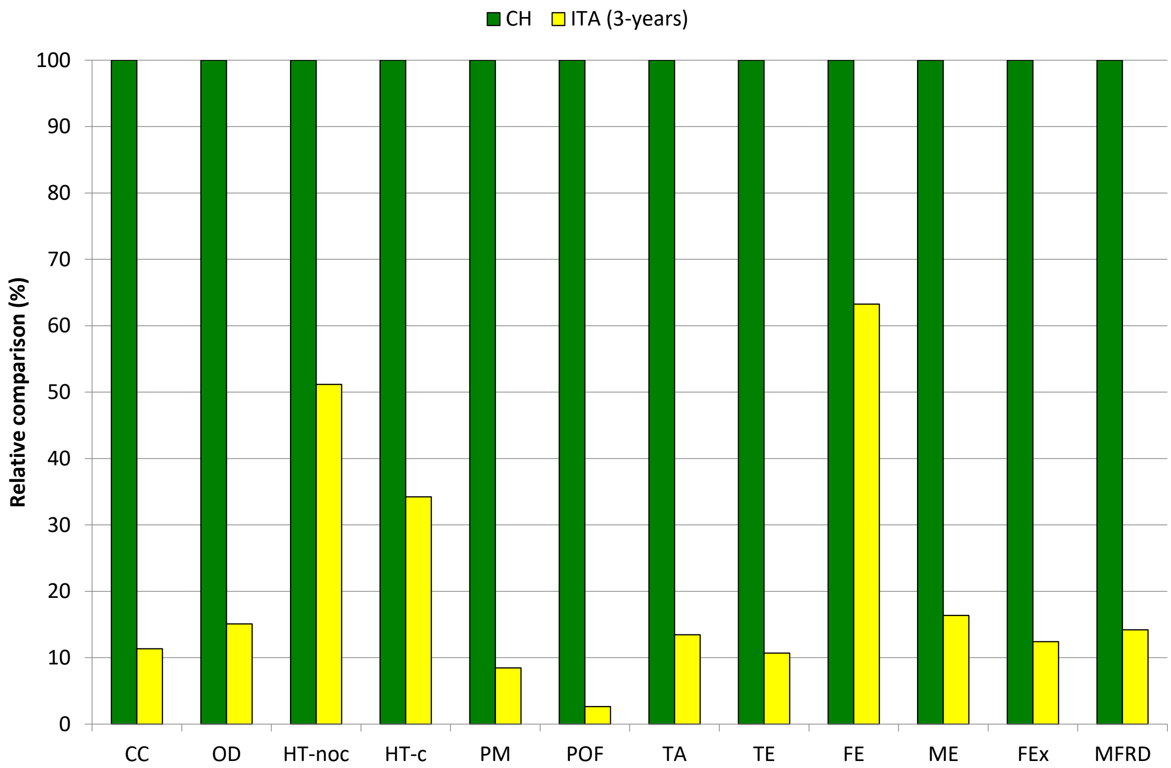


Figure 3 – Relative comparison between strawberry production in Switzerland and in Italy with 3-years crop cycle.

For all the evaluated impact categories, strawberry production in Switzerland shows higher impacts respect to the production in Italy. The impact reduction related to the Italian production in open fields (no soil sterilisation) ranges from 97.4% for POF (the impact more deeply affected by the soil sterilisation) to 36.7% for FE (the impact category for which the role of fertilisers related emissions is stronger). However, except for the human-toxicity related impact categories and FE, for all the other evaluated impact categories the impact reduction is higher than 70%.

Finally, **Figure 4** shows the comparison between the environmental impact of Italian strawberry production considering the two crop rotation cycles: 2-years and 3-years. For all the evaluated impact categories, the shorter crop cycle shows a lower environmental impact, with an impact reduction ranging from 8.8% in FE to 20.1% in OD with an average global reduction of 15%. Although with the longer crop cycle duration all the operations carried out for field preparation and planting are spread over a longer time, the low yield achieved in the third year (18 t/ha) does not compensate the environmental impact related to crop protection and weed control in the last year of the crop cycle.

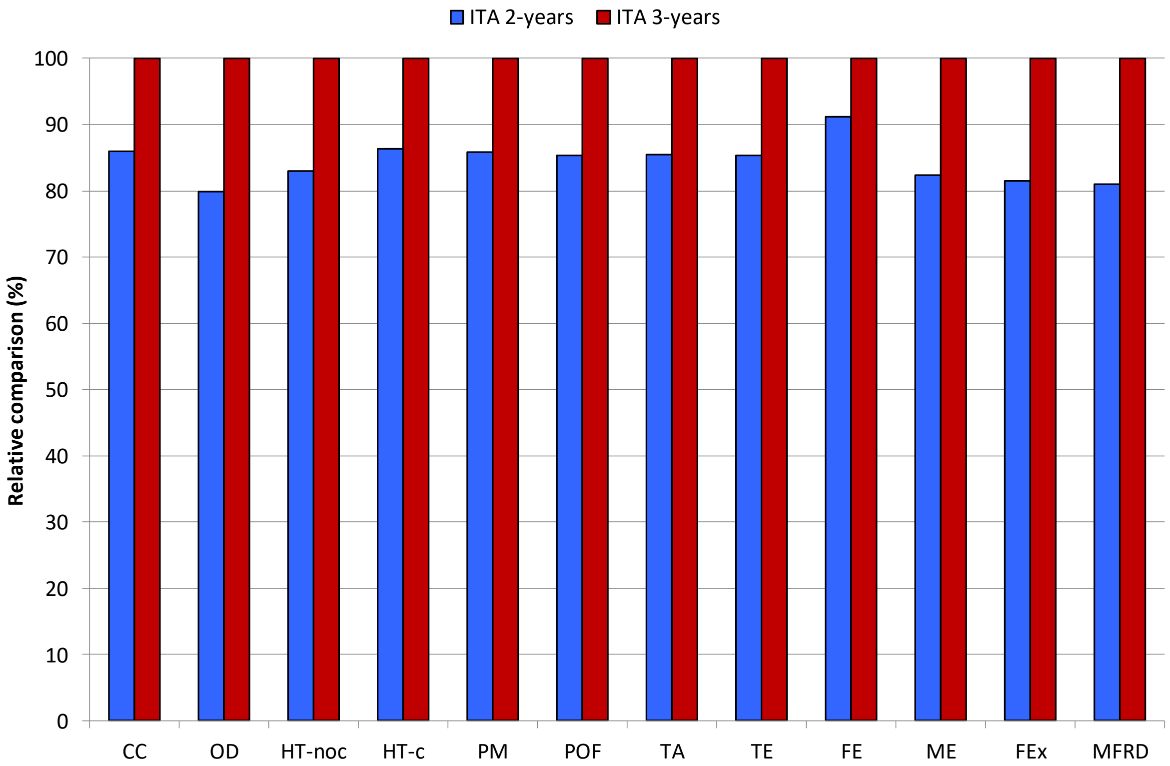


Figure 4 – Relative comparison between the Italian production with different crop cycle duration.

Despite the higher environmental impact, the lower yield, soil sterilisation and cultivation in tunnels, from an economic point of view, the production in Switzerland is justified by the higher selling price for fresh strawberry. In 2017, the price varied from 6 to 9 CHF/kg (5.3 – 7.9 €/kg) (DEFR, 2017) while in Italy from 1.5 to 4.0 €/kg.

3.1 Sensitivity analysis

A sensitivity analysis was carried out to investigate the effect of key parameters, and the robustness of the achieved environmental results. More in details, two key parameters were considered: yield variation (for the cultivation in both the countries) and life span of tunnel (only for the cultivation in Switzerland).

A yield variation was taken into account considering a wider variation (±30%) for open field production and a lower variation (±15%) for the tunnel productions. In fact, the production in open field is more affected by climatic conditions and pests respect to the cultivation in tunnel where humidity can be more easily controlled. Following Brentrup et al. (2000), emissions derived from fertilisers were modified according to yield variation: the nitrogen leaching is reduced with yield increase due to higher nitrogen removal by the crop and, on the contrary, it grows when the yield is lowered.

Figure 5 shows the impact variation for strawberry production in Switzerland and in Italy (3-years crop cycle) considering the yield changes (±15% for Switzerland and ±30% for Italy). Except for ME, for all the other evaluated impact categories the impact variation is proportional to the yield change. ME is the impact category mainly affected by nitrogen leaching, therefore when the yield decreases the impact variation is higher than the yield decrease because also a higher nitrogen leaching occurs. However, strawberry production in Italy shows always better environmental results than the Swiss one, even in the combination of a low yield for Italy and a high yield for Switzerland.

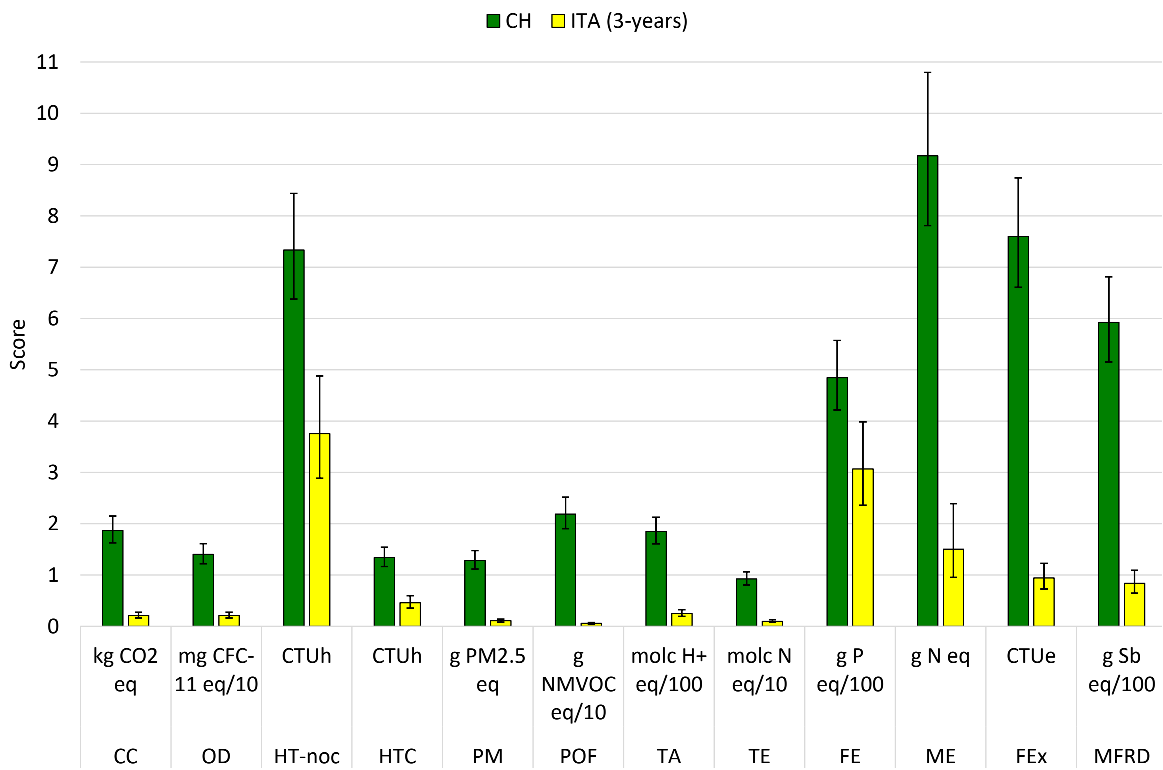


Figure 5 – Impact variation considering the yield changes

About the strawberry cultivation in Switzerland, a variation (± 10 years) of the tunnel lifespan was considered; with this regard, **Table 5** reports the related impact variation. Except for impact categories related to human toxicity and for MFRD, changing the tunnel lifespan involves small impact variations (<1% for 7 of the 12 evaluated impact categories). For HTnoc, HTC and, above all, for MFRD, the impact related to the tunnel is not negligible due to the consumption of aluminium and steel for its manufacturing and, consequently, the impact variation related to the tunnel lifespan is wider.

Table 5 – Impact variation due to changing of the tunnel lifespan

Impact Category	Variation of tunnel lifespan	
	+ 10 years	**- 10 years**
CC	-0.21%	0.50%
OD	-0.11%	0.27%
HTnoc	-5.30%	12.36%
HTC	-9.59%	22.37%
PM	-0.24%	0.56%
POF	-0.06%	0.15%
TA	-0.22%	0.52%
TE	-0.13%	0.31%
FE	-3.08%	7.18%
ME	-0.05%	0.11%
FEx	-0.88%	2.06%
MFRD	-22.27%	51.97%

3.2 Uncertainty analysis

An uncertainty analysis was carried out with the Montecarlo technique (1000 iterations and a confidence interval of 95%) to test the robustness of the achieved results in regard of the comparison between:

- the strawberry production in Switzerland and in Italy considering a 3-years crop cycle;
- the strawberry production in Switzerland and in Italy considering a 2-years crop cycle;

- the strawberry production in Italy considering the two different crop cycle duration.

The results of the uncertainty analysis are reported in **Figure 6 – 7 - 8**.

Figure 6 reports the results of the uncertainty analysis concerning the comparison between the strawberry production in Switzerland and in Italy with the 3-years crop cycle. The bars on the left represent the probability that the environmental impact of Swiss production is lower than the Italian one, while those on the right mean the opposite (the environmental impact of Swiss production is higher than the one of strawberry produced in Italy with a 3-years crop cycle). Except for the impact categories related to toxicity (HTnoc. HTC and FEx), for all the other evaluated impact categories there is a reduced uncertainty level. For them, the strawberry production in Switzerland has a higher impact than the one in Italy with a 3-years crop cycle with a level of statistical significance higher than 99.5%. Thus, these results show that the uncertainty due to the selection of the data source, the model imprecision, and the variability of data does not affect significantly the results.

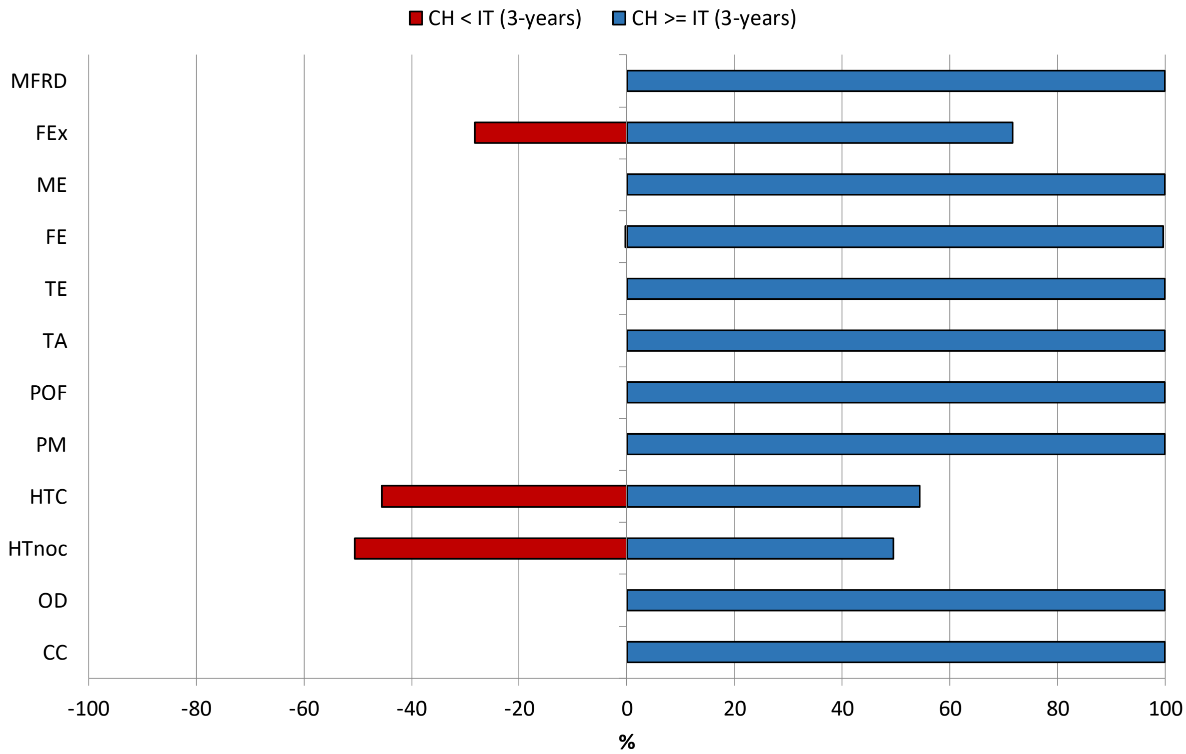


Figure 6 – Results of the uncertainty analysis for the 3-years cycles

Similar results are achieved with the uncertainty analysis when the production in Switzerland is compared with the one in Italy with a 2-years crop cycle (**Figure 7**): the uncertainty does not affect significantly the results. Once more, except for the toxicity-related impact categories (where the uncertainty is not negligible), for all the other evaluated impact categories, the level of statistical significance is 100%. However, for HTC, HTnoc and FEx, the level of statistical significance is higher compared to that calculated for the comparison between the Swiss production and the Italian production with a 3-years crop cycle.

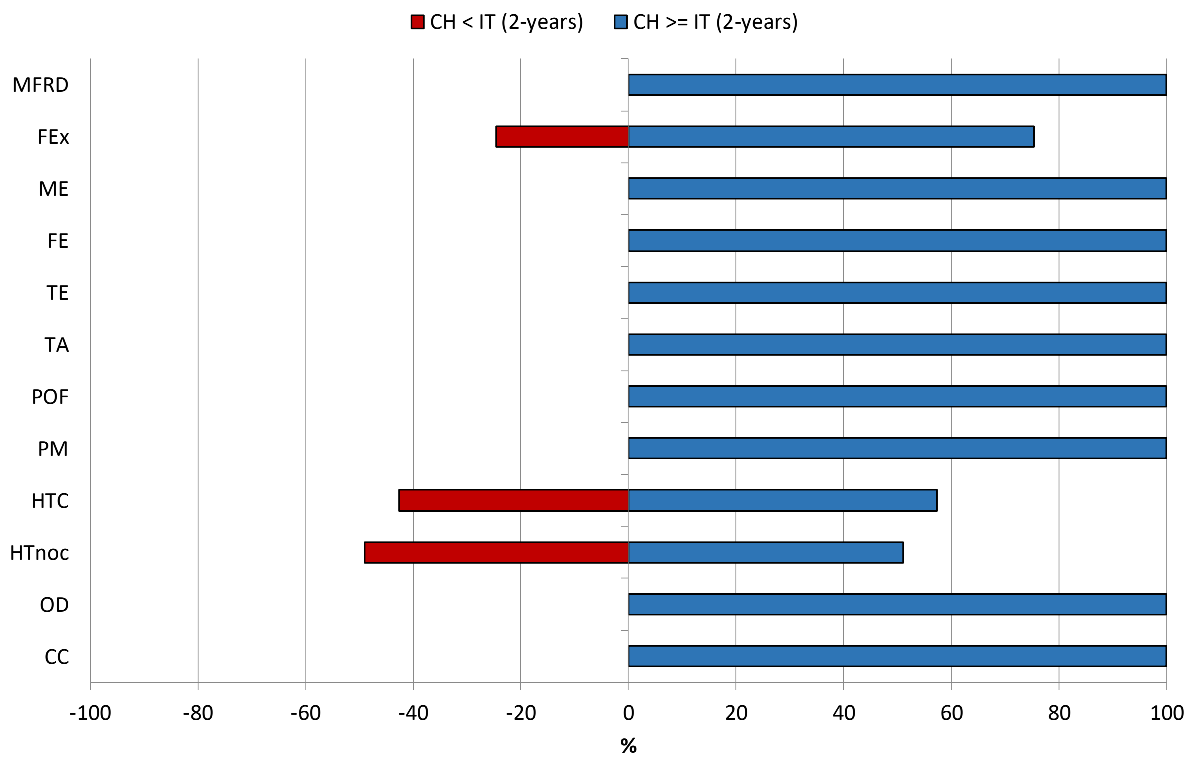


Figure 7 – Results of the uncertainty analysis for the 2-years crop cycles

The results of the uncertainty analysis about the comparison between the production in Italy with the two different crop cycle durations is reported in **Figure 8**. Even in this case, only the impact categories related to toxicity show high uncertainty, whereas for the other 9 impact categories the level of statistical significance is 100%.

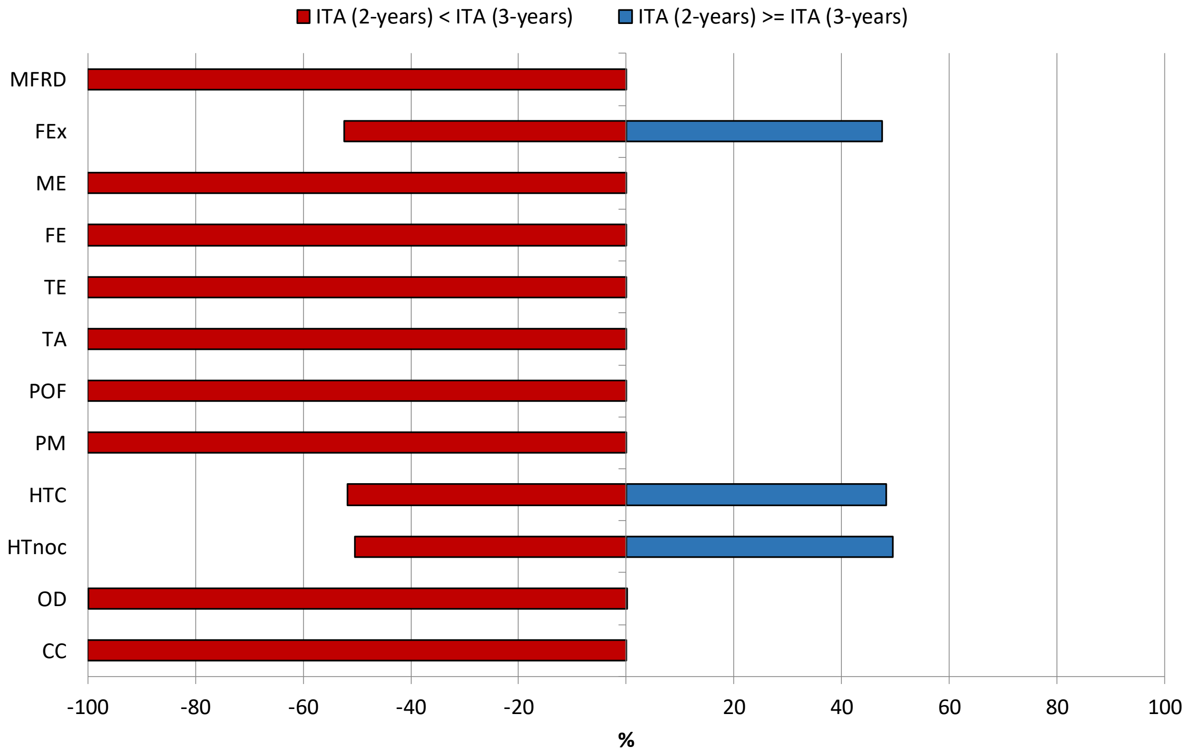


Figure 8 – Results of the uncertainty analysis for the Italian 3-years and 2-years crop cycles

3.3 Comparison with literature

Table 6 shows the comparison among the environmental results of this article and those of LCA studies carried out in the last 5-years. Considering that the studies were carried out with different impact assessment methods (Recipe, CML, ISO for Carbon footprint and ILCD) (Goedkoop et al., 2013; Guinee et al., 2002; ISO, 2013; ILCD, 2012), a direct comparison can be made only for the impact category of Climate Change. In this study, the CC ranges from 0.18 to 0.21 kg CO_2 eq, per kg of strawberry produced in Italy and it is equal to 1.87 kg CO_2 eq/kg of strawberry in Switzerland.

The CC achieved for the production in open fields in Italy is lower than the ones achieved in other studies about strawberry production in Iran (Khoshnevisan et al., 2013), Estonia and Germany (Soodle-Schimonsky et al., 2017; Soodle et al., 2015), UK (Michalsk et al., 2015) and USA (Bell et al., 2018). The main reasons for this difference are related to the identified system boundaries (packaging and transport are sometimes included) and, mainly, to the different yields. Regarding the production in protected field, the CC for Swiss production is similar to the one assessed in USA (Tabatabaie et al., 2016) and Germany (Soode et al., 2015), but lower to the one achieved for Iranian production where a higher production is achieved (72.5 t/ha). For greenhouse production, surprisingly, Girgenti et al. (2015) found a considerably lower value despite the low yield.

Table 6 – Climate change assessed in previously carried out studies

Study	Country	Open or protected field	Yield	Climate change kg CO^2 eq./kg
Girgenti et al., 2015	Italy	Protected	30 t/ha	0.015
Michalsk et al., 2015	UK, Europe and non-European (NE) countries	Both	Not reported	0.84 in UK 1.06 in Europe 1.39 out of Europe
Tabatabaie et al., 2016	USA	Protected	74 t/ha*	From 1.75 to 5.58
Khoshnevisan et al., 2013	Iran	Both	5.5 t/ha open field 72.5 t/ha greenhouses	0.58 in open field 0.7 in greenhouse
Soode et al., 2015	Germany	Both	Not reported	0.8-1.1 in open field 2.1 in greenhouse
Soodle-Schimonsky et al., 2017	Estonia and Germany	Both	7-22 t/ha in open fields 75 t/ha in protected fields	From 0.33 to 1.02 in open field 0.45 in protected fields
Bell et al., 2018	USA	Open fields	Not reported	0.63 – 0.84

*Only the maximum yield is reported.

4. Conclusions

In this study, different cultivation practices for strawberry production were considered by evaluating two systems with a different duration in the crop cycle (1 year in Switzerland and 2 or 3 years in Italy), and different soil management and cultivation in open and protected field. The achieved results highlighted how the yield and the pre-planting field operations are the main drivers of the environmental results. More in details, due to the soil sterilisation carried out with water steam, the Swiss production in tunnels shows a considerably higher impact respect to the Italian production in open fields considering both of the crop cycle durations. Furthermore, in Italy, the shorter crop cycle (2 years) characterised by higher average yield performs better than the longer crop cycle (3 years).

The sensitivity analysis carried out about yield highlighted how, even if wide yield variations are considered, the Swiss production still performs worse than the Italian one, and this is due to sterilisation. In this regard, from an environmental point of view, the substitution of the fuel used by the steam machine with other renewable sources (e.g., natural gas) could be opportune.

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Table 1 – Inventory data for strawberry production in Italy

SUBSYSTEM	FIELD OPERATION	YEAR	REP	TRACTOR	OPERATIVE MACHINE		NOTE
				Mass Power	Type	FC[a] (kg ha^{-1})	
Field preparation and soil tillage	Organic fertilisation	1	1	6000 kg 100 kW	Manure spreader, 2000 kg	22.0	Cattle manure 13.5 t ha^{-1}
	Ploughing	1	1	6000 kg 100 kW	3 furrow plough, 1100 kg, 30 cm depth	25.0	
	Harrowing	1	1	4800 kg 80 kW	rotary harrow, 2.4 m width, 10 cm depth	20.0	
	Tilling	1	1	4800 kg 80 kW	Hoeing machine, 7.5 cm depth	15.5	
	Positioning of irrigation and mulching system	1	1	2500kg 35 kW	Bed-maker-mulching machine, 600 kg	7.5	Plastic film (PET), 490 kg ha^{-1} 8125 m ha^{-1} of irrigation pipe, 162.4 kg ha^{-1} of HDPE
Planting	Planting	1	1	By hands	-	-	45000 cold-stored seedlings ha^{-1}
Crop Managem.	Chemical Pests control (fungicide)	1,2,3[d]	3+3	4800 kg 80 kW	Manual sprayer	4.0	Botrytis: 1.6 l ha^{-1} SINIUM – Piraclostrobin +boscalid + 1.3 l ha^{-1} TELDOR - Fenexamide. Powdery mildew: 1l ha^{-1} NIMROD bupirimate + 0.4 l ha^{-1} TOPAS Penconazole + 0.9 l ha^{-1} ORTIVA Azoxystrobin
	Chemical Pest control (insect and mites)	1,2,3[d]	2+2	4800 kg 80 kW	Sprayer	4.0	Mites: 1 l ha^{-1} VERTIMEC - Abamectine + 0.2 l ha^{-1} METACAR - Lexitiazox Insects: 0.2 l ha^{-1} LASER – Spinosad
	Fertirrigation	1,2,3[d]	5+5	Carried out during irrigations		n/a	225 kg ha^{-1} complex, 495 kg ha^{-1} complex [b]
	Weed control in the interrow	1,2,3[d]	5	Self- propelled rototiller 195 kg, 8.6 kW, 7.5 cm depth		9.0	
	Mulching	1,2,3[d]	1	Manual		10.0	15 t ha^{-1} of wheat straw
Harvest	Harvesting	1,2,3[d]	>2	By hands		n/a	54 t ha^{-1}, 45 t ha^{-1}, 18 t ha^{-1} [c]

[a] FC = fuel consumption; [b] the lower dose is applied during the pre-productive months while the higher one during the productive months; [c] for the 1st, 2nd and 3th year, respectively; [d] 3 refers to the case when a 3-years crop cycle is considered

Table 2 – Inventory data for strawberry production in Switzerland

SUBSYSTEM	FIELD OPERATION	REP.	TRACTOR	OPERATIVE MACHINE		NOTE
			Mass Power	Type	FC[a] (kg ha^{-1})	
Field preparation and soil tillage	Primary soil tillage	1	2035 kg 70 kW	Subsoiler, 1.1 m width, 355 kg, 25 cm depth	22.4	
	Harrowing	2	2035 kg 70 kW	Rotary harrow, 1.85 m width, 10 cm depth	19.6	
	Soil sterilisation	1	2035 kg 70 kW	Steam generation, 800 kW	2.5	1.20 kg m^{-2} of diesel for the steam generation
	Positioning of irrigation systems	1	Manual	-	-	8125 m ha^{-1} of irrigation pipe, 162.4 kg ha^{-1} of HDPE pipes
	Mulching	1	Manual	-	-	490 kg ha^{-1} of PET film
Planting	Transplanting	1	Manual	-	-	45000 plants ha^{-1}
Crop management	Chemical pest control (fungicide)	5	Manual	Portable sprayer	-	Phytophthora and radical rot: 10 kg ha^{-1} ALIETTE - Fosetil Aluminium Bacterioses: 2 kg ha^{-1} CUPROXAT – Copper . Powdery mildew: 4 kg ha^{-1} THIOVIT – Sulfur + 2.5 kg ha^{-1} + TOPAS VINO - Penconazole + 2 kg ha^{-1} + HELIOSOUFRE - Sulfur + 2 kg ha^{-1} AMISTAR – Azoxystrobin. Botrytis: 2.5 kg ha^{-1} SCALA – pyrimethanil + 1 kg ha^{-1} SWITCH - Cyprodinil and Fludioxonil + 2 kg ha^{-1} TELDOR - Fenhexamid
	Chemical pest control (insects and mites)	5	Manual	Portable sprayer	-	Mites: 0.8 kg ha^{-1} CREDO + 6 kg ha^{-1} KIRON - Ethofenprox + 1 kg ha^{-1}; VERTIMEC - Abamectine + 0.25 kg ha^{-1} ACRAMITE – bifenazate + 1 kg ha^{-1} ARABELLA - Oxazol Insects: 2.6 kg ha^{-1} KARATE - lambda- cyhalothrin + 0.4 kg ha^{-1}; PIRIMOR - Pirimicarb + 0.6 kg ha^{-1} AUDIENZ – Spinosald
	Fertirrigation	5	Carried out during irrigations			120 kg ha^{-1} of N as ammonium nitrate,

						10 kg ha^{-1} of P_2O_5, 200 kg ha^{-1} of K_2SO_4
Harvest	Harvesting	1	By hands	-	-	25 t ha^{-1}

[a] FC = fuel consumption.