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Greenhouse Gas Emissions and Carbon Sequestration from Conventional and Organic Olive Tree Nurseries in Tuscany, Italy

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Abstract: In this study, conventional and organic olive tree nurseries were compared through a Life Cycle Assessment (LCA) analysis to identify processes that have a greater environmental impact and which of the two systems leads to lower greenhouse gas (GHG) emissions. Carbon sequestration in the woody biomass of the plants grown with both management systems was also considered. The research was carried out on six olive tree nurseries, four conventional and two managed also with an organic system, located in the nursery district of Pescia (Tuscany, Italy). The functional unit considered was two-year-old pot-grown plants (pot 15 cm Ø) and the results were expressed in terms of kg of CO_2 equivalent (CO_2eq). In all the nurseries analyzed, LCA showed that pots were the highest CO_2eq emission source (45–63%), followed by potting mix (22.6–32.1%). This was due to the use of plastic in pots and peat for the growing media. Organic management was found to have a definite positive influence on the decrease of GHG, reducing the emissions up to 13% compared with conventional nurseries. Considering carbon stocked in the woody tissues of seedlings, the reduction of emissions attained 15.7% though a slightly lower (−6.7%) amount of CO_2 incorporated into biomass was detected in the olive plants grown in organic nurseries. In light of our results, conversion of the nursery industry from conventional to organic management has the potential to reduce its carbon footprint.

Keywords: carbon footprint; conventional management; life cycle assessment; *Olea europaea*; organic management; pot nursery production

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1. Introduction

The importance of olive (*Olea europaea* L.) cultivation is well recognized for its historical, social, and economic aspects [1]. Nowadays, there are more than 10.5 million ha (about 26 million acres) of olives cultivated all around the world [2] in 58 different countries [3]. Among them, Spain is the most important, with almost 25% of the total olive cultivation surface. In particular, Jaèn (Andalucia region) hosts the largest area of olive groves in the world with 70 million trees cultivated on 1.2 million ha [4,5]. Additionally, other Mediterranean countries such as Tunisia, Italy, Greece and Morocco, overcome 1 million ha cultivated, reaching, together with Spain, almost 70% of the world olive cultivation [2]. In recent decades, olive cultivation spread in Australia, Asia, and South America, with Argentina leading with 110,000 ha [6]. Regarding the Italian context, olive groves are mainly concentrated in the southern regions [7] although about 50% of the olive seedlings yearly produced in Italy come from Tuscany [8]. Indeed, the olive nursery industry was born in Pescia (43°53′13″ N, 10°41′18″ E—Figure 1) at the second half of the nineteenth century, and today the main production centers are still located there.

Figure 1. Geographical position of Pescia in the Tuscany Region (Italy).

Currently, this sector involves more than two hundred farms in this area, employing directly more than one thousand people and satellite activities almost doubling the working units. The olive tree nurseries are mainly managed in a conventional way but, in recent years, some of the most important olive tree nurseries of the Pescia district have started producing plants adopting the organic production method [9].

Organic farming is proposed as a solution to reduce the environmental impact of agriculture [10–16]. In order to develop more sustainable farming systems, researchers and decision-makers need information about the strengths and weaknesses of different farming approaches with respect to productivity and environmental impacts within the ecosystems' carrying capacity. Therefore, assessment tools that allow evaluation of the environmental impact of different farming systems are required [17].

Life Cycle Assessment (LCA) is increasingly seen as a useful tool to evaluate environmental impacts of the agri-food sector [18] and it is considered an interesting and objective approach to define and quantify greenhouse gas (GHG) emissions of the production process [19,20].

LCA has been used with regard to a number of agricultural systems. Audsley et al. [21] and Ceuterick [22,23] proposed different examples of LCA analysis for different crops and production processes. Other studies have been carried out with greenhouse horticulture production [24], strawberries [25], and fruit tree crops [26,27]. Plant nursery production, on the other hand, has received less attention so far [16,28–33].

Meier et al. [17] reported a growing number of LCA studies comparing environmental impacts of the same products produced in organic agriculture compared to conventional ones. Most of these LCA studies have found a lower environmental burden from organically produced products on a per unit area basis, although higher impacts have been found when evaluating emissions per product unit [12,13,34,35].

To better understand the environmental impact of different farming systems, a balance considering carbon sink and sources can be taken into account [36,37]. However, calculation of GHG and carbon sequestration was mainly conducted in traditional farming and forest systems [35,38], but only a few works analyzed the contribution of crop industry such as ornamental horticulture [29,31,39]. Currently, there is no research on the comparison between conventional and organic nursery in terms of carbon balance.

The present study proposes to analyze both GHG emissions and carbon sequestration in the olive woody biomass, comparing two different nursery management systems (conventional and organic). To this end, the research has had the following main goals: (i) determine the influence of organic management on GHG emissions; (ii) identify critical processes involved in the GHG emissions of organic and conventional nursery management; and (iii) calculate the carbon storage of both cultivation protocols to assess its effect on the global carbon balance. In order to achieve the goals mentioned above, the standard commercial production was analyzed in six different olive nurseries, two of them with both organic and conventional management systems.

2. Materials and Methods

2.1. Production System Description

The different olive nurseries were selected in Pescia, and they were chosen according with the average dimensions (2.5–5 ha) of the nurseries located in this olive trees production district. The characteristics of the two commercial olive tree production systems examined: conventional (C) and organic (O), are reported in Table 1. In both systems, the same substrates, irrigation type and plastic pots were used, while different inputs were obviously applied in the C and O systems. Basically, the differences between C and O concern the fertilizers (only organic fertilizers with O), herbicides and fungicides (not used in O), and insecticides (only natural products in O, e.g., *Bacillus thuringiensis* and *Pyrethrum*).

Table 1. Main characteristics of the conventional (C) and organic (O) olive tree nurseries considered. C/O nurseries produce both organic and conventional olive trees.

Nursery	Density (plants/m^2)	Conventional Nursery Surface (ha)	Organic Nursery Surface (ha)	Pot Volume (l)	Substrate (%)
1C	12	5.0		3	Pe [1] 50%-Pu [2] 50%
2C	12	5.0		3	Pe 50%-Pu 40%-Co [3] 10%
3C/O	12	3.8	1.0	3	Pe 65%-Pu 35%
4C	10	2.3		3	Pe 50%-Pu 50%
5C	8	2.5		3	Pe 50%-Pu 50%
6C/O	8	2.0	0.5	3	Pe 55%-Pu 45%

[1] Pe: Peat; [2] Pu: Pumice; [3] Co: Coconut fiber.

2.2. LCA Methodology and Impact Category

Life Cycle Assessment is a methodology standardized according to UNI EN ISO 14,040 and 14,044 guidances, able to investigate the environmental impact of a product, a production process or a system taking into account its life cycle. At the base of this kind of environmental analysis lies a holistic approach where all the production inputs (raw materials and energy consumption) and their interactions are considered. LCA methodology is divided into four steps: goal and scope definition, inventory phase (Life Cycle Inventory—LCI), software analysis (Life Cycle Impact Assessment—LCIA), and interpretation of results [40]. The LCA result is a quantified environmental impact via an official and standardized "Impact Category": the one used in this work is Global Warming Potential (GWP). GWP is an index based on a relative scale that compares each GHG (e.g., CH_4, N_2O, CFC) with CO_2. The GWP of CO_2 is, by definition, equal to 1 according to the Inter-governmental Panel on Climate Change (IPCC) [41]. The GWP factors updated by the IPCC are used to quantify the amount of equivalent CO_2 relative to each GHG. In the present study, GWP values of the GHGs refer to a time horizon of 100 years.

2.2.1. Goal, Scope, and Functional Unit

This study has the purpose of measuring GHG emissions in terms of GWP and analyzing the effect of using organic protocols on the total CO_2eq emissions in C and O olive tree production. The functional unit (FU) for the comparison per "product unit" of LCAs of the two farming systems was the single plant produced (two-year-old plant grown in plastic pot 15 cm Ø), as proposed by other authors [29–31]. In order to identify the most emitting steps in plant production, the system was split into individual, well-described processes. The LCA approach utilized was "from cradle to gate", or rather an assessment of the product until its exit from the nursery. All GHG emissions are reported as kg CO_2eq/plant. The temporal unit considered was one year's cultivation. GaBi software (PE—International, http://www.gabi-software.com/) was used to carry out the study, and the investigation was conducted in accordance with the International Organization for Standardization's Life Cycle Assessment, Requirements and Guidelines 14044:2006 [42] and the British Standards Institute's specifications in PAS 2050:2011 [43].

2.2.2. System Boundary

In the Pescia district, there are different types of wholesale nurseries, each of them characterized by specific structures related to the kind of production, or phase of life of the plants produced. For this purpose, in accordance with previous papers [16,33,44], a system boundary was used which included (Figure 2): (1) the emissions associated with the raw materials purchased (e.g., fertilizers, chemicals, plastic pots and substrate); (2) the emissions of electricity and diesel fuel associated with agricultural operations (e.g., potting plants; placement of plants; growing of plants). The CO_2 emissions from transportation of cultivation supplies was also considered because this category turned out to be the most important in other research papers [29,45].

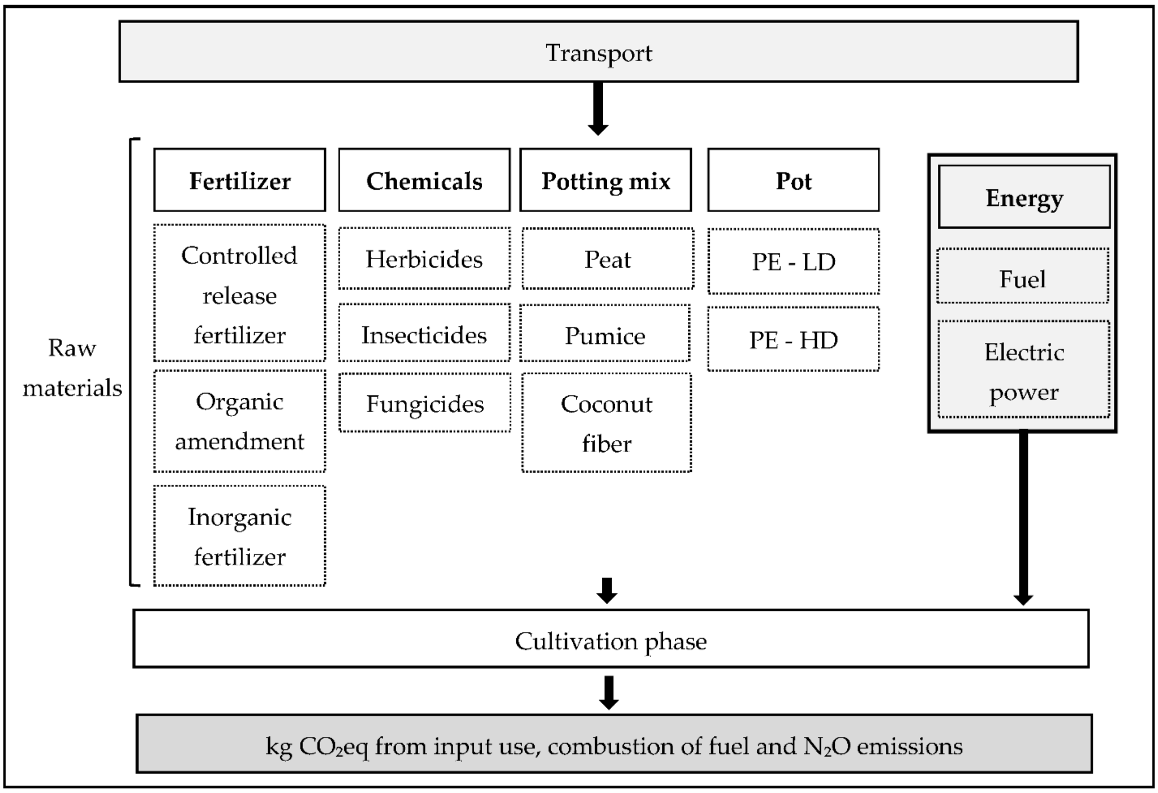

Figure 2. Nursery olive tree system diagram.

2.2.3. Life Cycle Inventory (LCI)

During the LCI phase, all data related to cultivation inputs of conventional and organic olive tree nurseries considered were collected (Table 2):

- *Fertilizers:* the quantity (kg) distributed on the surface unit (m^2) during the cultivation season was recorded. For controlled-release fertilizer, organic amendments, and inorganic/organic fertilizers used in ferti-irrigation, the element contents (N, P, K and microelements) were calculated.
- *Chemicals:* the quantity (kg) distributed on the surface unit (m^2) during the cultivation season was recorded. For fungicides, insecticides, and herbicides, the active ingredients were considered.
- *Potting mix:* many kinds of materials are used in the Pescia nursery district. The most common are peat, pumice, and coconut fiber. Each nursery has its own substrate "recipe" and, considering the number and volume of the pots, it was possible to calculate the quantities of any "ingredient" (kg) used on the surface unit (m^2) during the cultivation season.

- *Pot:* the weight (kg) of a pot of 15 cm diameter was determined (150 g per pot) and then the total number was considered. The plastic materials used in the analyzed nurseries are low-density polyethylene (LDPE) or high-density polyethylene (HDPE).
- *Energy consumptions:* the nurseries' yearly power consumption (MJ) was referred to farm surface (m^2).
- *Diesel consumptions:* the quantity of diesel fuel (both for machinery movement and greenhouse heating) was considered in kg/m^2/year and it was analyzed during the cultivation season. The emissions due to either production or combustion were considered.

All obtained data are reported as kg/plant/year, estimated per growing density (number of plants/m^2). All data were elaborated using "Pe/GaBi professional database", "Pe/GaBi extension database (agriculture)", or "Ecoinvent database".

Further assumptions were made:

- Emissions from Soil: N_2O emissions from the degradation of mineral fertilization were calculated using IPCC conversion [41]: quantity of N (kg) used × 0.01. The N_2O value was multiplied by 298 to obtain the CO_2eq conversion [41].
- The emissions from farm equipment and structures (e.g., greenhouses, build containers, plastic covers for container cultivations, irrigation systems, ferti-irrigation systems) and packaging (e.g., net used to wrap plants) were not considered because of their low relevance for the aims of our study [43]. Furthermore, a previous study [33] demonstrated that the equipment, structures, and packaging for outdoor container cultivation have minimal importance in terms of GWP in nursery production and transport.

Table 2. Different inputs of the conventional (C) and organic (O) olive tree nurseries considered.

Nursery	Organic Nitrogen Fertilizer (kg/plant)	Chemical Nitrogen Fertilizer (kg/plant)	Phosphorus Fertilizer (kg/plant)	Potassium Fertilizer (kg/plant)	Fuel (kg/plant)	Electric Power (kW/plant)	Herbicides (kg/plant)	Insecticides (kg/plant)	Fungicides (kg/plant)
1C	0.001	0.001	0.001	0.001	0.022	0.020	9.2×10^{-5}	3.7×10^{-3}	3.6×10^{-6}
2C	-	0.007	0.004	0.005	0.005	0.019	1.5×10^{-4}	1.7×10^{-5}	–
3C	0.001	0.011	0.009	0.002	0.008	0.083	5.4×10^{-4}	5.5×10^{-5}	4.8×10^{-6}
3O	0.001	-	-	-	0.014	0.034	-	1.5×10^{-4} *	-
4C	-	0.007	0.009	0.015	0.002	0.034	8.3×10^{-4}	2.1×10^{-4}	6.8×10^{-5}
5C	0.003	0.012	0.009	0.004	0.001	0.059	1.7×10^{-4}	3.7×10^{-4}	-
6C	-	0.016	0.016	0.016	0.005	0.019	1.6×10^{-4}	8.0×10^{-4}	7.2×10^{-5}
6O	0.003	-	-	-	0.001	0.059	-	1.5×10^{-4} *	-

(*) only natural products.

2.3. Sensitivity Analysis

A sensitivity analysis was carried out to understand which data categories should be considered more critical in terms of GHG emissions within a plant nursery. The value of each input in every cultivation phase was increased by 10%, while all the other variables were left unchanged [30,46]. Categories which cause a >1% increase of total value, according to the statistic model, must be considered significant data in terms of GHG emissions. The most interesting results were expected from the "input of cultivation" category, as previously indicated in other environmental analyses conducted in the Pistoia district [16,33,44].

2.4. Carbon Sequestration in Woody Biomass

Estimation of woody biomass is an essential factor for carbon stock and the effects of carbon sequestration on the global carbon balance. The destructive method is the most suitable to estimate the woody biomass in small plants cultivated in containers [47,48]. According to this principle, annual carbon sequestration is calculated according to the following algorithm:

$$C_{stock} = \{(Wt_1 - Wt_0) \times CC\} \times \frac{44}{12} \quad (1)$$

where C_{stock} is the CO_2 equivalent credit for annual biomass carbon stored in kg/plant, Wt_1 = annual biomass at the end of cultivation period (kg); Wt_0 = annual biomass at the beginning of the period of cultivation (kg); CC is the carbon content in the biomass (%); the multiplier $\frac{44}{12}$ converts carbon to CO_2. For the quantification of carbon sequestration in woody biomass, the leaves were not considered, as proposed by Dewar and Cannell [49]. Woody biomass was determined by taking five-plant samples of each of the three primarily cultivated varieties (cultivars) in the Pescia nursery district ('Frantoio', 'Leccino' and 'Maurino') at the beginning and at the end of the period of cultivation. For each cultivar, the increase of dry weight differentiated in root, trunk and branches was determined. To this purpose, the sampled roots were washed free, the fresh weight of the different plant parts were determined and subsequently oven dried (85 °C) for 5 days until a constant weight was achieved, to detect the dry weight. The weight of woody biomass and carbon content of different cultivars, calculated by analyzing in laboratory the different plant parts previously ground with an electric mill (Kjeldahl method), are presented in Table 3.

Table 3. Mean values (± standard deviation) of woody biomass (g) and carbon content (%) in conventional (C) and organic (O) cultivation of olive tree cultivars.

Olive Tree Cultivars	Management System	Woody Biomass ($Wt_1 - Wt_0$)			Carbon Content (CC)	
		Above Ground Biomass (g)	Roots Biomass (g)	Total Biomass (g)	Above Ground Biomass (%)	Roots Biomass (%)
Maurino	conventional	71.9 ± 18.0	23.8 ± 9.6	95.7 ± 27.6	44.6	45.5
Maurino	organic	48.1 ± 6.9	21.7 ± 5.8	69.9 ± 9.7	46.0	47.0
Frantoio	conventional	41.0 ± 8.1	13.8 ± 4.1	54.8 ± 12.0	46.2	45.4
Frantoio	organic	50.3 ± 10.4	18.9 ± 8.3	69.2 ± 18.4	46.2	48.9
Leccino	conventional	84.4 ± 11.7	25.5 ± 6.2	109.9 ± 16.2	45.3	45.6
Leccino	organic	75.0 ± 8.1	26.2 ± 3.6	101.2 ± 6.9	46.7	44.6

3. Results

3.1. GHG Emissions

The GHG emissions of different processes considered in this study are presented in Table 4 and Figure 3. Based on the results, GHG emissions (kg CO_2eq/plant) calculated in the olive tree nurseries showed a higher impact with conventional management compared to the organic one. The reduction of GHG emissions in organic nurseries concerns only the following cultivation inputs: chemicals, fertilizers, and N_2O emissions. Fertilizers showed the greatest reduction in CO_2eq emissions, more than 90% in both organic nurseries (3 and 6). In fact, ferti-irrigation was performed using organic fertilizers with a quantity of nitrogen much lower than that present in typical inorganic fertilizers used in conventional cultivation. With regard to chemicals, the reduction of emissions was significant in nursery 3 (59.5%), and even more in nursery 6 (>99%), due to the non-use of herbicides and fungicides and the use of biological insecticides. The reduction of N_2O emissions in soil were more than 80% and 62% in organic nurseries 6 and 3, respectively. For the other inputs of cultivation, the same levels of CO_2eq emissions were observed in both management systems since the same pot, potting mix (peat and pumice), and energy (in particular fuel for machine use) were employed. In all conventional and organic nurseries, pot (45–63%) and potting mix (22.6–32.1%) represented the highest CO_2eq emission source, due to the use of plastic pots and peat (production and transport). In three out of six conventional (1C, 3C, 4C), and both organic (3O and 6O) nurseries, the third CO_2 emission source came from fuel for machine use; while for the other three conventional nurseries (2C, 5C, 6C), the third CO_2 emission factor was fertilizer. The CO_2 emission of chemicals (in particular for insecticides use) was quite relevant only in nursery 1.

Table 4. GHG emissions in conventional (C) and organic (O) olive tree nurseries (kg CO_2eq/plant).

Input	1C	2C	3C	4C	5C	6C	3O	6O
Pot	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Potting mix:								
Peat	0.105	0.105	0.136	0.105	0.105	0.115	0.136	0.115
Pumice	0.045	0.036	0.031	0.045	0.045	0.040	0.031	0.040
Coconut fiber	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Total	0.150	0.147	0.168	0.150	0.150	0.156	0.168	0.156
Chemicals:								
Herbicides	0.003	0.003	0.006	0.002	0.018	0.002		
Fungicides	0.0001		0.0002		0.0002	0.0004		
Insecticides	0.064	0.000	0.001	0.007	0.004	0.014	0.003	0.0001
Total	0.067	0.003	0.007	0.008	0.022	0.016	0.003	0.0001
Fertilizer:								
Controlled release fertilizer		0.010	0.008		0.004	0.020		
Organic nitrogen	0.004	0.000	0.005	0.003	0.000	0.008		
Inorganic/organic [1] fertilized used in ferti-irrigation	0.009	0.049	0.003	0.036	0.102	0.035	0.001	0.002
Total	0.013	0.060	0.016	0.039	0.106	0.063	0.001	0.002
Energy:								
Electric power	0.001	0.001	0.002	0.004	0.002	0.003	0.002	0.003
Fuel for machine use	0.127	0.030	0.020	0.046	0.011	0.006	0.020	0.006
Fuel for greenhouse	0.000	0.000	0.061	0.000	0.000	0.000	0.061	0.000
Total	0.128	0.031	0.083	0.050	0.013	0.009	0.083	0.009
N_2O emission	0.006	0.022	0.011	0.035	0.022	0.042	0.004	0.008
Total Emissions	0.664	0.563	0.585	0.581	0.613	0.586	0.559	0.475

[1] in organic nursery the fertilizers used in ferti-irrigation contain organic nitrogen.

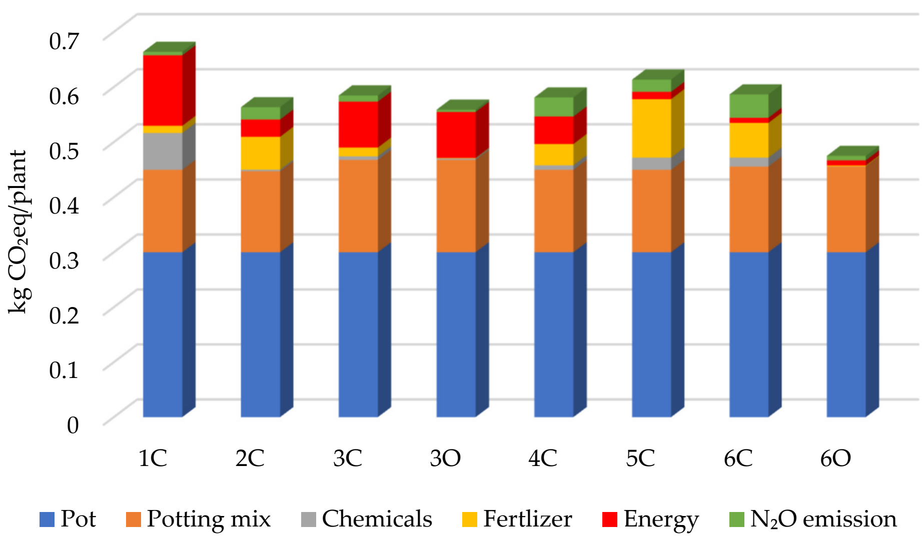

Figure 3. CO_2eq emissions from conventional (C) and organic (O) olive tree nurseries.

3.1.1. Carbon Balance

In both conventional and organic nurseries, a negative gap between CO_2 sequestration in woody biomass and CO_2 emission was detected (averaged data, Figure 4). This difference was greater with conventional management (+0.45 kg CO_2eq/plant) due to greater CO_2 emission (+0.60 kg CO_2eq/plant) compared with CO_2 sequestration (−0.15 kg CO_2eq/plant), while with organic management, the final carbon balance turned out to be +0.38 kg CO_2eq/plant, as a result of +0.52 kg CO_2eq/plant emission and −0.14 kg CO_2eq/plant sequestration. The biomass of trunk and branches determined most of the CO_2 sequestrated in the contribution of both nursery typologies (Table 5). In all cultivars, except 'Frantoio', the CO_2 sequestration was greater in conventional nurseries compared to organic ones. With regard to root biomass in the 'Maurino' and 'Leccino' cultivars, the same CO_2 sequestration in both nursery typologies was observed. Instead, in the organically managed 'Frantoio' cultivar, a higher value of CO_2 incorporated in root biomass was shown (mean value of 0.032 kg CO_2/plant in organic nursery and 0.025 kg CO_2/plant in conventional nursery, Table 5).

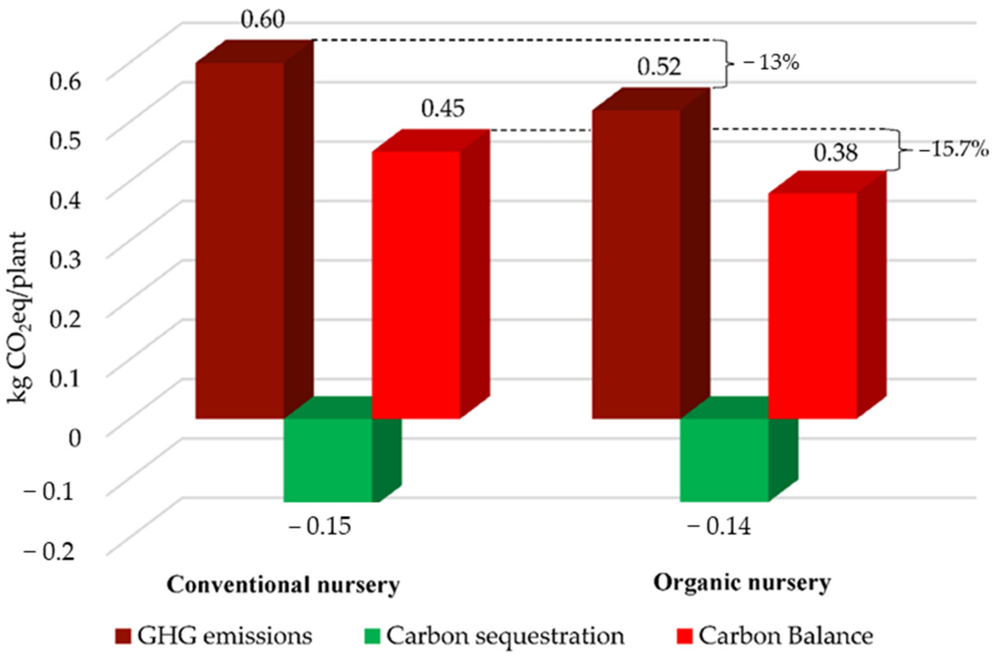

Figure 4. GHG emissions, carbon sequestration and carbon balance of conventional and organic olive tree nurseries.

Table 5. Mean value (± standard deviation) of carbon sequestration/incorporated in the woody biomass from conventional and organic nursery olive trees.

Cultivar	Management System	Trunk and Branches (kg CO_2/plant)	Root (kg CO_2/plant)	Total (kg CO_2/plant)
Maurino	Conventional	0.118 ± 0.033	0.039 ± 0.018	0.157 ± 0.051
Maurino	Organic	0.081 ± 0.013	0.039 ± 0.011	0.120 ± 0.018
Frantoio	Conventional	0.069 ± 0.015	0.025 ± 0.008	0.094 ± 0.023
Frantoio	Organic	0.084 ± 0.020	0.032 ± 0.017	0.115 ± 0.036
Leccino	conventional	0.144 ± 0.022	0.042 ± 0.012	0.186 ± 0.030
Leccino	Organic	0.128 ± 0.016	0.043 ± 0.007	0.171 ± 0.013

3.1.2. Sensitivity Analysis Results

The results of the sensitivity analysis related to "cultivation inputs" are shown in Table 6. N added to the substrates of the potted plants always shows increments of less than 1%. The most important inputs are pot and potting mix, respectively, with a sensitivity greatly higher than 1% for all the nurseries considered. Chemicals and fertilizer inputs showed in some cases values around the significant level (>1%), only the fertilizer in the 5C nursery had a more relevant value (1.730). Finally, in three out of six nurseries (1C, 3C, 3O) values higher than 1% were found for energy input.

Table 6. Sensitivity analysis of CO_2 emission for the different categories calculated with an increase of 10% from conventional (C) and organic (O) nursery olive tree.

Sensitivity (%)	**1C**	**2C**	**3C**	**4C**	**5C**	**6C**	**3O**	**6O**
Pot	4.519	5.325	5.132	5.164	4.890	5.115	5.369	6.317
Potting mix	2.254	2.609	2.868	2.576	2.439	2.654	3.001	3.277
Chemicals	1.008	0.051	0.112	0.141	0.362	0.276	0.047	0.003
Fertilizer	0.196	1.060	0.271	0.665	1.730	1.074	0.016	0.035
Energy	1.927	0.558	1.427	0.858	0.214	0.159	1.493	0.196
N_2O emissions	0.096	0.397	0.191	0.596	0.364	0.721	0.074	0.172

4. Discussion

LCA analysis showed the potential to assess the carbon footprint of conventional and organic olive trees nurseries, allowing us to emphasize the hotspots of these production sectors. This was already stated by many authors, such as Nemecek et al. [12,13], Williams et al. [24], Meisterling et al. [45], Cederberg and Mattsson [50], Haas et al. [51], Flessa et al. [52], De Boer [53], Pelletier et al. [54], and De Backer et al. [55], who illustrated the possibilities of using LCA to compare different agriculture systems.

Our results showed an average decrease of GHG emissions under organic versus conventional nurseries from 0.6 ± 0.036 to 0.52 ± 0.059 kg CO_2eq/plant (−13%). According to Aguilera et al. [15] these findings are mainly explained considering the following three cultivation inputs: chemicals, fertilizers and N_2O emissions. Simply replacing the inorganic fertilizer with the organic one (with a quantity of nitrogen much lower) during ferti-irrigation in organic system permitted the reduction of the CO_2eq investment [30]. According to previous works [16,33] and other researchers [28,30,56], the low contribution of chemicals to the total GHG emission was shown. They could probably play a more prominent role in other impact categories, not considered in this work, such as eutrophication potential, acidification potential, and human toxicity potential, as stated by Sahle and Potting [57] and Tuomisto et al. [34].

The plastic pot was the principal CO_2eq emitting source, as demonstrated in previous research carried out on container-production nurseries [28,29,56,58]. Therefore, to further reduce GHG emissions related to cultivation phase the use of environmentally friendly pot, alternatives to traditional petroleum-based plastic containers, should be considered, although it could be less sustainable from an economic point of view [59]. The second emission source in our research was potting mix, mainly due to peat use. According to previous results [16,33] peat-related emissions in the substrate input category have a relevant weight. Peat, currently still widely used as a component of nursery substrates, implies important environmental consequences related to its extraction and transport, as reported in various studies [60,61]. However, other authors attribute to peat less importance in terms of emissions either because the peat transport emission, an important fraction on the total GHG, is not considered [28], or because a peat-free potting mix was used [29]. The replacement of peat in substrates with other waste components as dredged sediments were already successfully tested, with significant reductions (about −24%) in GWP without compromising plant growth results [62]. Similar results were obtained introducing substrates based on co-composted dredged sediments with green waste, with a reduction in CO_2eq. emissions ranging from 15% to 35% [63]. Further sustainable alternatives such as biochar turned out to be effective, cutting down the environmental burden related to peat extraction and use [64]. The use of energy and fertilizers showed an irregular trend between the different nursery situations. Energy inputs, mainly due to fuel for machine use, were a relevant factor, as previously stated by Kendall and McPherson [29], in most cases (five out of eight), while in three nurseries, it was fertilizers that were the most important after plastic pots and substrates. Sensitivity analysis, conducted to understand the relative impact of each input variable, confirmed our results in terms of importance of the categories and/or inputs of cultivation as CO_2eq emitting factors.

Regarding carbon balance, the CO_2 sequestration by the olive tree seedlings was not able to offset the emissions related to the production process. This is because the plants considered were very young (2 years old). Nevertheless, expanding the time horizon, the carbon balance of adult trees could become positive as underlined by Proietti et al. [65] and Nicese et al. [66]. However, it is important to emphasize how the organic nursery showed a better carbon balance despite that the amount of CO_2 incorporated into biomass was slightly lower than that achieved with conventionally grown olive plants.

In details, considering the CO_2 sequestration in woody biomass, the averaged GHG decrease (13%) attains 15.7% under organic versus conventional nurseries. In other agricultural sectors, Aguilera et al. [15] demonstrated that organic fruit tree orchards have a higher potential to mitigate global warming by sequestrating carbon compared with conventional ones. Moreover, Venkat [35] showed that the conversion of cultivation to organic production may offer significant GHG reduction opportunities adopting management practices to increase soil organic carbon stocks. Currently, there is no research on the comparison between conventional and organic nursery in terms of carbon balance. In addition, considering the whole conventional and organic olive growing chain in economic terms, research carried out in the South of Italy stated that despite lower yields (about 25%), the profitability of the organic production sector was higher compared with the conventional one [67].

The results obtained in this work highlighted the potential of the organic cultivation method in limiting CO_2 emissions in the production protocols of olive nurseries. This ability to contain CO_2 emissions by organically produced olive trees is of great importance, as underlined also by studies carried out in the ornamental sector [39]. This could represent a useful incentive for a greater diffusion of organic cultivation standards, although more investigation is needed to fine-tune the cultivation protocols reaching best management practices (BMPs) to maximize productivity and profitability while minimizing GHG emissions. Therefore, continued research is requested to discover profitable and environmentally sustainable ways to produce organic olive plants.

5. Conclusions

The aim of the study was the identification of critical processes, implied in the emissions of GHG in organic and conventional olive nurseries using LCA approach evaluating, at the same time, the carbon balance of both cultivation methods.

Firstly, the present investigation demonstrated that LCA methodology is an effective tool to objectively assess the environmental impact, in terms of GWP, in both nursery systems. The main hotspots highlighted in the research were plastic pots and peat-based substrates, while the other inputs (energy, fertilizers, chemicals, N_2O emissions) played a minor role in the calculation of total emissions.

Secondly, organic nurseries had a positive influence on the decrease of greenhouse gas emissions; in fact, the study showed a 13% reduction in GHG emission reaching 15.7%, also considering the CO_2 sequestration in woody biomass. These findings are explained mainly with a reduced use of chemicals, fertilizers and N applied in soil, in spite of a slightly lower amount of CO_2 incorporated into biomass, compared to the conventional system.

Finally, we can assert that the conversion of the olive nursery industry from conventional to organic management has the potential to reduce its carbon footprint. However, further research is needed to allow the organic nurseries to reduce the two main factors responsible for the impact of CO_2 emissions, that is peat (for the potting mix) and plastic (for the pots). Technological innovations able to reduce these production factors could be beneficial with olive nurseries, as well as (or even more) with ornamental container plants production.

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