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Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis

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ABSTRACT

The island of Sicily has a long standing tradition in citrus growing. We evaluated the sustainability of orange and lemon orchards, under organic and conventional farming, using an energy, environmental and economic analysis of the whole production cycle by using a life cycle assessment approach. These orchard systems differ only in terms of a few of the inputs used and the duration of the various agricultural operations. The quantity of energy consumption in the production cycle was calculated by multiplying the quantity of inputs used by the energy conversion factors drawn from the literature. The production costs were calculated considering all internal costs, including equipment, materials, wages, and costs of working capital. The performance of the two systems (organic and conventional), was compared over a period of fifty years. The results, based on unit surface area (ha) production, prove the stronger sustainability of the organic over the conventional system, both in terms of energy consumption and environmental impact, especially for lemons. The sustainability of organic systems is mainly due to the use of environmentally friendly crop inputs (fertilizers, not use of synthetic products, etc.). In terms of production costs, the conventional management systems were more expensive, and both systems were heavily influenced by wages. In terms of kg of final product, the organic production system showed better environmental and energy performances.

1. Introduction

In 2010 the worldwide production of citrus was around 124 million tons. Italy is the eighth biggest producer with 3.2 millions tons and 172,618 ha, 60% of which are made up of orange orchards (103,313 ha) and 16.7% of lemon orchards (28,854 ha) (FAOSTAT, 2010). The areas of cultivation are mainly in Southern Italy, particularly in Sicily, where the production of red oranges, such as 'Tarocco', 'Moro', 'Sanguinello' and 'Sanguigno' is concentrated in the foothills of the Etna volcano and where along the coast 90% of the Italian lemon industry is located, based on three major cultivars: 'Femminello' (95%), 'Monachello' (2%) and 'Interdonato' (3%).

Over the last few decades, Italian citrus fruit producers have been losing their competitive edge to both the foreign and domestic markets (Baldi, 2011). Organic farming may represent a positive factor for the revival of citrus production, overcoming the negative factors that are currently weighing on the sector: lack of organization, small-sized farms, increasing input costs, and strong competition from other Mediterranean countries. In Italy, organic citrus growing represents 14% (23,424 ha) of the total acreage dedicated to citrus orchards. Of this 14%, organic orange groves account for 55% and lemon orchards for 19% (SINAB, 2010).

According to Madge (2009), citrus is well suited to organic production. It is considered by some (Kaval, 2004) as one of the more profitable crops using organic methods. As Kaval (2004) said, the quality of the end product benefits a lot from this technology.

The agro-food sector is one of the most significant contributors to energy consumption and thus to Global Warming Potential (GWP) (Gan et al., 2010) for the increase of greenhouse gases

Abbreviations: CL, Conventional Lemon; OL, Organic Lemon; OO, Organic Orange; CO, Conventional Orange; EA, Energy Analysis; LCA, Life Cycle Assessment; GWP, Global Warming Potential; AD, Abiotic Depletion; OLD, Ozone Layer Depletion; AA, Air Acidification; PO, Photochemical Oxidation; EU, Eutrophication.

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(GHG), mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere causing temperature to rise. Significant improvements are thus required to make food production and consumption more sustainable. As Gan et al. (2010) said, a comprehensive approach is needed to address issues such as technological innovation, consumer demand, and long-term environmental changes.

Efficient energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, preserves fossil resources and reduces air pollution (Pervanchon et al., 2002). According to Ozkan et al. (2004), considerable research has been conducted on energy use in agriculture and in conventional citrus production, however there is little scientific literature available on energy consumption in organic citrus production.

Namdari et al. (2011) carried out an input–output energy analysis of conventional citrus production in the Mazandaran province (Iran) to identify the major energy flows. Polychronaki et al. (2007) used an energy analysis to evaluate the energy efficiency of production processes, including conventional citrus production, in order to compare their energy consumption and to examine the sustainability of agro-ecosystems. Ozkan et al. (2004) carried out an energy and economic analysis of conventional citrus production in Turkey for an energy audit of citrus production. Only La Rosa et al. (2008) have used the energy analysis to compare conventional and organic productions of red oranges in Sicily, and to evaluate use of resources, productivity, environmental impact and overall sustainability. However this study is not directly comparable with our research since a different methodology was applied.

Although in the last decade the use of the life cycle assessment (LCA) methodology on food-processing has increased (Clasadonte et al., 2010), in the citrus sector only orange production is sufficiently weighed. As Knudsen et al. (2011) noted, LCA studies have focused mainly on orange juice (Coltro et al., 2009; Beccali et al., 2009; La Rosa et al., 2008; Schlich and Fleissner, 2005; Clasadonte et al., 2010; Munasinghe et al., 2009; PepsiCo UK & Ireland, 2008; Tesco, 2009; Tropicana, 2009). Regarding the carbon footprint (CF), data on greenhouse gas (GHG) emissions have been collected for orange production in Brazil, Italy and Spain, however, as Mordini et al. (2009) showed, only a few publications have reported data for agricultural production, while other data have been documented for the whole production chain of orange juice. Two studies reported GHG emissions for various production steps of the orange production in Spain (Ribal et al., 2009; Sanjuán et al., 2005). A complete literature review assessing the sustainability or environmental impacts of fruit production can be found in Cerutti et al. (2011).

The combined use of LCA and energy analysis could be useful to provide information for policy makers and producers in choosing sustainable management systems or products. In any case, increases in sustainable agricultural production with competitive costs, are vital to improve the economic conditions for farmers. In food production, the usual criteria to compare different management systems are the net return and the benefit–cost ratio (Ozkan et al., 2004, 2007), however as Mohammadi and Omid (2010) noted, the main objective in agricultural production is to increase yield and decrease costs.

Most studies, apart from Clasadonte et al. (2010), have analysed citrus production referring to only one crop year. Only a few research studies have compared organic and conventional farming (Knudsen et al., 2011; Ribal et al., 2009; La Rosa et al., 2008).

The aim of our study was to evaluate the sustainability of organic farming methods compared to conventional methods through an energy, environmental and production cost analysis of the whole production cycle of lemon and orange orchards (from orchard establishment to the end of the crop cycle).

2. Materials and methods

2.1. Orchard management systems

The study was performed in the provinces of Catania and Syracuse (Sicily, Italy). Data were collected from 80 face-to-face interviews with orange and lemon growers over the last four production years (2008–2011), using a survey questionnaire that was developed from results and information derived from previous focus groups. The questionnaire was administered to a stratified sample of producers, representative of study areas (farm size and homogeneous characteristic of cultivation and environment). Of these, four orchard systems, all of the same age, were chosen as case studies (conventional lemon – CL; organic lemon – OL; conventional orange – CO; organic orange – OO).

For a comprehensive analysis, field results, integrated with the literature data, were extended to the whole production cycle of citrus systems. Following suggestions from Milà i Canals et al. (2006) and Cerutti et al. (2010), the whole orchard life cycle was considered. The following farming operations were taken into account: orchard plantation (soil preparation, pre-plantation fertilization, tree plantation, irrigation system); soil tillage; fertilization; irrigation; weed and disease control; pruning; harvesting and orchard removal (Tables 1 and 2).

Lemon and orange orchards differed in terms of type and quantity of inputs used and also pruning operations: the lemon orchards were manually pruned every year, while the orange orchards were manually pruned soon after plantation and mechanically pruned a few years afterwards. Pruning residues were collected manually and removed from the lemon orchards for the subsequent burning, while they were cut and left on the ground as a mulch in the orange orchards. The two management systems (conventional and organic) differed mainly in terms of fertilization and weed and disease control techniques.

The reference period of the analysis was set at 50 years, equal to the average productive cycle for citrus orchards. The energy, economic and environmental evaluations performed refer to 1 ha and 1 kg of output (fruit crop yield).

2.2. Energy analysis (EA)

Following Namdari et al. (2011), the energy analysis technique was used to calculate the energy involved in the production of citrus. The data collected cover the duration of each operation and the quantities of each input (machinery, fuel, fertilizers, chemicals, irrigation water, labour, etc.). Energy values of unit inputs are given in mega joules (MJ) by multiplying each input by its own coefficient of equivalent energy factors taken from the literature (Pimentel and Pimentel, 1979; Volpi, 1992; Monarca et al., 2009; Page, 2009).

In order to calculate machinery energy, the following formula was used:

$$ME = \left[(E_{eq}*G/T)\right]*H \quad (1)$$

where E_{eq} was the machinery energy equivalent (MJ kg^{-1}), G the weight of machines (kg), T the economic life of machines (h), and H the number of hours the machine was used to carry out the various operations (h) (Ozkan et al., 2007).

Energy consumption for machinery maintenance was estimated as a percentage of energy in manufacturing and materials (23% for tractors; 30% for tillage machines) (Milà i Canals, 2003).

Table 1
Main features of the examined orchard systems.

Orchard characteristics	Conventional lemon	Organic lemon	Conventional orange	Organic orange
Cultivar	Femminello		Tarocco	
Planting density	484 trees ha^{-1} (4.5 m × 4.5 m)	625 trees ha^{-1} (4 m × 4 m)	400 trees ha^{-1} (5 m × 5 m)	
Training system	Globe			
Pruning method/frequency	Manual/annual		Mechanical and manual/annual	
Pruning residues management	Manually removed from the field		Used as soil mulching residues	
Irrigation	Microjet			
Fertilization	Conventional technique and fertirrigation[a]	Organic fertilization manure and fertirrigation	Conventional technique and fertirrigation	Organic fertilization and fertirrigation
Weed control	Mechanical tillage and herbicides	Light mechanical tillage	Mechanical tillage and herbicides	Light mechanical tillage
Disease control	Conventional products	Mineral compounds	Conventional products	Mineral compounds
Harvesting method	Manual			
Yield (t ha^{-1} year^{-1}) over 2008–2011	Range [24.8–34.8] mean 30.0	Range [24.5–32.3] mean 27.5	Range [22.2–34.5] mean 28.6	Range [17.8–32.2] mean 24.7

[a] Fertirrigation is an agronomic practice that provides fertilizers by means of irrigation system.

The energy input was examined as direct and embodied forms, renewable and non-renewable energies. Direct energy included human labour, electricity, diesel fuel, lubricants and water for irrigation used in the citrus production; while embodied energy covered machinery and maintenance, chemicals, fertilizers, manure and plastic materials. Non-renewable energy consists of diesel, lubricants, chemicals, electricity, fertilizers and machinery energies. Renewable energy includes human labour, plants, manure and water for irrigation (Namdari et al., 2011).

2.3. Environmental analysis

To quantify the environmentally significant inputs and outputs of the studied systems, the life cycle analysis was performed. The LCA methodology is an efficient method to assess impact on the environment, mainly used in industry, but in recent years largely used also in agriculture. As Clasadonte et al. (2010) noted, LCA can identify environmental improvement opportunities and suggest alternative methods for agricultural production in order to reduce the environmental impact and increase product sustainability. The analysis was conducted using SimaPro 7.2, with the problem-oriented LCA method developed by the Institute of Environmental Sciences of the University of Leiden (Centrum voor Milieukunde Leiden: CML, 2001). We chose this method because it focuses on a series of environmental impact categories expressed in terms of emissions to the environment or resource uses, and because in the characterization phase, inventory results are expressed in physical units (Guinée et al., 2002).

Table 2
Farm inputs used in the examined orchard systems during the reference period (50 years).

	Conventional lemon	Organic lemon	Conventional orange	Organic orange
Fertilizers (kg ha^{-1})				
Manure	1200	200,000	1200	24,000
Poultry manure		45,600		109,200
Organic fertilizer		9000		9000
NPK	40,000		57,200	
phosphorite			2250	
Potassium nitrate			2250	
Mineral superphosphate	800		800	
Ammonium sulphate	11,250		13,800	
Potassium sulphate	400		400	
Urea	23,100		15,100	
Chemicals (kg ha^{-1})				
Mineral oil	2210	1315	3149	1633
Spinosad				0.02
Chlorpyrifos	38		92	
Roundup				
Lannate	3		4	
Linuron			7	
Copper oxychloride	158			
Rogor	2			
Bordeaux mixture		456		
Glyphosate	113		32	
Irrigation water (m^3 ha^{-1})	243,700	203,600	241,500	199,600
Irrigation system (kg ha^{-1})	1383	2123	2629	4923
Trees (kg ha^{-1})	968	1250	800	800
Electricity (kWh ha^{-1})	28,603	28,272	24,338	28,309
Human labour (h ha^{-1})	34,789	35,959	21,504	18,397
Machinery and farm tools (h ha^{-1})	35,886	36,981	33,217	24,942
Diesel – oil (kg ha^{-1})	32,937	33,538	30,079	25,400
Lubricants (kg ha^{-1})	539	547	504	416

The system boundary was set at the farm gate, because the main goal of the research was to compare the four citrus production systems. So it was from orchard plantation to orchard removal (50 years), excluding transportation of the product to its final destination and the pruned residues burning. The system boundary encompassed impacts associated with the construction of capital equipment, machineries and infrastructures, fuel, electricity, water, fertilizers and pesticides used in the various farming operations.

As functional unit, that is the reference unit against which the inventory data and results are normalized, both 1 ha and 1 kg of oranges and lemons for fresh consumption were chosen in order to facilitate analysis and interpretation of the environmental impact (Seda et al., 2010; Cerutti et al., 2011).

Emissions from input consumption (water, diesel, electricity, fertilizers, pesticides) and those from the construction of capital equipment, machineries and infrastructures were derived from the ECOINVENT database and the LCA Food DK database in Simapro 7.2.

The impact assessment was performed in terms of the following impact categories commonly used in agricultural LCAs: abiotic depletion (AD), that is related to extraction of minerals and fossil fuels due to inputs in the system; global warming potential (GWP) or climate change; photochemical oxidation (PO), which represents the formation of reactive substances (mainly ozone) which are detrimental to human health and ecosystems and which also may damage crops; air acidification (AA), that describes the fate and deposition of acidifying substances on soil, groundwater, surface water, organisms, ecosystems and materials (buildings); eutrophication (EU), that includes all impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil.

The basic structure of impact assessment methods in SimaPro includes characterisation, damage assessment, normalisation and weighting, but only the first step is required according to the ISO standards. In particular, in the first step the substances that contribute to an impact category are multiplied with a characterisation factor that expresses the relative contribution of the substance. So, using manure as fertilizer, some impact categories show a negative environmental load, that is an environmental benefit (Goedkoop et al., 2010).

Besides the phases of classification and characterisation which represent the most objective approach including no interpretation of values in judging the importance of different impact categories, we performed data normalization to identify the highest impact category.

2.4. Production costs analysis

A production costs analysis was used to evaluate the costs related to different methods of citrus growing: organic and conventional farming.

On the assumption that the production techniques of all management cycles of the citrus have not been modified significantly over the last fifty years, the analysis identified four main life cycle phases of citrus farming: soil preparation and tree plantation, tree growth, full production, and plant removal. For each phase, the main typologies of cultivation management were identified along with the associated fixed and variable costs.

The cumulative costs of citrus production were evaluated for each year taking into account expenses over the whole life cycle of orchards related to materials, labour and services, quotas and other duties. Materials included the cost of all non-capital inputs such as fertilizers, pesticides, herbicides, fuel, water and other crop specifics; labour included the cost of workers involved in farm production; quotas and services include machinery, equipment, depreciation costs, and interest on circulating and anticipation capital (Pappalardo et al., 2013).

The analysis was based on the following assumptions:

- all costs were measured considering the current hourly wage of workers for manual and mechanical operations;
- machinery and equipment costs were calculated as fixed and operating costs. The estimation of the investment costs was based on the replacement values of the machines (depreciation) and on interest and insurance costs. Operating costs included repair and maintenance costs, as well as fuel and lubricants costs of self-propelled machinery.
- costs of irrigation were calculated as the cost of installing an irrigation system and as operating and maintenance costs.

In order to analyse the amount of total costs over fifty years, i.e. the life cycle cost (LCC), each value of the annual costs, whose current prices referred to 2010, was indexed and aggregated using a rate anticipation $(1/q^n)$, where: n refers to the individual years of cultivation ($n = 1$....,50) and q represents an indexing factor, whose interest rate was assumed to be equal to 2%. All values of the indexed costs were then added together.

To evaluate the whole LCC, expressed as the sum of costs for each cultivation, the cumulative value was calculated by taking into account the indexing of costs for different production phases as follows:

$$\sum_{n=1}^{50} \text{LCC} = \left[\sum_{n=1} \text{PP}*\left(\frac{1}{q^n}\right)\right] + \left[\sum_{n=1,\ldots 4} \text{GTP}*\left(\frac{1}{q^n}\right)\right] + \left[\sum_{n=5,\ldots 50} \text{FPP}*\left(\frac{1}{q^n}\right)\right] + \left[\sum_{n=50} \text{PRP}*\left(\frac{1}{q^n}\right)\right] \quad (2)$$

where:

$\sum_{n=1}^{50^{th}}$ LCC : are the "Life Cycle Costs" referring to the whole life cycle (50 years).

$\sum_{n=1}$ PP : is the "Plantation Phase" in the 1st year of the life cycle. It includes soil preparation, tree plantation and irrigation system installation.

$\sum_{n=1,..4}$ GTP: is the "Tree Growth Phase" from 1st to 4th year. It includes the normal production techniques (pruning, disease control, weed control, soil tillage, etc.).

$\sum_{n=5,..50}$ FPP: is "Full Production Phase" from 5th to 50th year. It includes the normal production techniques (pruning, disease control, weed control, soil tillage, etc.).

$\sum_{n=50}$ PRP: is the "Plant Removal Phase" in the 50^{th} year.

3. Results and discussion

3.1. Energy consumption

The total energy used, in terms of land unit (ha), in conventional orange and lemon systems was higher than in the organic system (+51% in lemon production; +39% in orange production) (Table 3). In fact Brodt et al. (2007) argued that conventional farming generally relies on higher per hectare fossil fuel inputs than organic systems due to the high energy requirements in the manufacture of synthetic nitrogen fertilizers (Kaltsas et al., 2007). In our research, fertilization, together with harvesting, consumed the largest amount of energy used (about 70%). Likewise, the harvest was the largest energy-consuming operation in the organic systems (61% in OL; 34% in OO). In particular, the harvesting of lemon tree is more intense in terms of energy consumption because plant density is higher (Table 1) and lemon fruits can be picked all year round (up to 5 times).

The analysis of the distribution of the anthropogenic energy input in citrus production (Fig. 1) suggested that in conventional systems, the highest energy input was provided by fertilizers and chemicals followed by diesel fuel and lubricants. Similar results were found in Ozkan et al. (2004), where nitrogen had the biggest share in the total energy input. Namdari et al. (2011) and Polychronaki et al. (2007) argued on the other hand, that in these systems the highest energy input was diesel fuel, which was similar

Table 3
Energy consumption for the examined orchard systems during the reference period (50 years).

Agricultural operations	MJ ha^{-1}			
	Conventional lemon	Organic lemon	Conventional orange	Organic orange
Soil preparation, trees plantation and irrigation system installation	192,128	232,401	289,936	475,179
Pruning	32,590	90,186	30,625	32,142
Diseases control	188,105	107,200	389,073	247,062
Weed control	29,466	0	10,127	0
Soil tillage	189,618	247,573	260,852	318,153
Irrigation	329,909	328,559	278,737	358,180
Fertilization	1,533,034	33,835	1,610,586	385,220
Harvesting	1,607,217	1,668,510	976,909	941,719
Plants' removal	6301	9188	7793	10,764
Total energy input	4,108,367	2,717,452	3,854,639	2,768,419

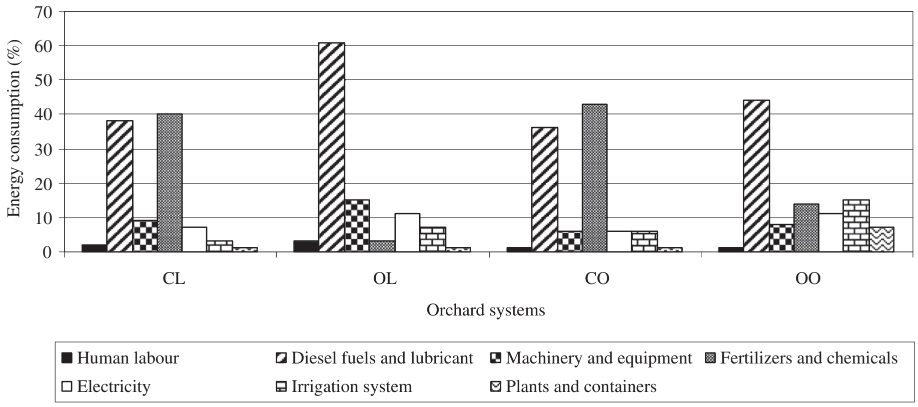

Fig. 1. Comparison of the energy inputs per hectare of the examined orchard systems during the reference period (50 years). (CL = Conventional Lemon orchard; OL = Organic Lemon orchard; CO = Conventional Orange orchard; OO = Organic Orange orchard).

in all the analysed organic systems, followed by machinery and equipment in OL and by irrigation in OO (Fig. 1).

On the other hand, as in other studies (Ozkan et al., 2004; Namdari et al., 2011; Polychronaki et al., 2007), we found that human labour was one of the least demanding energy inputs for citrus production with, on average, 53,900 MJ ha^{-1} (only 2% of the total consumed energy).

Conventional systems (CS) used more indirect energy (55% of total energy input) than direct forms, mainly due to the use of fertilizers and chemicals (Table 4). On the other hand, organic systems consumed more direct energy (74% in OL and 57% in OO), especially diesel fuels for field operations. However, all the investigated orchards were primarily based on non-renewable energy: the share of renewable energy use was very low (5% in CL; 7% in CO; 10% in OL; 16% in OO). This suggests that citrus production, at least in the research areas, depended mainly on fossil fuels, fertilizers and chemicals, machinery and electricity, as is also the case with most fruit production systems (Cerutti et al., 2011).

3.2. Environmental impacts per land unit

The LCA of lemon and orange systems revealed how on a hectare basis conventional systems led to higher environmental impacts (Table 5), particularly in terms of abiotic depletion, global warming and air acidification (Fig. 2). In terms of impact categories, negative numbers represented beneficial environmental impacts. More negative results therefore represented a greater environmental benefit (Recycled Organics Unit – The University of New South Wales, 2007).

The highest contribution to GWP, particularly in conventional systems, was largely due to the production of chemical fertilizers (75% in CL and 78% in CO), while in organic systems, it was from the electricity required in fertirrigation and irrigation, and from the diesel fuel consumed in harvesting (Fig. 3).

Throughout the life cycle of the conventional systems, acidification potential, was mainly due to air emissions of NH_3 and N_2O from fertilizer production and use (62% in CL; 79% in CO). On the other hand, SO_2 and SO_x emissions from diesel fuel consumed in harvesting, the second major cause of AA, contributed only 22% in CL and 10% in CO (Fig. 3). In organic systems, this impact category presented negative numbers, thus meaning a beneficial environmental impact for the use of manure in soil preparation and in fertilization.

Abiotic depletion and photochemical oxidation confirmed the above: fertilization and harvesting had the highest environmental impact, except in OO where irrigation was the second cause of AD and PO (Fig. 3). On the other hand, in all systems, eutrophication presented negative numbers due the beneficial effects linked to the use of manure as a fertilizer, particular in those organics.

In accordance with our data, Ribal et al. (2009) reported that in integrated production scenarios, the greatest impact was caused largely by fertilizer production, while in organic production, the emissions primarily responsible were a result of machinery and irrigation energy consumption.

The results obtained suggest the need to implement measures to save energy and resources and to reduce the environmental releases from the production systems (Beccali et al., 2009).

3.3. Cumulative production costs

Life cycle costs were employed to compare the economic results of conventional and organic methods of orange and lemon farming in order to better evaluate the sustainability of the two different

Table 4
Some energy forms in citrus production.

Item	MJ ha^{-1}			
	Conventional lemon	Organic lemon	Conventional orange	Organic orange
Direct energy	1,938,145	2,025,482	1,726,568	1,545,217
Indirect energy	2,175,022	714,586	2,230,439	1,188,855
Renewable energy	203,529	287,055	285,420	450,515
Non-renewable energy	3,909,638	2,453,013	3,671,587	2,283,558
Total energy input	4,113,167	2,740,068	3,957,007	2,734,073

Table 5
Results of the life cycle impact assessment per hectare for each examined orchard system during the reference period (50 years).

Impact categories	Unit ha^{-1}	Conventional lemon	Organic lemon	Conventional orange	Organic orange
Abiotic Depletion (AD)	kg Sb eq	1672	1491	1572	972
Global Warming Potential (GWP100)	kg CO_2 eq	169,057	55,224	179,515	51,052
Photochemical Oxidation (PO)	kg C_2H_4 eq	38	36	46	24
Air Acidification (AA)	kg SO_2 eq	801	−2237	1071	−1343
Eutrophication (EU)	kg PO_4 3-eq	−100	−4118	−90	−2564

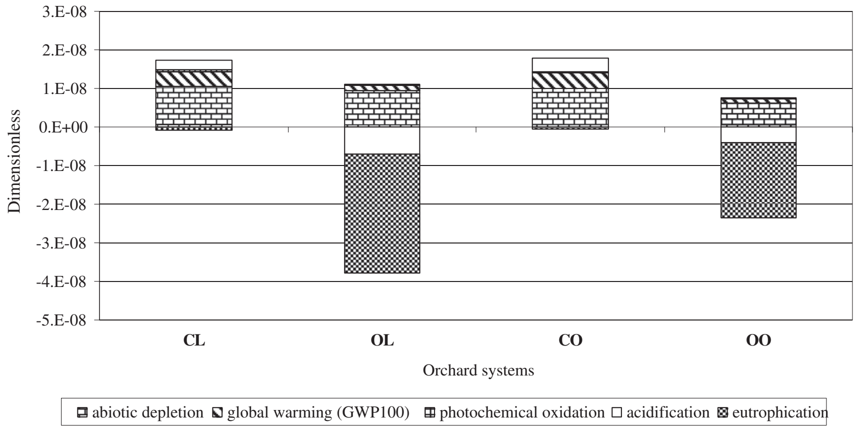

Fig. 2. Normalization of Impact Categories of the examined orchard systems during the reference period (50 years). (CL = Conventional Lemon orchard; OL = Organic Lemon orchard; CO = Conventional Orange orchard; OO = Organic Orange orchard).

methods of cultivation. Each agricultural operation included materials, labour and services and quotas, and other duties (Table 6).

Conventional lemon was the most expensive cultivation, averaging 180,533 € ha^{-1}, but at the same time organic lemon registered a very close value of life cycle costs to conventional growing (178,074 € ha^{-1}).

This low difference in cumulative costs between the organic and conventional methods of lemon cultivation was certainly due to the specificities of the cultivation process, which required fewer mechanical operations. In fact plant protection treatments and mineral nutrition activities were lower than those of orange. On the other hand, manual operations such as harvesting and pruning had the

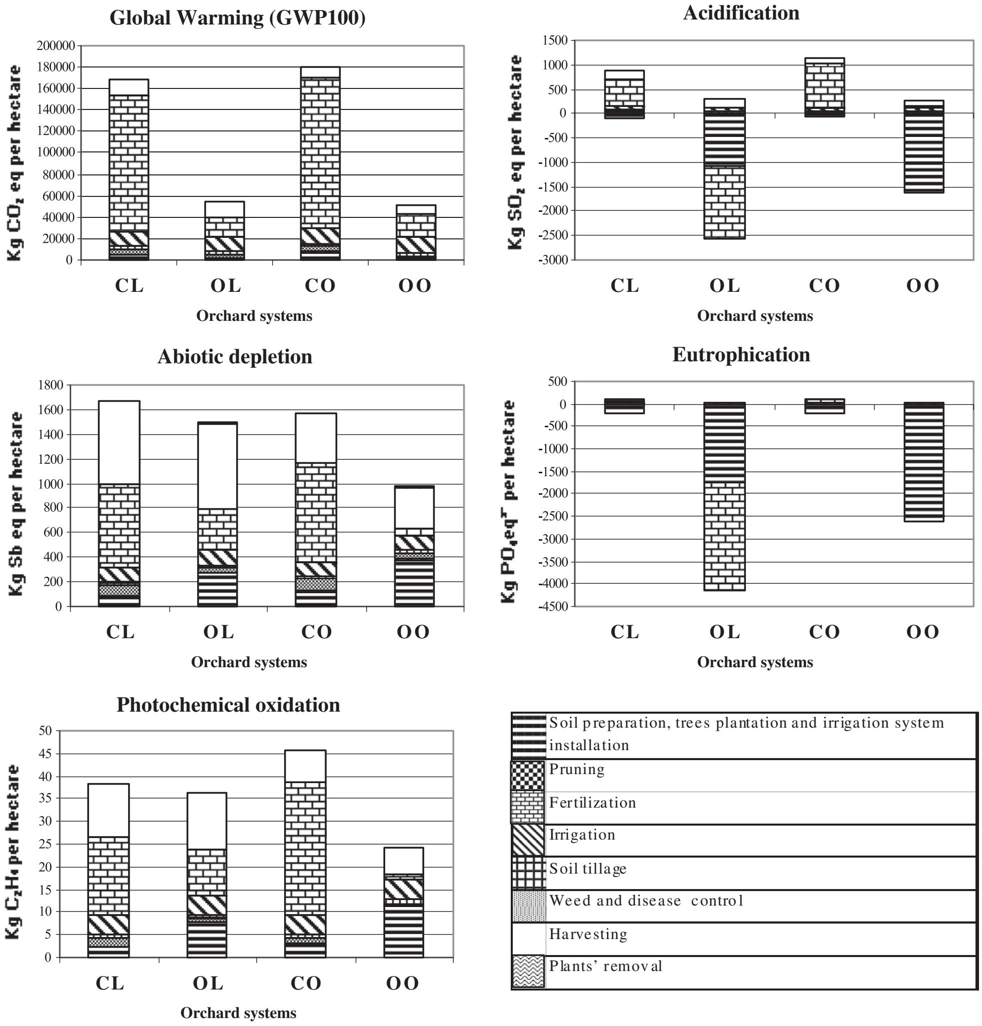

Fig. 3. The contribution of the agricultural operations to Abiotic Depletion, Global Warming Potential, Air Acidification and Eutrophication per hectare for each examined system during the reference period (50 years). (CL = Conventional Lemon orchard; OL = Organic Lemon orchard; CO = Conventional Orange orchard; OO = Organic Orange orchard).

Table 6
Operating costs of the examined orchard systems for the cumulative period of 50 years (€ ha^{-1}).

Agricultural operation	Conventional lemon		Organic lemon		Conventional orange		Organic orange	
	€ ha^{-1}	%	€ ha^{-1}	%	€ ha^{-1}	%	€ ha^{-1}	%
Plantation phase	6539	3.6	7031	3.9	8253	5.4	9430	7.1
Growing tree phase	5454	2.8	2940	1.9	5616	3.5	4613	3.7
- Pruning	629	0.3	466	0.3	670	0.4	569	0.4
- Disease control	291	0.2	240	0.1	246	0.2	342	0.3
- Weed control	124	0.1	–	0.0	244	0.2	–	0.0
- Soil tillage	829	0.5	719	0.4	721	0.5	1324	1.0
- Irrigation	805	0.4	763	0.4	744	0.5	891	0.7
- Fertilization	1727	1.0	338	0.2	1883	1.2	796	0.6
- Harvesting	736	0.2	298	0.4	803	0.3	504	0.6
- Other manual operation	314	0.2	116	0.1	305	0.2	188	0.1
Full production phase	167,254	92.9	166,852	93.6	138,723	90.2	117,458	88.0
- Pruning	20,902	11.6	27,392	15.4	18,632	12.1	20,879	15.6
- Disease control	11,008	6.1	4397	2.5	13,972	9.1	8030	6.0
- Weed control	977	0.5	–	0.0	954	0.6	–	0.0
- Soil tillage	6768	3.8	9539	5.4	6865	4.5	6395	4.8
- Irrigation	17,732	9.8	15,914	8.9	17,348	11.3	17,345	13.0
- Fertilization	17,161	9.5	16,207	9.1	22,571	14.7	25,626	19.2
- Harvesting	82,688	45.9	86,038	48.3	50,159	32.6	35,742	26.8
- Other manual operation	10,018	5.6	7365	4.1	8223	5.3	3441	2.6
Plants' removal phase	1287	0.7	1251	0.5	1519	1.0	1659	1.2
Total	180,534	100.0	178,074	100.0	154,111	100.0	133,160	100.0

greatest impact on lemon cultivation, in terms of work and costs, and their incidence was very similar for both methods of farming. In lemon cultivation, pruning also represented a useful means to prevent phytosanitary problems, thus reducing the use of chemicals for disease control (Sturiale and Scuderi, 2004).

With respect to orange, the conventional systems had higher cumulative costs (154,110 € ha^{-1}) than the organic systems (133,159 € ha^{-1}). In this case the difference in costs between the two different methods was much more evident in the lemon systems; our findings showed that disease control and harvesting lead to increased costs in conventional cultivation.

With regard to the individual agricultural operations, around 90% of total costs were related to the full production phase. Fruit harvesting was the most expensive operation in each of the four cultivations, amounting to 30% in orange cultivation (organic and conventional systems), and 50% in lemon, for both methods. The second mostly costly item was pruning in lemon production and fertilization in orange production (Table 6).

These results show how organic cultivation had a lower rate of overall costs than conventional farming, and appears to be twice as sustainable due to the lower use of chemicals and the subsequent reduction in overall costs.

At the same time we observed differentiations with respect to each cultivation: the gap between organic and conventional methods was higher in the orange than in the lemon. These findings suggest that organic orange farming is economically more sustainable than organic lemon, and confirm previous research (Sturiale and Scuderi, 2008; Scuderi and Zarbà, 2011; Chinnici et al., 2013).

Table 7
Energy consumption, production costs and impact assessment of the Global Warming Potential (GWP) referred to 1 kg of fruit crop for each examined orchard system during the reference period (50 years).

	Systems			
	Conventional lemon	Organic lemon	Conventional orange	Organic orange
Yield (kg ha^{-1})	1,440,973	1,292,375	1,345,375	1,160,900
Total energy input (MJ kg $citrus^{-1}$)	2.85	2.10	2.87	2.38
Production costs (€ kg $citrus^{-1}$)	0.13	0.14	0.11	0.11
GWP (kg CO_2 eq kg $citrus^{-1}$)	0.12	0.04	0.13	0.04

3.4. Analysis per output unit

Organic systems were the least energy consuming systems and had the least impact in terms of MJ kg^{-1} and kg CO_2 eq kg^{-1} harvested fruit crop. Production costs were slightly higher for the organic lemon orchards, and despite their lower productivity, resulted in a more sustainable fruit crop (Table 7).

In our studied systems, the energy used to obtain 1 kg of product was higher with respect to data available in the literature: 1.52 and 1.80 MJ kg^{-1} for orange and lemon productions, respectively, in Turkey (Ozkan et al., 2004); 1.92 MJ kg^{-1} for orange production in Iran (Namdari et al., 2011), 0.28 MJ kg^{-1} for citrus production in Epirus (Polychronaki et al., 2007). According to the authors, citrus production in Epirus was so low because the agricultural activity was less intensive despite an average yield equal to 33,000 kg ha^{-1}. The differences between our results (Table 7) and the literature data are due to the methodology used and probably to the different period of analysis (whole production cycle against one year crop).

On the other hand, our data (Table 7) showed much lower GHG emissions per kg of fruit crop than emissions found in Brazil for organic orange (0.84) and conventional orange productions (1.12) (Knudsen et al., 2011). Our data were also lower than those estimated by Ribal et al. (2009) (0.33 for oranges from integrated production and 0.22 for oranges from organic production), Sanjuán et al. (2005) (0.25 for oranges from integrated production) and Beccali et al. (2009) (0.10 for oranges) reported in the literature review of Mordini et al. (2009). In this case, the differences between our results and the literature data are due to the LCA method used and to the yield (kg ha^{-1}).

4. Conclusions

The concept of sustainability has been widely debated in the international scientific community for processed products (i.e. orange juice), however there are few studies that analyse the impact on the environment of unprocessed agricultural products. Our study attempted to bridge the gap by providing some important results.

Taking into account all the aspects investigated by this study (economic, energy, and of environmental impact), organic management systems were more sustainable than conventional ones both per hectare and per kg of final product, thanks to the use of environmentally friendly crop inputs (fertilizers, not use of synthetic products, etc.).

An increased use of non-renewable energy forms would reduce the negative effects to the environment and maintain sustainability and decrease energy consumption. In addition, replacing pesticides and chemical fertilizers with other more environmentally friendly products could have a positive effect on biodiversity and human health.

Organic farming may represent a positive factor for the revival of citrus production in Sicily, but farmers need to recognise that organic management involves a different approach to orchard management, and is not simply the 'standard' approach based on different inputs. Conventional producers should use organic techniques in order to meet the increasing international demand for sustainable products; to avoid depletion of nitrogen, phosphorus, potassium and water resources, and to spend less money in terms of pest weed control and the lack of heavy agricultural operations.

Lastly for a more realistic analysis, in terms of GWP, it is necessary to include soil carbon sequestration in LCA, as some studies have attempted to do, however using different methodologies and time horizons. Few data are available concerning the ability of traditional and intensive orange orchards to store carbon, while no data are currently available on the whole life cycle: this will be our future target.

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