Life cycle assessment applied to different citrus farming systems in Spain and Italy

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The increasing environmental awareness of the actors of agro-food supply chains has led to the implementation of new tools to analyze the impacts generated during agricultural practices. The impacts depend not only on the production system but also on the farmer’s management choices, in terms of input allocation, and on the production site, in terms of soil and climate conditions. In order to assess the environmental impact of conventional and organic farming systems on citrus growing in Italy and Spain, a Life Cycle Assessment method has been implemented. The results show the organic system to be more sustainable than conventional and they could be useful indicators for correcting and modifying agricultural practices.

KEYWORDS: *Life Cycle Assessment, Citrus Farming Systems, Environmental Performances, Environmental Sustainability*

1. INTRODUCTION

Agricultural farming systems deplete large amounts of resources and materials and generate

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high quantities of emissions into the different environmental compartments during production practices. Therefore, is useful to achieve a strategy based on low-impact systems and technologies to reduce environmental impacts. Nowadays, the enhancement of environment quality and the resource base is one of the goals suggested by the Committee on Twenty-First Century Systems Agriculture in order to be partially sustainable (Tarnapol Whitacre 2010). To this aim, numerous methods and techniques are available to identify the negative externalities produced during the agricultural processes in order to achieve environmental sustainability (Falcone et al. 2016). For this reason, Life Cycle Assessment (LCA) is a tool that allows the potential impacts of agricultural production practices to be quantified during their entire life cycle (De Luca et al. 2017).

According to ISO standard 14040, LCA is a "compilation and evaluation of the inputs, outputs and the environmental impacts of a product system throughout its life cycle" (ISO 2006a).

There are numerous studies and reviews, in which the environmental assessment of generic agricultural production systems has been performed, including citrus fruit (Beccali et al. 2009, 2010; Nicolò et al. 2017; Sanjuán et al. 2005). Other studies have evaluated the environmental performance of conventional compared to organic farming systems (De Luca et al. 2014; Knudsen et al. 2011; Pergola et al. 2013; Ribal et al. 2016; Strano et al. 2017). Many of these studies analyze the differences of the farming systems in terms of environmental impacts obtaining results affected by different sorts of variations. Other studies showed the causes of the variability between the farms or scenarios within both the same production system and the same region (Mouron et al. 2006; Da Silva et al. 2010). According to Basset-Mens et al. (2010) and Ribal et al. (2016) Monte-Carlo analysis could be a way to quantify the uncertainty linked to the dynamic and natural variability for process data generated from the different regional production practices (Renouf et al. 2010).

Another option is to study each farm separately, since this can help us to differentiate between the results among farms and also to define the potential for improvement of environmental impact management in individual farming enterprises. Mouron et al. (2006) affirmed that the promotion of environmentally sound farming is not only a question of choosing a farming system (e.g. organic vs. integrated), primarily, an understanding of the influences of specific system management is essential.

Nowadays, the environmental sustainability of agricultural practices in both organic and conventional farming systems is an important concern; just because a farm is organic does not mean that it is sustainable. Therefore, a comparison of citrus farming systems is necessary to analyze the emissions generated by each system and to identify the more eco-efficient management one.

In 2013, according to FAOSTAT data, the worldwide production area of tangerines, mandarins, clementines and satsumas amounted to about 2.8 million ha, corresponding to 29.8% (9.6 million ha) of the worldwide area devoted to the cultivation of citrus fruit. In the same year, the worldwide production of the above mentioned citrus represented about 21.1% (28.6 million tons) of the total citrus fruit production (135.7 million tons). The European area and its production of tangerines, mandarins, clementines and satsumas represent 5.6% (164.6 thousands ha) and 10.6% (3.0 million of tons), respectively, of the worldwide production of the same citrus group. Spain and Italy are the main European producer countries of citrus fruits and, relative to the tangerine, mandarin, clementine and satsuma group record, respectively, about 34.4% (2.1 million tons) and 23.6% (650.4 thousand tons) in the year 2013. In Spain, the largest clementine cultivation area is located in the Valencian Community and amounts to 58,063 ha with a production equal to 1,098,188 t of clementine in 2013 (MAAM 2014); the clementine productive area of the Valencian Community corresponding to 73.9% of the national clementine production area equal to 78,603 ha,. In Italy, clementine production is concentrated in the southern regions, in particular in Calabria, in which the area attributed to clementines is equal to 16,372 ha, with a production of 350,511 t (Agri-istat 2010). Considering the great surface area and production of citrus fruits in these territories, it is very important to know the impacts produced during the agricultural stage in order to plan a strategy to mitigate the impacts and to pursue environmental sustainability.

The aim of our study is to carry out a comparative environmental analysis of citrus farms pertaining to two farming systems, organic and conventional, in two different production sites, the Valencian Community and the Calabrian Region, in order to identify the potential environmental impacts caused by different management techniques. Therefore, in order to estimate the environmental impacts of the farming systems, the mean value (M) of the sample farms investigated in each impact categories has been taken into account. Organic and conventional systems may be different with respect to their environmental and resource use effect, but that does not just depends on the varieties cultivated but also on the farm type, degree of specialization, level of intensity, site specific aspects, and individual management abilities of the farmer (Stolze et al. 2000). The application of the LCA method allows the environmental hot spots of each farming to be identified; furthermore, knowledge and understanding of the global environmental impacts due to an agricultural production system can be useful for policy makers and farmers in order to undertake corrective actions.

2. MATERIALS AND METHODS

2.1. Life cycle assessment of clementine farming systems

In order to quantify the potential environmental impacts produced in the cultivation stage of the clementine, a comparative analysis of two systems, conventional and organic, has been performed, using the LCA method according to ISO guidelines (ISO 2006a, 2006b). LCA consists of four different and iterative steps defined by the ISO standards: goal and scope definition, inventory analysis, impact assessment and interpretation (De Luca et al. 2015).

In the first step, we defined the main objective of the analysis, which is to compare organic and conventional clementine production systems in the Valencian Community and the Calabrian Region. After that, we chose the reference unit, to which the systems' input and output are related, defined as functional unit (FU) (Milà i Canals and Clemente Polo 2003). In this analysis, the FU selected is 1 ha of clementines at the farm gate. The study is based on primary data, corresponding to the farming season 2009-2010. Input and output data have been collected directly by questionnaires and interviews with farmers. The study examined 42 clementine farms; 23 are located in Valencian Community (Spain), of which 12 correspond to organic production (OFS_{Sp}) and 11 to conventional farming systems (CFS_{Sp}), while 19 are situated in the Calabria Region (Italy), of which 9 correspond to organic farming (OFS_{It}) and 11 to conventional methods (CFS_{It}). In particular, the above-mentioned clementine farming systems have been considered as the four systems analyzed in the LCA implementation.

According to Brentrup (2012), LCA studies do not always cover all life cycle stages of a product but can be restricted to defined parts of it, for example in the so-called "cradle to gate" or "gate to gate" studies. In this study, the system boundary considered was from "cradle-to-farm gate", which included the use of machinery, the production and emissions of fertilizers, pesticides and fuels, and the field operations, as depicted in Figure 1. Irrigation, transport of fertilizers and pesticides were excluded due to lack of reliable data.

The second step of LCA is the Life Cycle Inventory (LCI) analysis; this involves the collection of data defined by the materials and energy used in the system, emission to air, liquid effluents and solid waste discharged into the environment (Azapagic 2006).

Data regarding the resource consumption and emissions produced during the fertilizers and pesticides manufacture were taken from the Ecoinvent 2.1 database (Frischknet et al.

2005). The method suggested from Audsley et al. (1997) was used to calculate the data regarding active ingredients not included in the Ecoinvent database. Concerning the mineral oil, used as an insecticide, the manufacturing process of the kerosene in Ecoinvent 2.1 has been considered due to its similar properties. For the manufacturing process of inorganic fertilizers not included in Ecoinvent 2.1, and the organo-mineral complex considered as inorganic, data suggested from Patyk and Reindhart (1997) have been used.

Data on tractor emissions have been calculated from the Ecoinvent 2.1 database, which also takes the manufacturing into account according to its life-time. Emissions from the manual weeding machine has been obtained from Oficina Catalana de Canvi Climàtic (2013).

Moreover, the emissions generated from the application of fertilizers have been calculated. IPCC Guidelines (2006) were utilized to estimate the nitrous oxide emissions (N_2O). To estimate the ammonia emissions (NH_3), the ammoniacal nitrogen content of both synthetic and organic fertilizers was obtained from the register of fertilizers suggested from MAGRAMA and Organazoto Fertilizzanti S.P.A.; then NH_3 emissions were estimated according to Brentrup et al. (2000) method. The leaching of nitrate (NO_{3-}) and phosphate (PO_4^{3-}) was calculated according to MAGRAMA (2010) and Nemecek and Kagi (2007) respectively.

To calculate the fate of pesticides, the general model of Hauschild (1999) has been used; this model allows the pesticide fractions arriving to the environmental compartments (soil, plant, surface- and groundwater) to be estimated. The fractions depend on both the physical and chemical properties and the degradation rate of the pesticide. These properties have been found in the following databases: Pesticide Footprint (Lewis et al. 2016), EU Pesticide Database, OSU Extension Pesticide Properties Database (Augustijn-Beckers et al. 1994; Wauchope et al. 1992) and The Pesticide Manual (McBean 2012). Furthermore, a Leaf Area Index (LAI) of 6.04 has been taken into account (Martins and Sanjuán 2006) for the deposition of the pesticide on crops, plants and field soil. The fraction that reaches the surrounding environment (drift from the field) has been calculated, taking into account both the surface water and the surface area in both countries. Surface areas of 2,320,000 ha in the Valencia province and of 1,510,000 ha in the Calabria Region, in addition to water surfaces of 23,216 ha and of 2,980 ha (ISPRA 2010) respectively, have been considered.

The life cycle impact assessment (LCIA) is the third step of LCA; its purpose is to translate the environmental burdens quantified in the LCI into the related potential environmental impacts (or category indicators) (Azapagic 2006). To this aim, Gabi 6.0 software was used. The impacts' assessment has been calculated by using a midpoint approach including the classification and characterization steps. Ten impact categories have been considered: Global Warming Potential (GWP 100 year, measured as kg CO_2 eq), Acidification Potential (AP, measured as kg SO_2 eq), Eutrophication Potential (EP, measured as kg PO_4^{3-} eq), Abiotic Depletion (ADP elements, measured as kg Sb eq), Abiotic Depletion (ADP fossil, measured in MJ), Ozone Layer Depletion Potential (ODP, measured as kg CFC-11 eq) and Photochemical Ozone Creation Potential (POCP, measured as kg Ethene eq) according to the CML-2001 method (Guinée et al., 2002) updated to April 2013. In addition, Ecotoxicity, Human Toxicity carcinogenic and Human Toxicity non-carcinogenic, expressed in CTUe (comparative toxic units) and CTUh have been calculated according to the USEtox method (Huijbregts et al. 2010).

The final step of LCA comprises the interpretation of results; it allows the identification of the key aspects highlighted by the results of impact categories. In this context, we compare two productive systems in two production sites, and this is one of the most common LCA implementations in the fruit sector (Cerutti et al. 2015).

Furthermore, in the agricultural system is essential to analyze the potential variability of the LCA results because of the difference in the production systems and management methods of the crops generated from different agronomical practices.

Therefore, for each farming system and impact category, the variability of the mean impact results was calculated by means the coefficient of variation (CV). This coefficient, expressed as percentage, was obtained by dividing the standard deviation associated to the impact category to the respective mean impact result and provides an indication of how uncertain is the average result.

3. RESULTS

3.1. Results

In Figure 2 depicts the environmental performances of the two farming systems considered in Spain and Italy (CFS_{Sp}, OFS_{Sp}, CFS_{It}, OFS_{It}) as percentages of the mean impact value of the farms investigated. The overall results show that the OFS is more sustainable than their CFS counterparts due to the use of environmentally friendly crop inputs as organic fertilizers; in contrast, the higher environmental impacts observed in CFS is due to the use of synthetic fertilizers and pesticides. The worst farming system in almost all categories' results is CFS in Italy, with the exception of ADP elements and Ecotoxicity indicators, where the CFS in Spain generates the highest impacts. When comparing the OFS of each country, it can be seen that the Spanish system shows respectively higher values of impacts than the Italian one in almost all categories except for POCP and human toxicity non-cancer. This is due to the heterogeneity of the agricultural practices; in fact, different levels and kinds of chemicals and organic fertilizers, pesticides and machinery are used. AP and EP show the highest levels of impact in all systems due to on-field emissions such as ammonia to air, and nitrate, and phosphate to groundwater, generated as a consequence of the application of mineral and organic fertilizers.

Table 1 shows the mean (M) and the coefficient of variation (CV) for each impact category in the four farming systems considered. The CV resulted higher in the OFS_{Sp} for all the impact categories, this indicating a strong variability of results because of the heterogeneity of the agricultural practices. These variations were mainly attributed to different kind of organic fertilizers and doses applied and also to the differences in the use of agricultural machinery. The lowest variability observed in CFS_{It} is due to more homogeneous management practices.

Analyzing Figure 3, the impacts generated by each production process stage in the Spanish and Italian CFS can be observed. In particular, the fertilizers' production is the most impacting operation in almost all indicators (GWP100: CFS_{Sp} 89% – CFS_{It} 92%; AP: CFS_{Sp} 80% – CFS_{It} 91%; ADPelements: CFS_{Sp} 81% – CFS_{It} 48%; ADPfossil: CFS_{Sp} 93% – CFS_{It} 96%; ODP: CFS_{Sp} 93% – CFS_{It} 98%; POCP: CFS_{Sp} 90% – CFS_{It} 93%; Human Toxicity cancer: CFS_{Sp} 97% – CFS_{It} 100%; Human Toxicity non-cancer: CFS_{Sp} 83% – CFS_{It} 93%). Furthermore, in Ecotoxicity (CFS_{Sp} 97% – CFS_{It} 78%) and Eutrophication categories (EP: CFS_{Sp} 49% – CFS_{It} 40%), the application of pesticides and fertilizers contributes greatly to the emissions generated in the field. Finally, in Abiotic Depletion of elements, a part of the impacts is caused mostly by pesticides production (CFS_{Sp} 18% – CFS_{It} 52%). Finally, in Abiotic Depletion of elements, a part of the impacts is caused mostly by pesticides production (CFS_{Sp} 18% – CFS_{It} 52%).

The impacts generated in the OFS are illustrated in Figure 4. The results show that the main difference between Italian and Spanish organic farms arises in the Ecotoxicity category; in Spain, 95% of the impacts are produced in the field operation stage, while in Italy about 87% of these impacts are caused by the fertilizers' production. Furthermore, a great contribution to the environmental performances is made by the emissions from agricultural machinery use (GWP100: OFS_{Sp} 18% – OFS_{It} 51%; AP: OFS_{Sp} 3% – OFS_{It} 14%; EP: OFS_{Sp} 3% – OFS_{It} 13%; ADPelements: OFS_{Sp} 6% – OFS_{It} 17%; ADPfossil: OFS_{Sp} 32% – OFS_{It} 69%; ODP: OFS_{Sp} 6% – OFS_{It} 0%; POCP: OFS_{Sp} 45% – OFS_{It} 79%; Ecotoxicity: OFS_{Sp} 0% – OFS_{It} 13%; Human

Toxicity cancer: OFS_{Sp} 1% – OFS_{It} 3%; Human Toxicity non-cancer: OFS_{Sp} 35% – OFS_{It} 75%).

As in the CFS, the fertilizers' production presents higher impacts in the following categories: ADPelements (OFS_{Sp} 58% – OFS_{It} 83%), ODP (OFS_{Sp} 80% – OFS_{It} 97%) and Human Toxicity cancer (OFS_{Sp} 97% – OFS_{It} 97%). Finally, pesticide manufacturing makes a smaller contribution to the impacts in the ADPelements (36%) and ODP (15%) categories in Spain. Generally, the impacts generated by OFS were lower than those by CFS, due to the minor application of the fertilizers and pesticides and consequently due to their absence in the production process.

4. DISCUSSION AND CONCLUSIONS

The environmental performances obtained by comparing organic and conventional farming systems in Spain and Italy show small differences between both production areas for the impact categories selected. This fact can be attributed to similar soil and climate conditions that are connected to comparable agricultural techniques and similar biocenotic processes. However, although the results show comparable performances, the Spanish farms show a higher variability in the impact results, due to the more advanced management strategies, which make for highly specific and customized farm cultivation techniques.

Several studies have been conducted to analyze the environmental performance of citrus fruit and citrus-based products. De Luca et al. (2014) performed a similar study in the Calabria region, but findings are not comparable because they used an end-point LCIA method (Ecoindicator 99), which expresses the environmental impacts from a damage-oriented perspective. Pergola et al. (2013) analyzed the production of lemons and oranges in the Sicily region, taking into account the whole life cycle of the orchard (50 years). These authors used the same impact assessment method; however, five impact categories (AD, GWP100yrs, PO, AA, and EU) have been considered. When separating the total results for one production year, impact values are lower; this is due, among other reasons, to the influence of the planting and growing phase, in which the lower quantity of inputs applied, reduces the mean value of the impact per year. Dwivedi et al. (2012) analyzed the production of orange juice in Florida, considering a farm cradle to industry gate system boundary. Results are related to 1893 L of not-from-concentrate orange juice. Considering an average production of 45 t oranges/hectare and comparing results in terms of GWP, the average value of 303 g CO_2/kg clementines for the Spanish conventional farming system is similar to Dwivedi`s result (312 g CO_2/kg oranges), even though the orange cultivation for juice production is less intensive than fresh consumption. In contrast, the Calabrian conventional farming system generates around 637 g CO_2/kg clementines. This value is mostly due to the higher quantity of fertilizer spread, which represents the most impacting operation for CFS_{It}. The reduction of the fertilizer dose could improve the environmental performances of these farms.

LCA implementation in agriculture is a useful tool for the decision support of farms' management strategies and, consequently, it can help to correct and modify agricultural practices in order to reduce environmental impacts. In this study, we analyzed the importance of the variability of the agricultural management techniques through the displaying of different levels of environmental performances. Indeed, we compared conventional and organic systems in two production sites in the Mediterranean area, based on primary data relative to a short time period, depending more on the farmer's management choices than on the general farming systems. Moreover, differences in input (fertilizers and pesticides) use generally depend on the location, and these differences are largely due to soil and climate conditions. This study cannot be considered as an overall environmental evaluation due to the lack of some input data in the agricultural stage. However, we can assert that, in all cases, the organic management practices are more environmentally friendly.

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Table 1. M and CV values for each impact category of the clementine farming systems.

Impact categories [Reference Units]	CFS_{Sp}		CFS_{It}		OFS_{Sp}		OFS_{It}	
	M	**CV (%)**	**M**	**CV (%)**	**M**	**CV (%)**	**M**	**CV (%)**
GWP 100 yrs [kg CO_2 eq]	1.37E+04	77	2.87E+04	10	3.57E+03	154	2.80E+03	61
AP [kg SO_2 eq]	1.10E+02	93	2.61E+02	10	1.94E+02	157	8.69E+01	48
EP [kg PO_4^{3-} eq]	4.30E+01	64	8.01E+01	11	4.69E+01	117	2.24E+01	36
ADP elements [kg Sb eq]	1.17E-02	63	9.01E-03	68	4.62E-04	266	3.17E-04	122
ADP fossil [MJ]	1.26E+05	92	3.05E+05	10	2.86E+04	209	2.90E+04	56
ODP [kg CFC-11 eq]	7.30E-04	80	1.56E-03	10	1.17E-04	271	4.96E-05	145
POCP [kg Ethene eq]	5.08E+00	99	1.32E+01	10	1.42E+00	182	1.88E+00	53
Ecotoxicity [CTUe]	9.41E+05	57	3.39E+05	43	9.18E+04	345	2.54E+03	129
Human toxicity cancer [CTUh]	4.36E-04	105	1.12E-03	11	7.04E-05	325	3.42E-05	144
Human toxicity non-cancer [CTUh]	2.15E-03	82	4.63E-03	11	4.50E-04	214	5.06E-04	54

Figure 1. System boundary of the clementine crop.

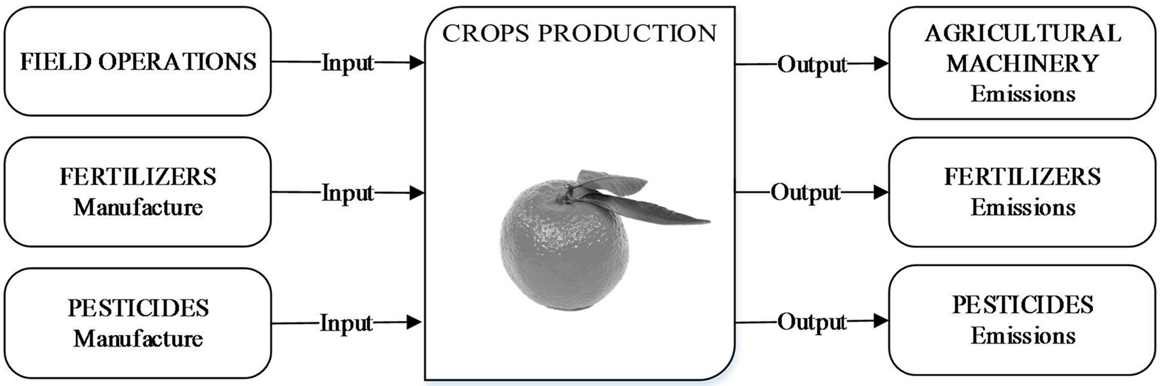

Figure 2. Environmental performances of the conventional and organic farming systems in Spain and Italy.

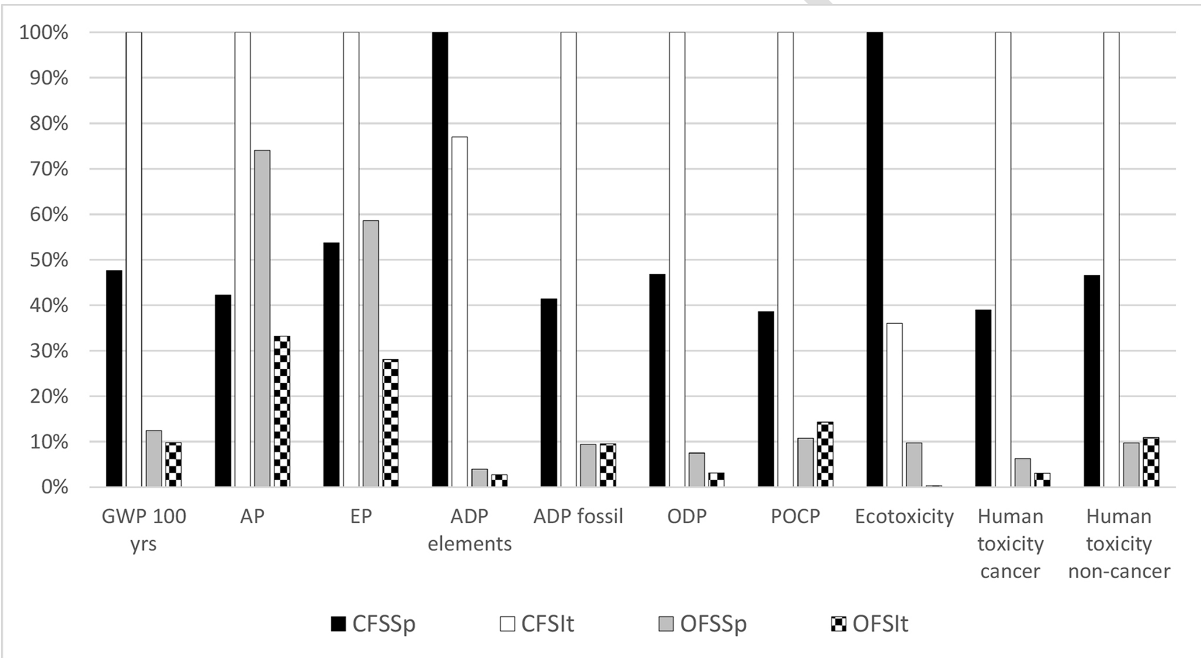

Figure 3. Environmental performances of the conventional farming systems in Spain and Italy.

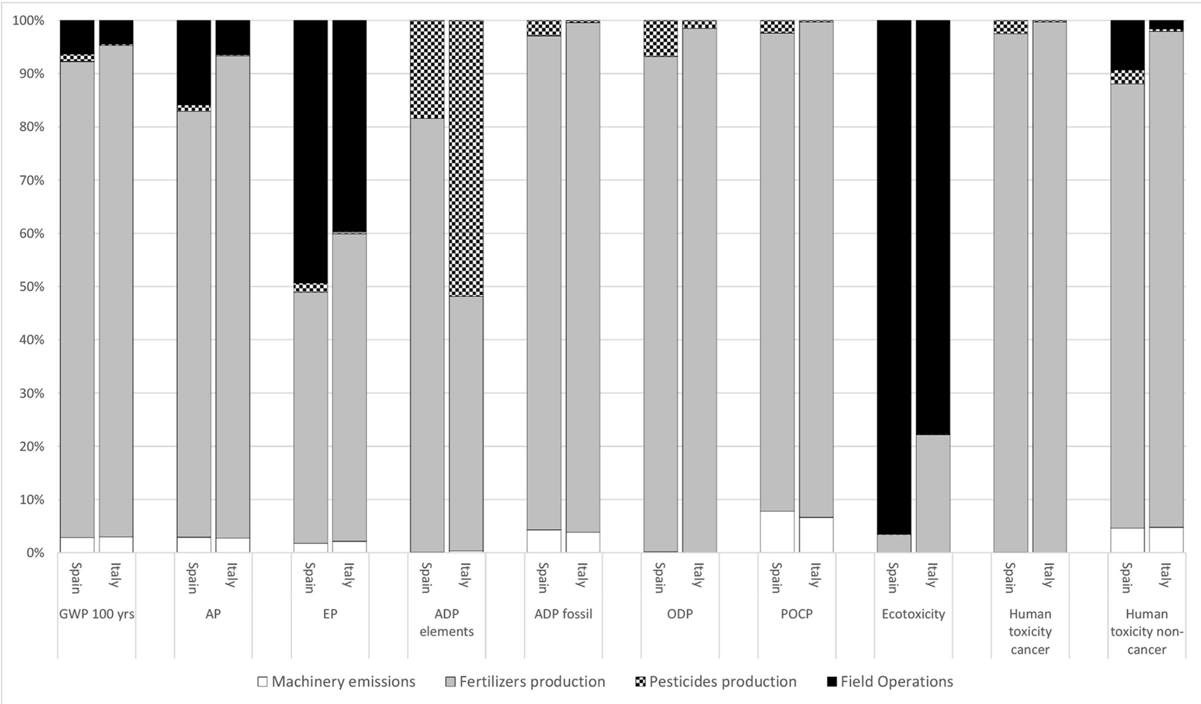

Figure 4. Environmental performances of the organic farming systems in Spain and Italy.