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Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives

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ABSTRACT

Olive growing is an important cultural and traditional system in the Mediterranean region that has considerable environmental impacts. Italy is ranked second in the world in terms of olive production and olive-cultivated area. Apulia is Italy's largest olive growing region and accounts for 33% of the total Italian surface area planted to olive trees.

Organic farming is assumed to have beneficial effects by reducing the environmental impacts of agricultural practices. However, literature shows that this system is not always less harmful to the environment than the conventional one. This study investigates this hypothesis through the comparison of environmental impacts and economic performances between organic and conventional olive systems in Apulia region. It also provides options to optimize the agricultural practices that could contribute to the reduction of the environmental impacts. Life Cycle Assessment (LCA) was applied to evaluate the environmental impacts, and Life Cycle Costing (LCC) was utilized to assess the economic performance of the studied systems referring to one hectare as functional unit and to a system boundary limited to olive production (cradle-to-farm gate).

Results showed a lower environmental impact of agricultural practices in the organic system, mainly due to the higher efficiency in reducing the impact on fossil fuel depletion. Moreover, the organic system resulted to have higher Net Present Value and Internal Rate of Return values that indicate its higher profitability as compared to the conventional system. Optimization of fertilization is the first priority to optimize olive growing, particularly in the organic system, since manure fertilization results in higher costs and higher environmental impact on almost all impact categories compared to synthetic foliar fertilization. Good agricultural practices with electrically-driven irrigation system, mechanical weeding and biological pest control, no-tillage or reduced tillage can be considered as further optimization options to mitigate environmental burdens and reduce their costs.

1. Introduction

Agriculture is a multifunctional complex system that causes high environmental burdens ranging from the consumption of natural resources to the production of wastes. It is mainly the result of intensive agricultural practices and new techniques.

Agriculture is the first step of the food supply chain and is characterized by additional impact categories related to biodiversity, landscape, soil fertility, erosion and hydrological changes (Guinée et al., 2006). Moreover, emissions from agriculture are highly variable depending on climate, soil type, farming practices and many other inter-related factors (Audsley et al., 1997). Therefore, it is difficult to avoid emissions associated with the agricultural practices, but some measures for the control of farm management practices could reduce them.

Extensive research has been and is still being developed to evaluate farming practices and assess the total agricultural impact on the environment, using different methodologies. Among them, life cycle thinking seems to be the most holistic approach, which includes the whole life cycle of any product or service. LCA was developed primarily for industrial production systems (Heijungs et al., 1992), and then adapted to agriculture (Audsley et al., 1997)

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by appropriate adjustments (Cowell and Clift, 1997; Haas et al., 2000). This methodology has become a fundamental tool to compare the environmental impacts between alternative systems in the agricultural sector. One of the major themes in LCA studies related to agricultural production systems is the comparison between organic and conventional farming (Hayashi et al., 2005). With this in mind, De Backer et al. (2009) have assessed the ecological sustainability of leek production, Venkat (2012) has compared the greenhouse gas (GHG) emissions of 12 crops, Mattsson and Wallén, (2003) and Williams et al. (2006) have studied the energy of organic and conventional potatoes. In addressing the environmental impacts associated with the conversion from conventional to organic farming, Wood et al. (2006) have reported the conversion as a viable way of reducing energy use and greenhouse gas emissions in the Australian conditions and Haas et al. (2005) have discussed the environmental impact of 9 categories associated with the conversion from conventional to organic grassland in Germany. Martínez-Blanco et al. (2009) have compared the impacts between organic waste compost and mineral fertilizer.

In agriculture, like in other sectors, LCA practitioners have tended, over the past decade, to link the environmental evaluation to economic and social aspects. The most common economic methodology integrated with LCA is Life Cycle Costing (LCC). Although the basic methodology of LCC is still under discussion and no related databases do exist, researchers are sometimes forced to do things differently than in the LCA (Guinée et al., 2006) keeping the same functional unit and system boundary. There is, however, a little literature on this type of integration concerning the agricultural production (Brandão et al., 2010; De Gennaro et al., 2012; Notarnicola et al., 2004; Strano et al., 2013).

Olive oil production is the most common and traditional cultivation in the Mediterranean countries. Olive area is increasing yearly at global scale particularly in Italy which is ranked second in the world for olive production and cultivated area (FAOSTAT, 2010) and first for the world's organic olive areas (Willer and Kilcher, 2012). Apulia, as the Italian leader region of olive area, represents 33% of the total olive area in Italy (ISTAT, 2009) and 30% of Italian organic olive area (SINAB, 2010).

Intensive olive farming is a major cause of one of the most serious environmental problems affecting the EU today, namely soil erosion and desertification that concern specifically Spain, Greece, Italy and Portugal (Beaufoy, 2001; Tombesi et al., 1996). The European Communities (EC) have reported the harmful effects caused by intensive olive production on the environment (EC, 1999).

Despite the lack of concrete data on the environmental effects of olive farming in EU Member States, especially on specific impacts such as soil erosion, water use, biodiversity and chemical pollution (Beaufoy and Pienkowski, 2002), some authors have studied the influence of soil management on soil erosion in olive orchards in different Mediterranean areas (Francia Martínez et al., 2006; Kosmas et al., 1996; Pastor and Castro, 1995). However, few researchers have investigated the environmental impact of olive cultivation using LCA methodology. Some of them have assessed the environmental impact of the olive oil production process for the purpose of designing an environmental profile to improve the olive oil production chain (Michalopoulos et al., 2011; Salomone and Ioppolo, 2012) or evaluating the consumption of raw materials and emissions of pollutants (Avraamides and Fatta, 2008). These studies were also aimed at identifying the processes that cause the most significant environmental problems. They have reported the agricultural production phase as the heaviest contributor to the environmental impact of olive oil production. De Gennaro et al. (2012) have assessed the environmental impacts of innovative olive growing models through a comparison between the high density and super-high density of olive systems. Salomone and Ioppolo (2012) have included organic scenarios in the evaluation of olive oil supply chain. Another study has concerned the organic system analysis (Notarnicola et al., 2004) through the comparison between conventional and organic olive oil production systems in order to assess whether the organic olive oil is more eco-compatible than the conventional one.

However, all previous studies have focused on the whole olive oil production system without going into the details of each single field operation. Hence, the present study has focused on field agricultural practices of organic and conventional olive systems to identify what are the practices that have the highest environmental impacts and how to optimize them. Moreover, LCC was integrated with LCA analysis to assess the economic dimension of all agricultural practices and of the whole system. The analysis involved the entire 50-year life cycle to extend the comparison to different scenarios of each agricultural practice and to evaluate economically both systems as a long term investment.

Based on the above, the objectives of this study are:

- To compare the environmental impacts and the economic performances of two (organic and conventional) olive production systems through their life cycle.
- To identify the environmental and economic hot-spots of each system for the potential optimization of olive agricultural practices.
- To compare, environmentally and economically, different scenarios of each agricultural practice.

2. Methodology

2.1. System description

The study area was the province of Bari, in Apulia, a region in southern Italy. In this province, around 10.4% of olive-growing area is managed organically (the largest organic olive-growing area) and accounts for 30.4% of the total organic olive-growing area of Apulia region (ORAB, 2009).

In the present study, two drip-irrigated olive systems, i.e. organic (Org.) and conventional (Conv.) plantations of 30–40 year-old olive trees were selected to be compared. Both systems are oriented to olive production and planted with 200–280 trees/ha following the system indicated as traditional in the classification of Gabrielli et al. (2008) or as intensive traditional (Beaufoy and Pienkowski, 2002) by the European Environmental Agency (EEA). Moreover, both systems are planted with *Olea europea* L., cv. Coratina as the prevalent variety in the region (Vossen, 2007).

On the basis of farmers' information and according to the classification of olive life cycle stages proposed by Barone and Di Marco (2003), the total olive life cycle was assumed to extend over 50 years and was divided into the three following stages:

- Juvenility stage from planting till the fourth year of the tree. This stage is characterized by training pruning without significant production from olive trees.
- Growth stage from the 5th (start of bearing) till the 17th year when the tree is shaped to produce optimal yield. During this stage, the tree continues to grow and is pruned so as to ensure both training and production.
- Productive stage from the 18th year – when the production can be considered as being constant – till the 50th year when olive yield starts to decrease. In this stage, the tree is subjected only to productive pruning that ensures productivity and reduces the effect of alternate bearing.

Table 1
Agricultural practices during the olive life cycle.

Agricultural practice		Juvenility stage[a]		Growth stage[a]		Productive stage	
		Organic	Conventional	Organic	Conventional	Organic	Conventional
Pruning	Pruning	Manually every year	Manually every year	Manually every 2 years	Manually every 2 years	Mechanically every two years	Mechanically every two years
	Collecting residues	Disposal outside the field	Disposal outside the field	Collecting in channel between rows and crashing them over the surface	Collecting in channel between rows and crashing them over the surface	Collecting in channel between rows and crashing them over the surface	Collecting in channel between rows and crashing them over the surface
	Green pruning	Manually every year	Manually every year	Manually every two years	Manually every two years	Manually every two years	Manually every two years
Harvesting		–	–	Semi-mechanized	Semi-mechanized	Mechanically by tractor and shakers	Mechanically by tractor and shakers
Soil management	Tillage	Heavy tillage once per year covering all surface	Heavy tillage twice per year covering all surface	Heavy tillage once per year covering all surface	Light tillage 3 times/year covering all surface	Once per year at 15 cm depth between trees rows	No tillage
	Harrowing	Twice per year for all surface	–	Twice per year for all surface	–	Twice in the year at 4–5 cm depth between trees rows	1–2 times in the year (4 –5 cm depth)
Weed control		Twice per year, using herbicides	Twice per year, using herbicides	Integrated with Harrowing activity	Two times/year, using herbicides	Mechanically under the trees using weed cutter	Chemically, 1–2 times in the year
Pest control		–	–	6 treatments every year, using chemical pesticides	8 treatments every year, using chemical pesticides	Spraying copper, distributing traps	Spraying chemical products 7 times
Irrigation		Water distribution by water tank and tractor	Water distribution by water tank and tractor	Water distribution by water tank and tractor	Water distribution by water tank and tractor	Drip irrigation using well driven by electrical energy	Drip irrigation using well driven by electrical energy
Fertilization		Mechanical distribution on the soil, using N.P.K fertilizers	Mechanical distribution on the soil, using N.P.K fertilizers	Mechanical distribution on the soil, using N.P.K fertilizers	Mechanical distribution on the soil, using N.P.K fertilizers	Manure fertilization	Foliar fertilization only

[a] The organic system was still conventional during this stage.

Actually each stage was associated with changes in agricultural practices to fit the plant development stages. Within each stage, agricultural practices do not change significantly.

The main agricultural practices are presented in Table 1. They were performed conventionally in a similar way during the juvenility and growth stages of both systems. The main differences between the two systems are related to the productive stage, in particular for the performance of fertilization, soil management, weed and pest management.

2.2. Data collection and analysis

Data were taken for the whole life cycle starting from the period of farm establishment till the time of performing this study. Most data were collected through farmers by means of specific and detailed questionnaires concerning the following items:

- Machinery/tool inventory (type, mass, power, related economic data, …)
- Input inventory, including all the products used for each agricultural practice (type, active ingredients, quantity, prices)
- Irrigation system inventory, including the materials and inputs used for setting up the system (type of materials, diameter, weight, length, prices, …)
- Labor classification and associated wages
- Production and selling prices
- Detailed description of each agricultural practice (performance, time and efficiency, applied inputs, labor, transportation, machinery, etc...).

Missing or incomplete data were collected through experts or from official websites. The data of farm establishment procedures were also collected through farmers and/or from Italian references (Augusti and Baglini, 1992; Porciani, 1997). The data related to the agricultural machinery efficiency and to the characteristics of olive plantations were compared with the Italian references (Bellomo and D'Antonio, 2009; Gabrielli et al., 2008; Pampanini and Pignataro, 2006) for improving their accuracy.

Table 2 describes all quantities of inputs applied for each agricultural practice. Collected data were processed in an inventory table (combination of Tables 1 and 2) describing in detail all the agricultural practices over the entire life cycle. The agricultural practices were grouped in different categories (soil management, fertilization, pest control, weed control, irrigation, harvesting and pruning).

2.3. Life Cycle Assessment of olive production

2.3.1. Goal and scope of the study

Comparing the potential environmental impacts of two (conventional and organic) Apulian olive production systems was the main goal of this study. This comparison is aimed to assess whether the organic system is a good alternative for reducing the environmental impact and how to optimize the local agricultural practices, either organic or conventional. The evaluation of both systems throughout the entire life cycle was intended to assess the potential changes in the environmental performance as influenced by the change in crop management.

The results of this study were referred to a 1-ha olive-growing area, taken as functional unit.

The system boundary of this study (Fig. 1) is considered since the extraction of raw materials of inputs up to the farm gate when the olive is harvested. All inputs (fuel, fertilizers, pest control products, water, electricity, materials for setting up the irrigation system etc.) were included considering their manufacturing

Table 2
Agricultural practices and input quantities applied during olive life cycle.

Agricultural practice	Input	Active ingredient	Unit/ha/yr	Juvenility stage[a]		Growth stage[a]		Productive stage	
				Org.	Conv.	Org.	Conv.	Org.	Conv.
Pruning	Gasoil		L	8.0	7.0	6.0	5.0	4.5	12.5
	Gasoline		L	–	–	–	–	13.0	9.2
	Lubricant		L	0.3	0.3	0.2	0.2	0.6	0.8
Fertilization	Single superphosphate		kg	–	150	–	230	–	–
	Triple superphosphate		kg	120	–	180	–	–	–
	Ammonium sulfate		kg	225	230	–	–	–	–
	Urea		kg	–	–	250	250	–	40
	NPK 20:20:20		kg	–	–	–	–	–	10
	Potassium chloride		kg	–	150	–	220	–	–
	Potassium sulfate		kg	150	–	250	–	–	–
	Manure		kg	–	–	–	–	10,000	–
	Gasoil		L	4.0	9.0	10.0	9.0	4.0	8.0
	Lubricant		L	0.2	0.4	0.4	0.4	0.2	0.3
Soil management	Gasoil		L	80.0	70.0	50.0	45.0	30.0	22.6
	Lubricant		L	3.2	2.8	2	1.8	1.2	0.9
Weed control	Gasoil		L	–	3.0	–	6.0	–	6.0
	Gasoline		L	–	–	–	–	20	–
	Lubricant		L	–	0.12	–	0.24	0.6	0.24
	Roundup[b]	Glyphosate 41.5%	L	–	10	–	18	–	15
Irrigation	Gasoil		L	118.3	126.0	135.0	120.0	–	–
	Electricity		kwh	–	–	–	–	303.6	384
	Lubricant		L	4.7	5	5.4	4.8	–	–
	Water		L	77,760	82,800	103,680	124,200	30,000	353,280
Pest control	Gasoil		L	–	–	27.0	25.0	6.7	24.0
	Lubricant		L	–	–	1.1	1	0.3	1
	Oliocin[b]	Mineral oil 80%	L	–	–	–	–	–	12.0
	Polvere caffaro[b]	Copper 30%	kg	–	–	4.9	4	–	7
	Bordeaux mixture[b]	Copper 20%	kg	–	–	–	–	12	–
	Supracide[b]	Methidation 400 g/l	L	–	–	–	1.2	–	–
	Lebaycid[b]	Fenthion 100 g/l	L	–	–	8	5.2	–	–
	BT		L	–	–	–	–	0.5	–
	Roger L 40[b]	Dimethoate 38%	L	–	–	1	0.8	–	3
Harvesting	Gasoil		L	–	–	8.0	65.5	78.1	61.2
	Gasoline		L	–	–	57.4	–	–	17.5
	Lubricant		L	–	–	2	2.6	3.1	3

[a] The organic system was still conventional during this stage.
[b] Commercial name.

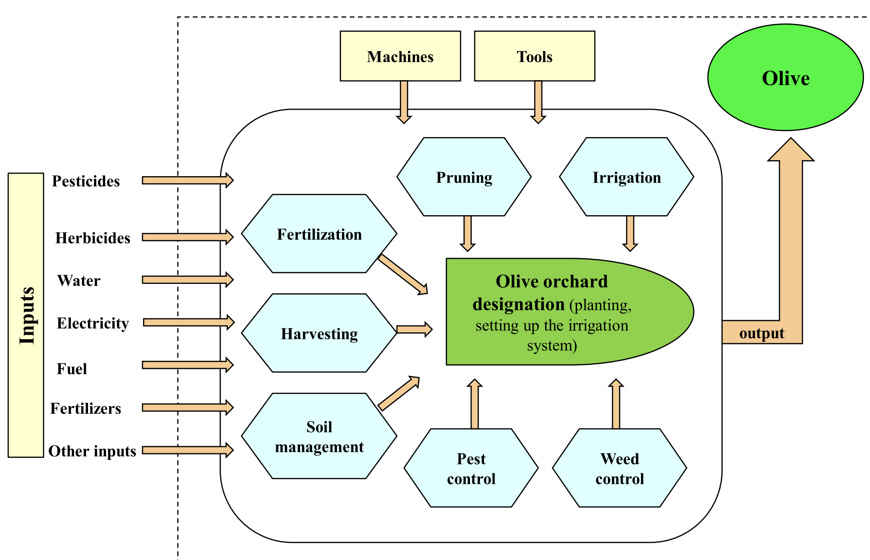

Fig. 1. System boundary of studied systems.

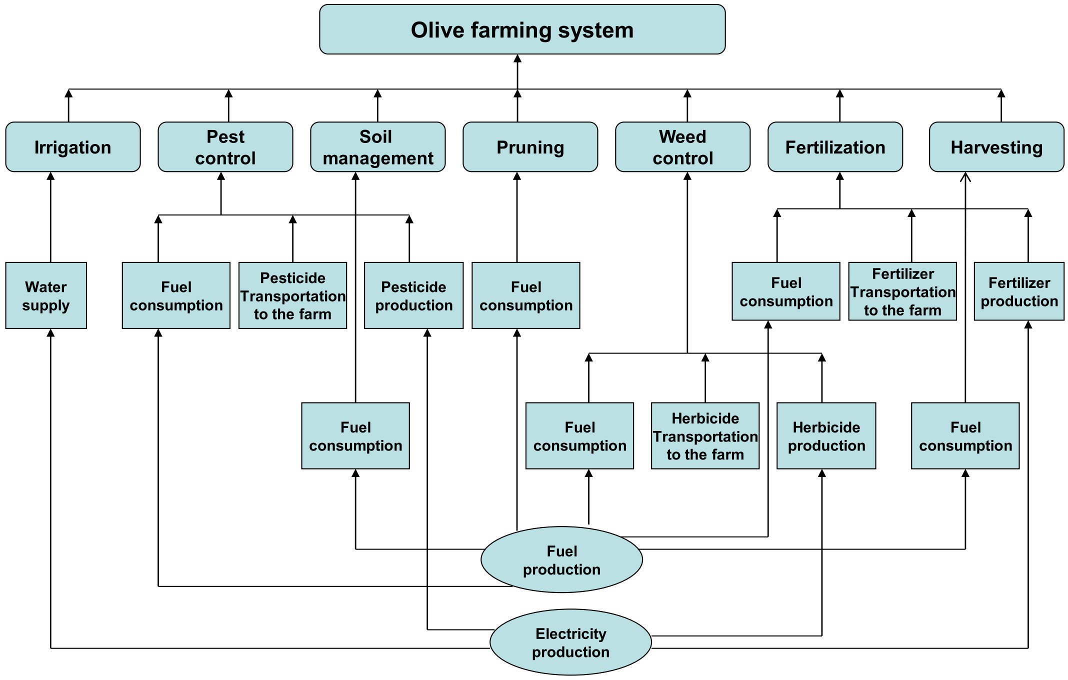

Fig. 2. Flow chart of olive farming system.

processes. Both internal and external transportation of all inputs, as well as olive transportation inside the farm, were considered. Olive seedlings, buildings and machines were excluded from the analysis due to the lack of appropriate information in the databases and because they were similar in the two systems. Land use for different crops in the past was excluded due to incomplete data.

Based on Hammond and Jones (2010) approach, the environmental impact of manure fertilizer production was assumed to be zero as it is wastes produced by other systems responsible for the environmental impact up to the point of delivering these wastes to a new system to be used. Moreover, manure fertilizer is sourced locally and was assumed to be transported by single-unit truck over a 60-km distance. All other inputs (including synthetic fertilizers and pesticides) were assumed to be transported for 15 km from the local market by a van.

2.3.2. *Life Cycle Inventory analyses*

Collected data were inserted in Simapro software and were processed in accordance with the agricultural processes described in Fig. 2 by using existing LCA databases, particularly Ecoinvent. Each agricultural practice was categorized as a process in the software. For each process, input quantities taken from the collected data were associated with appropriate default values (representing the environmental impacts of each input type production) taken from the software databases.

Regarding the impact assessment of fertilization and pest control practices, additional data were estimated and inserted in the software as output emissions concerning on-field emissions caused by the application of fertilizers and pesticides. In order to make this estimate, some information were taken from laboratory analyses (soil analyses) and other data, based on site-specific information,

Table 3
Data and methodological sources for emission estimation.

Emission item	Methodology source	Information required for the estimate	Information source
NH_4^+ from manure	(Brentrup and Küsters, 2000)	Manure type, application time (temperature, time between application and precipitation/incorporation, rainfall after application)	Farmer
		Applied quantity	Farmer
NH_4^+ from mineral fertilizers	(Brentrup and Küsters, 2000)	Applied quantity	Farmer
N_2O from manure and mineral fertilizers	(Brentrup and Küsters, 2000)	Applied quantity	Farmer
NO_3^- from manure	(Brentrup and Küsters, 2000)	N removed by harvesting	(Fernández-Escobara et al., 2012), farmer
		N removed by pruning	(Fernández-Escobara et al., 2012), farmer
		Soil texture	MAIB institute laboratory
		Precipitation, evapo-transpiration	Regione Puglia
		Applied quantity	Farmer
NO from manure and mineral fertilizers	(Bouwman et al., 2002)	Applied quantity	Farmer
CO_2 from urea fertilizers	(IPCC, 2006)	Applied quantity	Farmer
Pesticides	(EEA, 2009)	Applied quantity	Farmer
		Pesticide vapor pressure	Pesticide's label

Table 4
Estimated on-field emissions caused by fertilization and pest control practices.

Agricultural practice	On-field emissions	Compartment	Unit/ha/yr	Juvenility stage[a]		Growth stage[a]		Productive stage	
				Org.	Conv.	Org.	Conv.	Org.	Conv.
Fertilization	Nitrous oxide N_2O[b]	Air	kg	1.68	1.81	4.52	4.52	1.97	0.44
	Carbon dioxide CO_2	Air	kg	–	–	183.33	183.33	–	29.30
	Ammonia NH_3	Air	kg	5.46	5.58	20.94	20.94	2.99	3.54
	Nitric oxide NO	Air	kg	0.96	0.98	2.46	2.46	0.54	0.43
	Nitrate NO_3	Groundwater	kg	4.97	6.06	2.46	74.37	13.57	–
Pesticides	Methidathion	Air	kg	–	–	–	0.07	–	–
	Fenthion	Air	kg	–	–	0.12	0.08	–	–
	Copper	Air	kg	–	–	0.04	0.03	0.02	0.02
	Dimethoate	Air	kg	–	–	0.08	0.06	–	0.57

[a] The organic system was still conventional during this stage.
[b] The emitted quantities in the table were converted to Carbon Dioxide equivalent (CO2-eq) based on IPCC emission factors for Greenhouse Gas Inventories (N2O = 310 CO2-eq).

were obtained from literature or simulated from published models, as shown in Table 3. The result of estimated on-field emissions is shown in Table 4.

In this contest, LCA databases lack the majority of agricultural input information, particularly the complete production process of fertilizers and pesticides. This problem was not substantial in the handling of fertilizer products that have been mentioned in this study, except the production process of complex NPK fertilizer (NPK 20:20:20). The data for this fertilizer have been associated with the production of three single fertilizers (fertilizer N, fertilizer P, fertilizer K) taken form Ecoinvent database.

Handling pesticides and herbicides is very crucial and difficult at the same time in the agricultural LCA studies. In the present study, the active ingredient of each product has been calculated and used in the analyses. Polvere caffaro, Bordeaux mixture, Olicin and Roundup products were used in the analyses based on the quantity of their active ingredients, and the default values for the production of those active ingredients were taken from the software databases. The quantity of active ingredients of other products (Supracide, Lebaycid, Rogor) has been associated with the production of organophosphorus compounds. On the other hand, biological products such as *Bacillus Thuringiensis* (BT) were excluded due to the absence of the production processes of biological agents in the databases.

2.3.3. Life Cycle Impact Assessment

Environmental profiles were analyzed by means of LCA methodology using Simapro 7.1 software (Pré Consultants, 2006) following the damage oriented method using the Eco-indicator 99 (H) V2.04/Europe (EI 99 H/A). The aim of using damage oriented method in the analyses was to involve the normalization step in the impact assessment having a single point (pt) for each impact category in order to facilitate the comparison between impact categories.

Three end-point damage categories identified by Eco-indicator 99 method were studied, i.e. human health, which includes six impact categories (carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, stratospheric ozone depletion), ecosystem quality, which includes three impact categories (ecotoxicity, acidification/ eutrophication, land use) and resources depletion, which includes minerals and fossil fuel impact categories.

2.4. Economic analyses

2.4.1. Life Cycle Costing (LCC) analyses

The SETAC working group on LCC classifies three types of LCC: conventional, environmental and societal LCC (Hunkeler et al., 2008). The first type does not consider externalities, contrary to the second and third types. In the present study, conventional cradle-to-gate LCC was applied and includes the assessment of all costs during the entire olive life cycle using the same functional unit and system boundary of LCA.

Life Cycle Costing in this study was based on the cash flow analysis, by calculating all the costs and revenues associated to the agricultural practices of each single year and for the entire olive life cycle; this results in the economic evaluation of olive systems as a long-term investment and of the operating costs associated with the agricultural practices.

The first step of the analysis was the calculation of the initial investment costs. In this context, soil preparation and olive planting (soil break-in, drill-hole fertilization, soil refinement, holes digging, planting, supporting olive seedlings by pallets, etc...) were considered as initial investments performed at the beginning of the olive orchard establishment. Setting up the irrigation system and its reconstruction were instead considered as future investments, since they were installed after many years from the establishment of the olive orchard.

The costs of agricultural practices and revenues were calculated taking into consideration the following:

- The discount rate was estimated to 1.25%;
- The operational costs included the input costs, labor costs and the interest on working capital;
- Taxes were not considered, since some taxes are not mandatory in the region, while others are related to the farm as a whole and difficult to be allocated to agricultural practices;
- The input prices and wages were referred to the 2010–2011 crop year. Most prices were taken directly from the farmers, while others were based on average market prices.
- Fresh olive, which is used for olive oil extraction, was the main source of income for farmers. Subsidies given to promote organic farming were considered to be 335€/ha/year (the average premium over the period certified as organic) as determined by the Rural Development Program (RDP) of Apulia region (Regione Puglia, 2008). This subsidy was considered starting from the year in which the organic system was certified till the end of the study period.
- Olive prices were provided by olive merchants trading in the province of Bari, and reflected the market prices referred to 2011.

2.4.2. Net Cash Flow and profitability analyses

In the present study, the annual net cash flow was determined for each year by calculating the total costs and revenues of all agricultural practices. As for the remaining years of the study period (50 years), the costs and olive yields were assumed to vary (as a result of alternate bearing) and they were determined by taking the average of the last 4 high yielding years and the average of the last 4 low yielding years. Net cash flow was used for determining the profitability of both systems based on the Net Present Value (NPV) and the Internal Rate of Return (IRR). They are the preferred methods for long-term economic evaluation, since they consider the time value of money as well as the size of cash flow through the full investment life cycle (Kay et al., 2008).

NPV was calculated based on Eq. (1):

$$\mathrm{NPV} = \frac{P_1}{(1+i)^1} + \frac{p_2}{(1+i)^2} + \cdots + \frac{p_n}{(1+i)^n} - C \quad (1)$$

where NPV is the Net Present Value, P_n is the net cash flow in year n, i is the discount rate and C is the initial cost of the investment.

The Internal Rate of Return is the discount rate that makes the net present value equal to zero (Kay et al., 2008). It was calculated using Eq. (1), by making the net present value equal to zero and solving the equation for the rate of return (i), as shown in Eq. (2):

$$C = \frac{P_1}{(1+i)^1} + \frac{p_2}{(1+i)^2} + \cdots + \frac{p_n}{(1+i)^n} \quad (2)$$

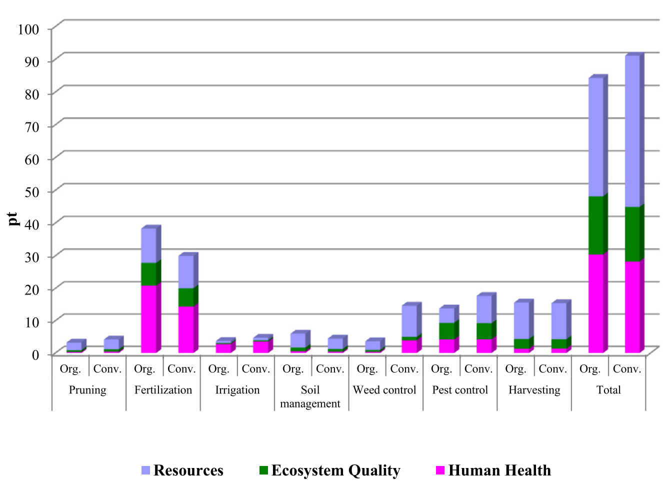

Fig. 3. Annual environmental impact by end-point impact categories and agricultural practices.

3. Results and discussion

3.1. Environmental evaluation

The environmental results are discussed in two different parts. In the first part, the environmental impacts caused by both systems in the productive stage were compared in order to find out the main differences between the organic and conventional agricultural practices. The second part describes the environmental impacts caused by agricultural practices during the three stages of the entire life cycle. The aim of this part was not to compare different stages but to extend the comparison between agricultural practices involving more scenarios for each single practice, so as to identify the scenario that most contributes to the reduction of environmental impacts.

3.1.1. Annual environmental impact in the productive stage

The overall environmental impact was higher in the conventional system than in the organic one due to the higher weight of environmental impacts on the resource depletion end-point category as a result of higher fuel consumption for weed and pest control activities (Fig. 3). Similar results were obtained using different impact assessment methods, different functional units and system boundary by Notarnicola et al. (2004) and Salomone and Ioppolo (2012) who have reported a better environmental performance of the organic system compared to the conventional one, although the organic system had higher impacts on some impact categories.

On the other hand, the organic system showed higher environmental impact on human health and ecosystem quality end-point categories, mainly due to the impacts caused by manure fertilization on those categories.

Slight differences were found between both systems regarding the environmental impact caused by irrigation, pruning and harvesting activities (Fig. 3). These differences are related to the number of trees per hectare or to the performance efficiency, since similar machines were used in both systems. The main differences are related to soil management, pest control, fertilization and weed control activities that are managed differently.

Table 5 shows the main differences between the two systems considering each end-point impact category. Manure fertilization induced higher environmental impacts on respiratory inorganics, climate change and eco-toxicity impact categories compared to the use of synthetic foliar fertilizers in the conventional system. This is mainly due to the higher emissions of NH_4^+, NO_3^-, N_2O, NO associated with the field application of manure and its transportation.

Compared to the conventional system, soil management in the organic system induced higher environmental impacts on all

Table 5
Annual environmental impact (in pt) by impact categories and main agricultural practices.

Damage categories	Impact categories	Fertilization		Soil management		Weed control		Pest control	
		Org.	Conv.	Org.	Conv.	Org.	Conv.	Org.	Conv.
Human Health	Carcinogens	0.301	0.146	0.019	0.014	0.014	0.281	1.641	1.403
	Respiratory organics	0.030	0.003	0.001	0.001	0.001	0.003	0.001	0.002
	Respiratory inorganics	15.759	12.316	0.408	0.306	0.290	2.741	2.487	2.631
	Climate change	4.706	1.882	0.090	0.068	0.066	0.888	0.073	0.195
	Radiation	0.013	0.008	0.001	0.001	0.001	0.046	0.002	0.005
	Ozone layer	0.008	0.001	0.000	0.000	0.000	0.001	0.000	0.001
Ecosystem Quality	Eco-toxicity	1.063	0.321	0.017	0.013	0.014	0.503	4.593	3.851
	Acidification/Eutrophication	5.039	4.967	0.051	0.038	0.032	0.193	0.119	0.152
	Land use	0.889	0.410	1.086	0.815	0.551	0.344	0.444	1.001
Resource depletion	Minerals	0.089	0.125	0.003	0.002	0.002	0.098	3.176	2.664
	Fossil fuels	10.404	9.822	4.313	3.235	2.661	9.557	1.242	5.763
Total		38.302	29.999	5.989	4.492	3.631	14.654	13.778	17.667

impact categories particularly on fossil fuel depletion (Table 5). This is obvious because reduced tillage in the organic system required more frequent use of machines and consequently more fuel consumption than no-tillage. In fact, reduced tillage in the organic system is aimed at partially controlling weeds mechanically, since the use of chemical herbicides is forbidden. Hence, Table 5 shows significantly lower environmental impacts, in all categories, to control weeds in the organic system, as compared to the conventional one, which required more fuel for spraying chemical herbicides thus inducing higher environmental impacts particularly on respiratory inorganics and fossil fuel impact categories. The integration between agricultural practices seems to have a positive effect for environmental impact reduction.

The total environmental impact caused by pest control was lower in the organic system compared to the conventional one (Table 5), mainly due to the lower impact on fossil fuel depletion; this reflected the higher efficiency of the organic system in reducing fuel consumption as a result of the lower number of treatments. However, the impact was slightly higher on mineral depletion, eco-toxicity and carcinogens impact categories due to the higher levels of copper. Actually the copper was applied in the organic system without monitoring procedures before the application, as it should be in organic farming.

Fig. 3 shows that fertilization, pest control and harvesting activities were the main contributors to the total environmental impact of both systems due to the higher fuel consumption and to the emissions from fertilizers and pesticides. Moreover, around 50% of the environmental impact in both systems was on resources depletion particularly on fossil fuel consumption that must be given more attention in the context of agricultural practices optimization efforts.

3.1.2. Environmental impacts of agricultural practices scenarios (optimization opportunities)

Going through the three stages of olive life cycle, Table 6 shows the environmental impacts associated to the dynamics of each agricultural practice. It shows the environmental impacts of three fertilization scenarios using three different types of fertilizers: synthetic soil fertilizers in the juvenility and growth stages, manure fertilizers in the productive stage of the organic system and synthetic foliar fertilizers in the productive stage of the conventional system. Including all end-point impact categories, the highest environmental impact was produced when using synthetic soil fertilizers, due to the large quantities of fertilizers, while the lowest environmental impact was induced by synthetic foliar fertilizers that are normally used in small quantities. Therefore, for reducing the environmental impact caused by fertilization, it would be recommended to apply techniques that avoid the intensive use of fertilizers, particularly nitrogen fertilizers that must be applied based on the leaf nitrogen content. This hypothesis was approved by Sánchez-Zamora and Fernández-Escobar (2002) who have reported the non-necessity of obtaining good olive productivity and growth when leaf nitrogen content is above the deficiency threshold. Furthermore, their results showed that leaf nitrogen concentration was higher when the nitrogen was applied to both soil and leaves rather than to the soil only. Thus, the use of biological foliar fertilizers in balance with manure might be an option to reduce the impacts caused by manure application in organic

Table 6
Environmental impacts (in pt) of the agricultural practices during olive development stages.

Agricultural practice	End-point impact category	Juvenility stage[a]		Growth stage[a]		Productive stage	
		Org.	Conv.	Org.	Conv.	Org.	Conv.
Pruning	Human Health	0.1	0.1	0.1	0.1	0.3	0.4
	Ecosystem Quality	0.3	0.3	0.2	0.2	0.6	0.8
	Resources	1.2	1.0	0.9	0.7	2.4	3.0
	Total	1.6	1.4	1.2	1.0	3.3	4.2
Fertilization	Human Health	71.5	61.6	146.9	129.7	20.8	14.4
	Ecosystem Quality	14.6	15.3	38.8	38.8	7.0	5.7
	Resources	47.3	48.1	79.2	76.3	10.5	9.9
	Total	133.5	125.0	265.0	244.7	38.3	30.0
Soil management	Human Health	1.4	1.2	0.9	0.8	0.5	0.4
	Ecosystem Quality	3.1	2.7	1.9	1.7	1.2	0.9
	Resources	11.5	10.0	7.2	6.5	4.3	3.2
	Total	16.0	13.9	10.0	9.0	6.0	4.5
Weed management	Human Health	–	2.6	–	4.7	0.4	4.0
	Ecosystem Quality	–	0.7	–	1.2	0.6	1.0
	Resources	–	6.3	–	11.4	2.7	9.7
	Total		9.6		17.4	3.6	14.7
Irrigation	Human Health	2.0	2.2	2.3	2.1	2.8	3.5
	Ecosystem Quality	4.6	4.8	5.2	4.6	0.3	0.4
	Resources	17.0	18.1	19.4	17.3	0.6	0.8
	Total	23.6	25.2	27.0	24.0	3.7	4.7
Plant protection	Human Health	–	–	3.1	2.9	4.2	4.2
	Ecosystem Quality	–	–	6.8	5.8	5.2	5.0
	Resources	–	–	6.5	6.1	4.4	8.4
	Total			16.4	14.7	13.8	17.7
Harvesting	Human Health	–	–	1.2	1.1	1.4	1.4
	Ecosystem Quality	–	–	2.0	2.5	3.0	2.9
	Resources	–	–	8.8	9.4	11.2	11.1
	Total			12.0	13.1	15.6	15.4
Total		174.7	175	331.5	323.8	84.3	91.1

[a] The organic system was still conventional during this stage.

olive farming and to add nutrients considering the low yield of organic olive trees. However, this assumption needs to be proved by further studies.

Table 6 also shows three soil management scenarios, i.e. intensive tillage in the juvenility and growth stages, reduced tillage in the productive stage of the organic system and no-tillage in the productive stage of the conventional system. The highest environmental impact, for all end-point impact categories, resulted from intensive tillage, while the lowest was found in the no-tillage scenario due to the associated reduction of fuel consumption. Some authors have reported the higher efficiency of reduced or no-tillage systems in lowering the environmental impact as compared to the conventional tillage by reducing the use of machines, reducing CO_2 emissions and increasing carbon sequestration (Smith et al., 2008; West and Marland, 2002). Combination between tillage restriction and other soil management techniques as mulching the soil with pruning residues (Nieto et al., 2010) or cover crops (Castro et al., 2008) decreases indirectly the environmental impact in olive orchards by increasing soil organic carbon.

Two irrigation scenarios can be compared, i.e. manual water distribution (fuel-based energy) during the juvenility and growth stages, and drip irrigation system (electricity-based energy) during the productive stage. Irrigating olive trees by an electrically-driven system induced lower environmental impacts, specifically on the ecosystem quality and resources depletion end-point impact categories (Table 6), compared to the use of manual water distribution, due to the associated reduction of fuel combustion. However, it has higher environmental impact on human health end-point impact category due to higher greenhouses gas emissions associated with the production of electricity.

Table 6 shows two scenarios for pruning and harvesting activities, i.e. semi-mechanized in the growth and mechanized in the productive stage. Obviously the higher environmental impact was found in the case of mechanized performance, which is associated with greater use of machines use and higher fuel consumption.

There are no further scenarios regarding weed and pest control activities in addition to those discussed in the previous chapter.

Indeed, the optimization of fertilization can be classified as the first priority in olive system optimization, followed by irrigation. The third priority is weed and pest control, besides soil management activities, whilst pruning and harvesting can be classified as the fourth priority. This classification was based on the environmental results and on the relevance of environmental impact reduction potential when alternative agricultural practices are compared.

Table 8
Annual operating costs (€/ha) in different development stages.

Agricultural practice	Juvenility stage[a]		Growth stage[a]		Productive stage	
	Org.	Conv.	Org.	Conv.	Org.	Conv.
Pruning	324.4	241.7	395.0	338.9	373.2	330.8
Fertilization	245.7	184.9	315.8	294.9	363.8	59.8
Soil management	176.8	218.0	168.2	149.8	163.6	86.6
Weed control	–	32.2	–	36.14	128.4	151.6
Irrigation	763.1	713.4	896.9	834.1	104.4	152.4
Pest control	–	–	464.2	467.4	124.3	210.3
Harvesting	–	–	951.1	838.4	774.1	676.2
Total	1510.1	1390.2	3191.3	2959.7	2032.0	1667.7

[a] The organic system was still conventional during this stage.

3.2. Economic analyses (LCC)

The initial and future investment costs were almost similar in both systems (Table 7). Moreover, the total operating costs, as well as each single operation's costs were similar during the juvenility and growth stages (Table 8); the differences were not related to the management since both systems were managed conventionally. Therefore, the major cost differences between the two systems were related to the productive stage and are discussed in the following chapter.

3.2.1. Operational costs during the productive stage

The operational costs in the organic system were higher than in the conventional one (Table 8), mainly due to the higher fertilization costs related to the higher costs for manure transportation and soil-application compared to synthetic foliar fertilization. Soil management costs were also higher in the organic system due to the higher input and labor costs of reduced tillage compared to the costs of no-tillage management. On the other hand, the costs for weed and pest control were lower in the organic system which uses less control products and treatments and consequently less inputs and labor.

3.2.2. Operational costs of different agricultural practices scenarios

Based on agricultural practices scenarios (described in Section 3.1.2) and Table 8, further comparison between different scenarios of each agricultural practice can be addressed. The costs of manure fertilization were higher than the costs of the two other synthetic fertilization scenarios due to the higher transportation costs. Relevant decrease of irrigation costs occurred when the management changed from manual water distribution to electrically driven irrigation due to the relevant decrease of fuel

Table 7
Investment costs.

Investment	Operation	Description	Total costs €/ha	
			Organic	Conventional
Olive orchard establishment	Soil break-in		6505.2	6107.9
	Soil fertilization	Organic and chemical fertilizers		
	Soil refinement	Plowing and harrowing		
	Holes digging			
	Drill-hole fertilization	Organic and chemical fertilizers		
	Planting			
	Supporting olive seedlings	Wooden pallets		
Setting up the irrigation system	Digging	Ditches and holes	1887.8	1905.4
	Installation of the irrigation net	Main and secondary tubes, tubes' connectors, drippers		
	Supporting the irrigation system	Pallets and wires		
Reconstruction of the irrigation system	Eliminating the old irrigation net		1640.4	1767.5
	Installing the new irrigation net			

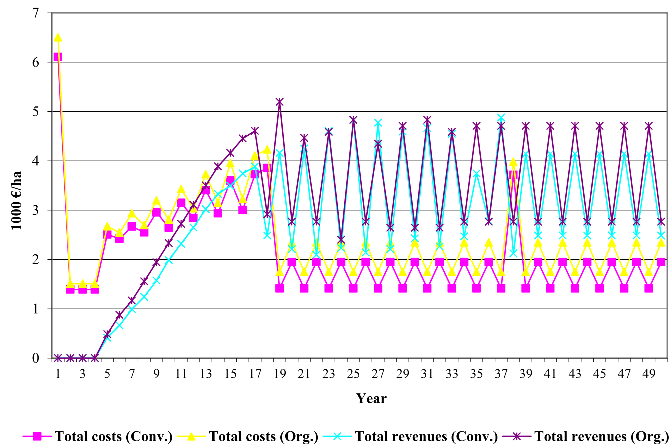

Fig. 4. Total costs and revenues during the entire olive life cycle.

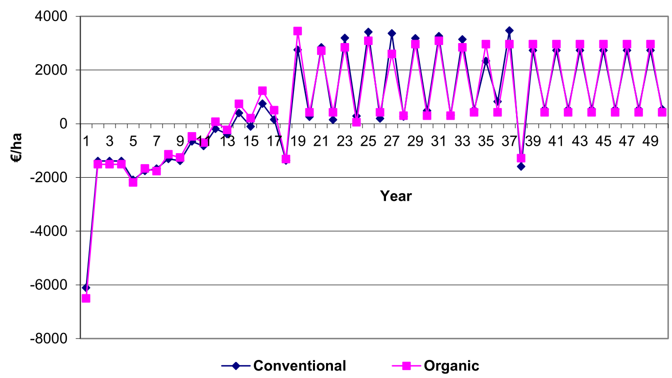

Fig. 5. Net cash flow of the entire olive life cycle.

consumption. The costs of intensive tillage management were higher than reduced and no-tillage management costs due to the direct correlation between soil management intensity and related fuel consumption. Another direct correlation is between pest control intensity and the related costs, as a relevant decrease in input and labor costs occurs when control products and the number of treatments are lower. Weed management increased along olive life cycle because in the juvenility stage additional crops were cultivated between olive trees, so controlling weeds was not needed. On the contrary, when olive trees are growing, no more crops are cultivated and controlling weeds becomes essential. Mechanical pruning and harvesting costs (in the productive stage) were lower than semi-mechanized harvesting in the growth stage due to the relevant decrease of labor costs.

3.2.3. *Net cash flow*

The total annual revenues and costs were increasing along the growth stage (Fig. 4) due to the continuous increase in production and growth and to the rise in labor costs for pruning and harvesting.

In the productive stage, the annual costs and revenues started to fluctuate as a result of the olive alternate bearing. During this stage, the revenues were higher than costs in both systems due to the associated full production stage of olive tree's life. Revenues were higher in the organic system than in the conventional one due to the subsidies and the higher price of organic olive, although the average production of olive trees was lower (25.8 kg/tree/year) in the organic system than in the conventional one (40.8 kg/tree/year).

The three peaks of total annual costs illustrated in Fig. 4 refer to the three aforementioned investments: i.e. initial investment, irrigation system and reconstruction of the irrigation system.

The net cash flow resulting from costs and revenues (Fig. 5) showed higher values in the organic system due to the higher weight of revenues.

3.2.4. *Profitability analysis*

The economic indicators applied to evaluate the cost effectiveness of investments were the NPV and IRR. At the current market prices referred to 2011 (0.36 €/kg for conventional olive and 0.45 €/kg for the organic one), both systems had a positive NPV and an IRR higher than the discount rate (1.25%). The NPV (16,040.5 €/ha) of the organic system was higher compared to the conventional one (15,118.2 €/ha) thus reflecting a better investment (Table 9). The IRR (3.51%) was also higher in the organic system than in the conventional one (3.37%) thus confirming the higher profitability of the investment related to the subsidies and the premium price which was 25% higher than the conventional olive price.

Table 9 shows the importance of prices and subsidies to organic olive farming by illustrating the NPV and IRR as a function of the organic olive prices compared to a fixed conventional olive price (0.36 €/kg). As for subsidies, it is enough for the organic system to have a price (0.45 €/kg) 25% higher than the conventional olive price to have higher profitability. On the other hand, in the absence of subsidies, the organic system should have a price of 0.49 €/kg, namely 36% higher than the conventional system to have higher profitability.

Table 9
NPV and IRR as a function of olive prices in the organic system.

Olive price €/kg		NPV (€)			IRR %		
Conv.	Org.	Conv.	Org. (including subsidies)	Org. (excluding subsidies)	Conv.	Org. (including subsidies)	Org. (excluding subsidies)
0.36	0.39	15,118.2	6465.4	−651.8	3.37	2.31	1.12
	0.4		8,061.3	944.0		2.54	1.43
	0.41		9,657.1	2,539.8		2.75	1.7
	0.42		11,253.0	4,135.7		2.95	1.96
	0.43		12,848.8	5,731.5		3.15	2.21
	0.44		14,444.6	7,327.3		3.33	2.44
	0.45		16,040.5	8,923.2		3.51	2.66
	0.46		17,636.3	10,519.0		3.67	2.86
	0.47		19,232.1	12,114.9		3.84	3.06
	0.48		20,828.0	13,710.7		3.99	3.25
	0.49		22,423.8	15,306.5		4.14	3.43
	0.5		24,019.6	16,902.4		4.29	3.6

4. Conclusions

The organic olive system, compared to the conventional one, has better performance in reducing the environmental burdens of the agricultural practices mainly because of the lower environmental impacts on resource depletion, reflecting a higher efficiency in reducing fossil fuel consumption, particularly during weed and pest control activities.

Although the application of manure fertilizers is more environmentally friendly than the use of synthetic soil fertilizers, it has a higher environmental impact on human health and ecosystem quality, if compared to synthetic foliar fertilizers. Furthermore, manure fertilization is an additional operating cost in the organic system which is, however, more performing in reducing the costs of almost all other agricultural practices.

However, organic fertilizers, such as manure are preferable sources for increasing soil organic carbon and soil organic matter that are very crucial in organic farming. Therefore, adding the effect of manure application on the soil fertility and soil organic carbon content provides a more complete picture for comparing different fertilizers scenarios.

Mechanical weed control and biological pest control contribute to the mitigation of environmental impact and to the reduction of costs, compared to the use of chemical pesticides and herbicides. However, much more attention must be given to the application of copper, particularly in the organic system; it should be used in minimum quantities in order to reduce as much as possible its impact on the ecosystem quality.

Reduced tillage decreases the environmental impact and costs as compared to intensive conventional tillage. However, no-tillage management has better performance than reduced tillage in mitigating the environmental impact and the costs caused by the soil management practice.

Among all agricultural activities, fertilization during the olive life cycle has the highest environmental impact. Optimizing this practice is a priority for optimizing the olive system. In this context, fertilizing organic olive trees based on biological foliar fertilizers in balance with manure could be a good option to reduce the environmental impact and to ensure appropriate nutrients that result in good yields. Moreover, fertilization modeling could be interesting for future studies to select the appropriate scenario and reduce the environmental impacts.

Using electrically driven irrigation, mechanical weeding and biological pest control, no-tillage or reduced tillage application can contribute to mitigate the environmental burdens and reduce their related costs. Optimization of pruning and harvesting activities is less relevant than other activities, in terms of environmental impacts. However, manual or semi-mechanized performance of both activities contributes to reduce the environmental impact but has higher costs compared to the mechanical system.

Olive cultivation is considered as being a profitable investment in both conventional and organic systems. However, profitability is higher in the organic system mainly due to the subsidies and the premium market price that is 25% higher than the conventional olive prices, thus compensating the higher operating costs. The profitability of the organic system becomes lower than the conventional one when subsidies are not taken into consideration; in this case the prices should be higher by at least 36% to reach the same profitability as the conventional system.

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