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Economic and Environmental Effects of Replacing Inorganic Fertilizers with Organic Fertilizers in Three Rainfed Crops in a Semi-Arid Area

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Abstract: This study evaluates the economic and environmental effects of replacing inorganic fertilization with organic fertilization (manure and compost) in three characteristic crops of the rainfed land of southeastern Spain: almond, olive, and barley. To do this, the conventional cultivation model of the three production systems was established and analyzed through the LCC (Life Cycle Costing) and LCA (Life Cycle Assessment) methodologies. Next, a sensitivity analysis was performed to see the effects of the substitution. In the three conventional systems, inorganic fertilizers represent at least 11% of the total costs. At the same time, they are the element with the greatest global contribution to environmental impacts (between 60 and 88%). Through the sensitivity analysis, it was shown that tillage practices that involve the addition of manure or compost not only reduce costs for the three crops (with a maximum reduction of EUR 88/ha in the case of olive trees with compost application), but also most of the impact categories evaluated. In terms of global warming, the reduction varies from 2–9% depending on the crop and the organic fertilizer used. And if we take into account that the production of inorganic fertilizers is avoided, the results of this category decrease between 28% and 48%.

Keywords: life cycle assessment; life cycle costing; barley; olive tree; almond tree; compost; manure; semi-arid

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1. Introduction

Agroecological management, or agricultural management inspired by natural ecosystems, uses a wide range of practices related to land management [1], with the aim of improving internal ecological processes that optimize the functionality and resilience of the agricultural activity [2]. In the Mediterranean area, no-till practices, vegetative coverage, and the application of organic amendments to the soil have been identified as important to stimulate ecological functions [1–3]. Although the environmental benefits of agroecological practices are well-established, the economic impacts have been studied less [3]; furthermore, these practices can result in reduced crop yields, adding uncertainty to the investment [4] and, consequently, serious doubts arise for the farmer regarding their application. For example, one study showed that implementing no-till with natural understory vegetation in a Spanish almond plantation reduced yield by 63% compared to conventional tillage management [5]. It must be borne in mind that if the yield achieved with organic management is lower than for conventional management but in the former, the management costs are lower (which is usually the case) and, very importantly, the market price is higher (which is not always the case), profitability can be obtained [6–8].

In a study on almond cultivation in southeastern Spain (SE), it was found that zero tillage and green manure provided lower net economic benefits (Net Present Value, NPV) over the useful life of the project than conventional tillage, underlining why there is a need for public policies that make such agroecological practices advantageous [3]. However, that same study also concluded that, under current economic conditions, compost application provided the highest long-term profitability (Internal Rate of Return, IRR) and, together with conventional tillage, had the shortest payback period (Discounted Payback Time, DPBT); compost, from a cost analysis perspective, also had the highest net income, due to increased productivity [3].

It is well-known that the application of organic fertilizers, such as compost and manure, increases organic matter in the soil, representing a source of nutrients for agricultural production [9–13], and improves the agronomic characteristics of the soil. The application of compost to the soil increases its total cation exchange capacity as well as levels of potassium (K), calcium (Ca), and magnesium (Mg), among other nutrients [14]. It also improves the physical properties of the soil, such as porosity, structural stability, and water retention capacity [10,15,16], the mineralization of nitrogen and its availability to the crop [12], and the number of worms [10]. As a consequence, in some studies, increases in yields have been recorded for different agricultural products, such as wine grapes (*Vitis vinifera*) [13], white mulberry (*Morus alba*) [17], and calafate (*Berberis microphylla*) [11]. However, another study [12] found no significant difference in yields between the application of organic and inorganic fertilizers. Also, compost improves the quality of the fruit. In strawberry, the concentration of anthocyanins, the phenolic content, and the antioxidant capacity of the fruit increased with increasing the dose of compost [18]. In calafate, a higher content of polyphenols and total anthocyanins was recorded [11] and in wine grapes there was a positive influence on the polyphenol content [9].

Also, the application of organic fertilization over 21 years to eroded soils that were nutritionally deficient and with low pH significantly increased the soil pH, organic carbon content, total nitrogen, phosphorus, potassium, available nitrogen, and biological activity [19]. In this sense, the value of the ecosystem services provided should also be taken into account, especially in relation to the increase in carbon in the soil and the decrease in erosion in semi-arid areas of Europe [3].

Furthermore, manure is a waste from livestock farming and compost is made with organic wastes of different origins, so they can be considered as by-products of the Mediterranean food chain. In this way, they can contribute to the sustainability of the agricultural sector by reducing the use of synthetic fertilizers, since nutrients that favor the functioning of agriculture are reused as part of a circular economy approach [20].

In line with the above, Europe advocates policies that promote sustainable development. Through the Green Deal and its Farm to Fork Strategy, it aims to achieve a healthier, fairer, and more environmentally friendly food system [21]. To achieve this, it has established specific objectives such as a 20% reduction in the use of fertilizers by 2030 and a 25% increase in the area devoted to organic farming. Likewise, the second pillar of the CAP (Common Agricultural Policy) offers member states a package of measures for the period 2023–2027 that contribute to achieving the specific objectives of Regulation 2115/21 [22], including more efficient management of resources. Some measures directly related to it are those intended to support organic farming—which encourage the elimination of pesticides and inorganic fertilizers and their replacement by organic ones—as well as knowledge transfer and information, advisory services, and cooperation measures that can be used to disseminate knowledge about more efficient nutrient management.

Murcia, and SE Spain in general, is a semi-arid area in which water resources are highly limiting [23] and rainfall is low, of the order of 300 mm per year [24,25]. The soils are characterized by being poor in organic matter, with a high pH and high contents of calcium carbonate and active limestone [25–28]. This area is considered the most vulnerable in Spain to the impact of climate change, since it is subject to a serious desertification process [29,30]. In these agroclimatic conditions, the application of organic fertilizers instead of inorganic ones could be beneficial not only for conservation of soil, but also for improving its agronomic characteristics.

In Murcia, 55% of the cultivated area is rainfed and the remaining 45% is irrigated [31]. Despite their low economic productivity, rainfed systems play an essential role in areas influenced to a high degree by edaphoclimatic factors, such as SE Spain [32,33]. In the Region of Murcia, rainfed land produces benefits that are both environmental, since it conserves the soil and preserves the landscape, and socioeconomic, maintaining the population in the territory through the generation of employment [34].

However, the productive and climatological vulnerability of the regional rainfed land has led to many farms becoming unviable, resulting in a significant decrease in the area farmed: from 377,928 ha in 2006 to 204,779 ha in 2020, a loss of 45.8%. The decrease in the fallow area in this period is also relevant, linked to the reduction in the area of cereals grown in the most arid zones where there is a stricter need for fallow [35]. This drastic decline in area represents a serious socioeconomic and environmental problem in a zone like the Region of Murcia, where there are few viable cultivation alternatives in the face of the advance of desertification. Furthermore, as a consequence of this vulnerability, farmers have been increasing the size of their farms to establish economies of scale that allow them to reduce costs and maintain the economic viability of their farms. In this sense, Murcia has the largest average farm size among the Spanish regions [36].

In the Region of Murcia, the main rainfed crops are barley, among the herbaceous crops, and almond trees, vineyards, and olive trees, among the woody crops. These four crops represent practically 83% of the total rainfed cultivated area [31]. The vineyard has already been the subject of a study in which conventional and organic crops were evaluated economically and environmentally [25].

Based on all the above, the objective of this study was to evaluate the economic and environmental effects of replacing inorganic fertilizers in conventional rainfed almond (*Prunus dulcis*), olive (*Olea europaea* L.), and barley (*Hordeum vulgare* L.) crops with organic fertilizers (manure and compost). To do this, the model of each of the three conventional crops was established prior to analysis using LCC (Life Cycle Costing) and LCA (Life Cycle Assessment), to finally evaluate the economic and environmental impacts of replacing inorganic fertilizers with organic ones.

2. Materials and Methods

To evaluate the economic and environmental effects of replacing inorganic fertilizers with organic ones, first the conventional cultivation model was established for the three products (almond, olive, and barley); second, the LCC and LCA were applied to these conventional crops; and third, a sensitivity analysis was carried out to evaluate the effect of replacing inorganic fertilizers with manure and compost.

2.1. Data Collection

The data used to establish the three conventional cultivation models were taken from surveys of farmers and technicians from the regional offices, and are described in [32,37,38]. However, the input prices were updated for this study.

2.2. Description of the Conventional Crops

2.2.1. Description of the Study Area

Almond, olive, and barley cultivation in the Region of Murcia (SE Spain) is carried out in inland regions with a continental Mediterranean climate. Precipitation is scarce and irregular, typical of semi-arid areas. The average annual precipitation in the last 20 years is about 300 mm, while evapotranspiration is 1100 mm [25,28]. The average annual temperature is about 16 °C. As they are inland areas, they are not influenced by the sea and have extreme temperatures. In the summer, the temperature frequently exceeds 30 °C, while winters are cold, with temperatures falling below zero. The soils are poor in organic matter, having a high pH, low salinity, and high contents of calcium carbonate and active limestone; most of them have a clay-loam or sandy-clay loam texture [25–28].

2.2.2. Characteristics of the Conventional Crops

The characteristics of the conventional almond, olive, and barley crops (areas, planting scheme, useful life of the plantation, average yields, etc.) are shown in Table 1.

Table 1. Agronomic data of the three conventional dryland crops.

	Almond	**Olive**	**Barley**
Characteristics			
Useful life (years)	30	40	1
Sowing density (kg ha^{-1})			180
Planting scheme (m × m)	7 × 7	8 × 8	
Yield in productive years (*) (kg ha^{-1})	215	2200	1500
Non-productive years	2	2	
Partially productive years	3	3	
Inputs' productive years			
Machinery hours (h ha^{-1})	11.00	13.50	5.00
Diesel consumed by machinery (dm^3 h^{-1})	94.02	112.24	35.00
Phytosanitary			
Paraffin oil (83%) (kg ha^{-1})	8.00		
Copper hydroxide (35%)	2.00	2.50	
Deltamethrin (pyrethrin)	1.00	0.65	
Mancozeb (80%)	2.00	2.50	
Tau-fluvalinate (10%)	0.50	0.65	
Fertilizers			
N-P_2O_5-K_2O (20-8-14) (kg ha^{-1})	118.6	217.5	115.0
N-P_2O_5-K_2O (8-15-15) (kg ha^{-1})	3.3		25.7
Potassium sulfate (kg ha^{-1})	38.0		
Diammonium phosphate (kg ha^{-1})		1.7	36.9

(*) Yield. Barley: kg of grain; almond: kg of kernel; olive: kg of olives.

The usual sowing density in barley is 180 kg of seed per hectare. The useful life is 1 year, since it is an annual cycle. The average grain yield is 1500 kg ha^{-1} [39]. The investment in barley cultivation only includes a 50 m^2 warehouse for tools.

The majority of rainfed almond tree systems in the Region of Murcia have a plantation with a planting scheme of 7 m × 7 m or 8 m × 8 m. In this case, the analysis was developed for the 7 m × 7 m planting scheme, equivalent to 204 trees ha^{-1}. The useful life of the rainfed almond tree was estimated to be 30 years, with an initial 5 years of growth for which it was considered that the yield and inputs increase until the average yield of the adult tree is reached. The remaining years (25) are totally productive. An average yield for adult almond trees of 215 kg ha^{-1} of almond kernel was established. The investment in almond cultivation includes a 50 m^2 tool shed and the work involved in preparing and planting the land (clearing, surface grading, refining and leveling, manual hilling, support machinery for planting, and grafted plants).

The most common planting scheme for rainfed olive trees in Murcia is 8 m × 8 m, equivalent to 156 trees ha^{-1}. It was estimated that the useful life is 40 years, with an initial 5 years of growth in which it is considered that the yield and inputs increase until the average yield of the adult trees is reached. The remaining 35 years are totally productive. The average yield of adult olive trees is 2200 kg ha^{-1} of fruits. The investment in olive cultivation includes a 50 m^2 tool shed and the work of preparing and planting the land (clearing, surface grading, refining and leveling, manual hilling, supporting machinery for planting, and grafting plants).

2.2.3. Processes and Means of Production

A description of the annual means of production was made in relation to the costs; these were grouped so that the economic analysis (LCC—Life Cycle Costs) was analogous to the environmental analysis (LCA—Life Cycle Assessment).

The processes and means of production considered in an annual cycle for each of the conventional cultivation scenarios were:

- Production insurance. To establish the cost of the insurance, the report "Average cost of insurance in the Autonomous Community of Murcia", written by Agroseguro and described in several official regional publications, was used [37,39].
- Pruning. This part corresponds only to the woody crops and refers to the labor cost associated with pruning, which is carried out manually. It was considered as part of the fixed labor costs of the annual pruning. After pruning, the wood is crushed between the rows of trees and incorporated into the soil, due to the agronomic and economic advantages [40].
- Machinery. The farms were considered to hire external services. Therefore, the cost of machinery was accounted for based on the market unit cost. Each task includes: tractor + implement + labor. The machinery involved in the harvest was accounted for as a harvest cost [37].
- Fertilizers. The crop requirements in fertilizer units (N-P_2O_5-K_2O) were considered to be 32-30-20 for barley, 24-10-36 for almond and 44-18-30 for olive (Table 1). These values were quantified based on the optimal balance for these crops, according to fertilization programs recommended by [41].
- Phytosanitary treatments. Standard treatment programs (Table 1) were established for each of the woody crops [39]. No treatments were carried out during barley cultivation. The most common practice in olive trees is two annual treatments, one in winter and another in spring. In almond trees, generally, three treatments are carried out (winter, spring, and summer).
- Harvest. This includes labor and the necessary mechanical means [37].
- Maintenance. The cost of the maintenance section was calculated as a percentage (1.50%) of the cost of the fixed assets, only for the woody crops [37].
- Permanent staff. The permanent staff comprises, in most cases, the farmer who owns the land. He/She usually works on tasks related to management and the production process, such as: the acquisition of production factors, irrigation programming where appropriate, contracting of external work, and support of the various activities (harvesting, pruning. . .etc.) It is a figure similar to that of a manager on a farm belonging to a company. This concept is reflected as a cost in hours per hectare and year [37,39].

2.3. Cost Analysis

The production and cost structure of the conventional scenarios was developed for one year in full production. The costs were subdivided into fixed costs and variable costs [37,39,42].

The fixed costs are equivalent to the costs derived from the amortization of the investment. The amortization was calculated using the constant installment method. In this way, the fixed costs of the scenarios were considered: the tool shed and the preparation and planting (woody crops). Variable costs are those that can vary from one production cycle to another (in this case, the costs of fertilizers, phytosanitary treatments (woody crops), costs associated with work carried out using machinery, etc.)

Once the cost structure of the conventional scenarios had been established, the economic analysis of the improvement practices was carried out. The aim was to produce an annual balance, in EUR ha^{-1}, of what these practices entail; that is, to establish whether they represent an extra cost relative to the conventional scenarios.

2.4. Life Cycle Assessment

An environmental assessment was carried out using life cycle assessment (LCA). The LCA is an environmental assessment tool standardized by the ISO 14040-14044 set of standards [43,44]. The methodology consists of four phases: definition of objective and scope; life cycle inventory analysis; impact evaluation; and interpretation of the results.

2.4.1. Objective and Scope

The objective of this LCA was to environmentally evaluate three conventional rainfed crops (almond, olive, and barley), while in the sensitivity analysis (Section 2.5) the effect of replacing inorganic fertilizers with organic ones was evaluated.

The functional unit (FU) used in the analysis was 1 kg of product in each crop (barley: 1 kg of grain; almond tree: 1 kg of kernel; and olive tree: 1 kg of olives). The scope, in this case, focused exclusively on the cultivation phase (this being the limit of the analysis). For the cultivation of almond and olive trees, it was considered that there is only one product and, therefore, these were treated as monofunctional systems. However, in barley cultivation, there are two products: grain and straw. Through the economic allocation of loads, the environmental aspects were distributed among the products generated; specifically, grain was assigned a load of 89.29% of the total impact of barley cultivation. A similar value (91%) was used by [45].

To carry out this LCA, SimaPro 9.5 software [46] was used, and the background data (fuel, materials, energy, fertilizers, products, etc.) were extracted from the Ecoinvent 3.8 database available in said software. The system components taken into account in the LCA were:

- Machinery. For the woody crops, this included the fuel and lubricant consumed by the machinery during the preparation and planting of the land and its emissions into the atmosphere. In all three crops, the fuel and lubricant consumed during the agricultural work necessary in the production cycle and the corresponding emissions were also included.
- Fertilizers. This comprised the raw materials, manufacturing and transportation of inorganic and organic fertilizers, and their packaging, as well as emissions into the atmosphere derived from the application of nitrogen fertilizers in the field.
- Phytosanitary treatments. This comprised the raw materials, manufacture and transportation of pesticides, and their packaging. No phytosanitary products are used in barley cultivation.

2.4.2. Inventory Analysis

The foreground data used were those shown in Table 1, and they are also shown in relation to the FU in Tables 2 and 3. The background data (fuel, energy, materials, products, and transport) were extracted from the Ecoinvent 3.8 database.

The emissions produced by the consumption of diesel by agricultural machinery were calculated using the emission factors established by [47]. Emissions to the atmosphere due to the application of nitrogen fertilizers were estimated according to the following sources: NH_3 and NO_2 according to [47], and direct and indirect N_2O emissions as described by del Hierro et al. [48] and, therefore, according to IPCC [49]. The leaching of nitrate was not taken into account, since the IPCC states that the leaching fraction can be considered null in arid climates without irrigation [49]. Furthermore, the precipitation is low (300 mm) and lower than the potential evapotranspiration (1100 mm) [28,50].

2.4.3. Life Cycle Impact: Assessment and Interpretation

For the characterization of the potential environmental impacts, the CML-IA Baseline 4.7 (August 2016) midpoint methodology (available in SimaPro) was used. This has been applied widely in LCA for agri-food products [42,51–56]. The impact categories used were abiotic depletion (AD), abiotic depletion fossil fuels (ADFF), global warming (GW), ozone layer depletion (OLD), human toxicity (HT), fresh water aquatic ecotoxicity (FWAE), marine aquatic ecotoxicity (MAE), terrestrial ecotoxicity (TE), photochemical oxidation (PO), acidification (A), and eutrophication (E).

To interpret the results, a contribution analysis was carried out to calculate the percentage contribution of each of the different components of each scenario to each impact category. In addition, the overall contribution was used; this shows how each component of the system contributes to all of the impacts [42].

Table 2. Life cycle inventory of primary data of almond and olive crops in relation to the functional unit.

Components	Almond			Olive		
	Conventional (S1)	Manure (S2)	Compost (S3)	Conventional (S1)	Manure (S2)	Compost (S3)
Planting						
Diesel (g kg^{-1})	23.999	23.999	23.9999	1.6653	1.6653	1.6653
Lubricant oil (g kg^{-1})	0.0258	0.0258	0.0258	0.0018	0.0018	0.0018
Agricultural machinery						
Diesel (g kg^{-1})	385.1165	381.3377	381.3377	44.2497	43.8860	43.8860
Lubricant oil (g kg^{-1})	0.4143	0.4102	0.4102	0.0476	0.0472	0.0472
Phytosanitary products						
Paraffinic oil 83% (g kg^{-1})	32.6901	32.6901	32.6901			
Copper hydroxide 35% (g kg^{-1})	3.4462	3.4462	3.4462	0.4146	0.4146	0.4146
Deltamethrin (pyrethrin) 2.5% (g kg^{-1})	0.1231	0.1231	0.1231	0.0077	0.0077	0.0077
Mancozeb 80% (g kg^{-1})	7.8771	7.8771	7.8771	0.9477	0.9477	0.9477
Tau-fluvalinate 10% (g kg^{-1})	0.2462	0.2462	0.2462	0.0308	0.0308	0.0308
Packaging (g kg^{-1})	0.1462	0.1462	0.1462	0.0065	0.0065	0.0065
Local transportation (kg·km)	3.3232	3.3232	3.3232	0.1473	0.1473	0.1473
Fertilizers						
N-P_2O_5-K_2O (20-8-14) (g N kg^{-1})	116.7500			20.6124		
N-P_2O_5-K_2O (8-15-15) (g N kg^{-1})	1.2859					
Diammonium phosphate (g N kg^{-1})				0.1466		
Potash salt, K_2O (g kg^{-1})	93.3402					
Packaging (g kg^{-1})	1.6398			0.1092		
Manure (g N Kg^{-1})		117.9199			20.8307	
Compost (g N Kg^{-1})			118.1292			20.8325
Local transportation (kg·km)	81.9907	398.3782	324.5397	5.4600	70.3738	57.2321

Table 3. Life cycle inventory of primary data of barley crop in relation to the functional unit.

Components	Conventional (S1)	Manure (S2)	Compost (S3)
Agricultural machinery			
Diesel (g kg^{-1})	19.4133	21.9260	21.9260
Lubricant oil (g kg^{-1})	0.0209	0.0236	0.0236
Fertilizers			
N-P_2O_5-K_2O (20-8-14) (g N kg^{-1})	15.3333		
N-P_2O_5-K_2O (8-15-15) (g N kg^{-1})	1.3707		
Diammonium phosphate (g N kg^{-1})	4.4340		
Packaging (g kg^{-1})	0.1184		
Manure (g N kg^{-1})		21.3120	
Compost (g N kg^{-1})			21.3547
Local transportation (kg·km)	5.9217	72.0000	58.6667

2.5. Sensitivity Analysis

2.5.1. Inorganic Fertilization vs. Organic Fertilization

For the three crops, the replacement of inorganic fertilizers with organic fertilizers, specifically manure and compost, was evaluated economically and environmentally (Table 4).

- Contribution of manure. Sheep–goat manure was applied through the use of a tractor with a trailer. The fertilizer units provided by the manure were 1.48-0.56-2.35 [33,34,57]. This practice replaces inorganic fertilization and the machinery with which it is carried out in the conventional woody crops. In barley, it only replaces inorganic fertilization since in the conventional barley scenario, the application of inorganic fertilizer and sowing are carried out together with the same machinery. As data relating to this type of manure are not available in the Ecoinvent database, the data for cow manure were used.

- Contribution of compost. Compost produced in a pilot plant located in the Xiquena experimental plot was used (LIFE16 CCA/ES/000123—LIFE AMDRYC4—Climate change adaptation of dryland agricultural systems in the Mediterranean area). For its preparation, different locally sourced materials were used, some of them obtained from the farm's own activity and others from other farms in the area (pig manure, crushed almond and olive tree pruning, cereal straw from cattle bedding, sheep manure). This compost provided the fertilizer units 1.82-0.48-1.06, and was applied with a tractor and trailer. The price of compost production was EUR 0.023 kg^{-1} (Table 4). The information about the composting process, its cost, and its analysis were provided by the technicians participating in the LIFE AmdryC4 project. This practice replaces inorganic fertilization and the machinery with which it is carried out in the conventional woody crop scenarios. For barley, it only replaces inorganic fertilization in the conventional barley scenario since the application of inorganic fertilizer and sowing are carried out together with the same machinery.

Table 4. Amounts of manure and compost applied annually in each of the three crops.

	Manure	**Compost**
Fertilizer balance (N-P_2O_5-K_2O)	1.48-0.56-2.35	1.82-0.48-1.06
Price (€ kg^{-1})	0.036	0.023
Annual supply		
Almond (kg ha^{-1})	1618	1318
Olive (kg ha^{-1})	2970	2416
Barley (kg ha^{-1})	2160	1760

The amount of manure and compost to be supplied to each crop (Table 4) was calculated based on the fertilizer units needed by each of them [33,34,57]. As the specific data for this compost are not available for the LCA, a generic process available in Ecoinvent was used.

The differences were evaluated as the relative difference (RD) between the values of the conventional crop (Scenario-1: S1) and the crops fertilized with manure (Scenario-2: S2) or with compost (Scenario-3: S3).

DR (%) = $100 \times (S1 - Sn)/S1$; Sn being each of the defined scenarios.

2.5.2. The Use of Manure or Compost Avoids the Use of Inorganic Fertilizers

The following consideration was also raised in the LCA. Manure is a waste from livestock farming and compost is made with organic wastes of different origins. Both, if used as organic fertilizers, cease to be waste and remove the need for the production of inorganic fertilizers [58]. The inclusion of avoided products in the analysis represents a negative contribution of the environmental impacts derived from the production of inorganic fertilizers [58]. The reference substance used here was the total nitrogen content of manure (1.48%) and compost (1.82%). Thus, two other scenarios were evaluated for the three crops: S5 (manure prevents the production of inorganic fertilizers) and S6 (compost prevents the production of inorganic fertilizers).

3. Results and Discussion

3.1. Cost Structure in the Conventional Crops

The production and cost structure of the conventional scenarios was developed for one year in full production. The costs are subdivided into fixed costs and variable costs, as indicated in Table 5. We show the costs in euros and as a percentage of the total cost in order to indicate the relative importance of each of the costs. In all the crops, the fixed costs are very low (between 1.63% and 5.05%), especially in barley. They are rainfed crops in which there is no irrigation infrastructure and, therefore, they entail low investments and fixed costs associated with them. They are somewhat superior in the woody crops since these require the planting of plant material with a relevant initial value.

Table 5. Cost structure. Absolute annual costs in EUR ha^{-1}, and relative costs in relation to the total cost (%).

Concept	Almond		Olive		Barley	
	€	%	€	%	€	%
Fixed costs:						
Shed for equipment	17	1.26	17	1.06	8	1.63
Preparation and planting	51	3.79	34	2.12	-	-
Total fixed costs	68	5.05	51	3.18	8	1.63
Variable costs:						
Seeds	-	-	-	-	55	11.20
Pruning	156	11.58	215	13.41		
Machinery	382	28.36	363	22.65	106	21.59
Fertilizers	152	11.28	202	12.60	149	30.35
Phytosanitary products	93	6.90	83	5.18	-	-
Harvesting	151	11.21	378	23.58	46	9.37
Maintenance of infrastructure	8	0.59	8	0.50	-	-
Insurance	72	5.35	38	2.37	-	-
Fixed personal	265	19.67	265	16.53	127	25.87
Total variable costs	1279	94.95	1553	96.82	483	98.37
Total costs	1347	100	1603	100	491	100

Among the variable costs, the items of labor and machinery stand out (Table 5), linked to tillage and harvesting. For the woody crops, pruning is a relatively important cost, also linked to labor. In general, in the rainfed crops of SE Spain, the inputs are tightly controlled to minimize costs and thus to maintain the economic viability of the crops [25,28]. Of the inputs (fertilizers and phytosanitary products), the cost of fertilization in the three crops stands out, especially in barley, since it is the crop with the greatest fertilizer requirements, followed in descending order by the olive and almond trees (30.35%, 12.60%, and 11.28% of the total cost, respectively). The cost of inorganic fertilizers has been rising progressively, due to international problems such as the current war in Ukraine. The rise in prices and the European dependence on third countries in relation to inorganic fertilizers has caused the application of organic fertilizers to increase, also in parallel with the European agricultural policy that promotes the latter [22].

The costs of phytosanitary practices are minimal, and even non-existent in the rainfed cereals, which is due to their very low use, given the low incidence of pathologies in semi-arid areas, especially fungal diseases [25,59].

The total cost of production in the woody crops is around triple that of barley cultivation, being somewhat higher in olive trees, mainly due to the greater productivity and harvesting associated with production.

3.2. LCA of the Conventional Crops

3.2.1. Almond

In the conventional almond cultivation, fertilizers are the component of the system that contributes the most overall (Table 6) to the environmental impacts (60.1%), especially with regard to the toxicity impacts (HT, FWAE, MAE, and TE), but also to A and E. Taking into account only the values of the impacts of fertilizers, the emissions due to the application of nitrogen products only affect GW (24.6% of the total fertilizers), PO (56.6%), A (85.1%), and E (81.9%); for HT the contribution is negligible (1.1%). For all other impacts, fertilizer production represents a contribution of 100%.

Table 6. Characterization of the potential environmental impacts and contributions of the components of the system in the conventional almond crop. FU: 1 kg of kernel.

Impact Category	Values	Machinery	Phytosanitary Contribution (%)	Fertilizers
AD (kg Sb-eq)	2.358×10^{-5}	0.96	44.57	54.48
ADFF (MJ)	3.531×10^{1}	61.22	7.90	30.88
GW (kg CO_2-eq)	2.655×10^{0}	57.47	3.41	39.12
OLD (kg CFC-11-eq)	4.516×10^{-7}	63.08	17.28	19.64
HT (kg 1,4-DB-eq)	8.801×10^{-1}	10.82	16.95	72.23
FWAE (kg 1,4-DB-eq)	4.998×10^{-1}	6.69	16.66	76.65
MAE (kg 1,4-DB-eq)	8.434×10^{2}	11.34	19.59	69.07
TE (kg 1,4-DB-eq)	2.361×10^{-3}	16.90	8.82	74.28
PO (kg C_2H_4-eq)	4.709×10^{-4}	33.93	17.00	49.07
A (kg SO_2-eq)	2.809×10^{-2}	9.46	6.48	84.06
E (kg PO_4-eq)	6.367×10^{-3}	5.57	3.35	91.08
Overall contribution (%)		25.22	14.73	60.05

Although its overall contribution is smaller (25.2%), machinery makes the largest contribution to ADFF, GW, and OLD. Considering only the values of the impacts due to the diesel consumed by the machinery, emissions have a great impact on GW (85.7%), PO (42.0%), and E (28.5%), but a lower impact on A (12.8%), HT (6.0%), and TE (3.4%), being practically negligible for MAE (0.9%) and FWAE (0.6%). The contribution of diesel is 100% for AD, ADFF, and OLD. These results are the same for the other crops.

The phytosanitary treatments are the component that contributes the least to the environmental impacts, although they make a relevant contribution to AD. The low contribution to GW has also been recorded by other authors [60,61].

In GW, it is machinery that contributes the most (57.5%), although fertilizers also make a relevant contribution (39.1%). Similar results have been recorded in other studies of conventional and irrigated almond cultivation (California and Greece) in which, however, there was also a significant contribution of the energy associated with irrigation [60,62,63]. However, the absolute GW values of those studies are higher (1.630–2.479 kg CO_2-eq per kg of shelled almonds) than those found here (0.796 kg CO_2-eq per kg of shelled almonds), which are similar to those registered for Mediterranean crops in Spain (0.972 kg CO_2-eq, [64]).

3.2.2. Olives

In the conventional olive cultivation, the pattern of contributions of the system components to the environmental impacts is similar to that of the conventional almond cultivation (Table 7). In general, fertilizers have been identified as the component of the system that contributes the most to the impacts of olive cultivation [65].

Taking into account only the values of the impacts of fertilizers, the emissions due to the application of nitrogen products only affect GW (26.0% of the total fertilizers), PO (56.2%), A (85.0%), and E (82.6%); for HT, the contribution is negligible (1.1%). For all other impacts, the contribution of fertilizer production is 100%.

For GW, the value in this study for olive cultivation (0.354 kg CO_2-eq) is similar to that found by [64] (0.324 kg CO_2-eq), and is in the range recorded in other studies (0.224–0.865 kg CO_2-eq, [65,66], the lowest values being obtained in intensive and super-intensive agricultural systems where yields are higher [67].

The phytosanitary treatments make a very low contribution, due to their scarce use (Table 1), which coincides with [64]. However, this component has frequently been included among those that contribute the most to the environmental impacts of olive cultivation, especially to global warming [65,68]. The low contribution of phytosanitary treatments is due, as has been suggested for vineyards [25,59], to the fact that in the study area, as in others with dry climates (low rainfall), fungal pests are limited and so very low amounts of pesticides are applied.

Table 7. Characterization of the potential environmental impacts and contributions of the components of the system in the conventional olive crop. FU: 1 kg of olives.

Impact Category	Values	Machinery	Phytosanitary Contribution (%)	Fertilizers
AD (kg Sb-eq)	3.415×10^{-6}	0.74	34.42	64.84
ADFF (MJ)	4.350×10^{0}	55.78	3.04	41.18
GW (kg CO_2-eq)	3.538×10^{-1}	48.41	2.30	49.29
OLD (kg CFC-11-eq)	5.528×10^{-8}	57.84	16.74	25.42
HT (kg 1,4-DB-eq)	1.349×10^{-1}	7.92	11.49	80.59
FWAE (kg 1,4-DB-eq)	7.730×10^{-2}	4.85	10.68	84.46
MAE (kg 1,4-DB-eq)	$1.345 \times 10^{+2}$	7.98	11.37	80.65
TE (kg 1,4-DB-eq)	3.644×10^{-4}	12.28	6.00	81.72
PO (kg C_2H_4-eq)	6.824×10^{-5}	26.28	13.14	60.58
A (kg SO_2-eq)	4.660×10^{-3}	6.40	4.31	89.29
E (kg PO_4-eq)	1.076×10^{-3}	3.70	2.11	94.19
Overall contribution (%)		21.11	10.51	68.38

3.2.3. Barley

In the conventional barley cultivation, the overall contribution of fertilizers (Table 8) is very high (88.09%), the contribution exceeding 90% in all impact categories except ADFF, GW, and OLD. Taking into account only the values of the impacts of fertilizers, the emissions due to the application of nitrogen products only affect GW (23.6% of the total fertilizers), PO (23.7%), A (65.2%), and E (79.4%); for HT, the contribution is negligible (0.8%). For all other impacts, fertilizer production represents a contribution of 100%. The contribution of machinery is only 11.91%, having a notable impact only on ADFF, GW, and OLD.

Table 8. Characterization of the potential environmental impacts and contributions of the components of the system in the conventional barley crop. FU: 1 kg of grain.

Impact Category	Values	Machinery Contribution (%)	Fertilizers
AD (kg Sb-eq)	2.253×10^{-6}	0.42	99.58
ADFF (MJ)	2.690×10^{0}	33.94	66.06
GW (kg CO_2-eq)	2.288×10^{-1}	28.17	71.83
OLD (kg CFC-11-eq)	2.580×10^{-8}	46.63	53.37
HT (kg 1,4-DB-eq)	1.319×10^{-1}	3.05	96.95
FWAE (kg 1,4-DB-eq)	6.926×10^{-2}	2.04	97.96
MAE (kg 1,4-DB-eq)	3.695×10^{2}	1.09	98.91
TE (kg 1,4-DB-eq)	3.862×10^{-4}	4.36	95.64
PO (kg C_2H_4-eq)	8.982×10^{-5}	7.51	92.49
A (kg SO_2-eq)	4.993×10^{-3}	2.25	97.75
E (kg PO_4-eq)	9.593×10^{-4}	1.56	98.44
Overall contribution (%)		11.91	88.09

Taking into account only the values of the impacts of fertilizers, the emissions due to the application of nitrogen products only affect GW (26.0% of the total fertilizers), PO (56.2%), A (85.0%), and E (82.6%); for HT, the contribution is negligible (1.1%). For all other impacts, the contribution of fertilizer production is 100%.

3.3. Sensitivity Analysis

3.3.1. Cost Analysis

The application of sheep/goat manure to replace inorganic fertilizers reduces the cost of production; that is, it gives a positive balance in economic terms for all the crops analyzed. The balances are high, especially for woody crops; in particular, in olive trees, an annual value of EUR

45 ha^{-1} is reached. Furthermore, they are relatively low quantities of organic amendment that would allow even more efficient economic and environmental management, supplying them every 3–4 years to facilitate the retention of water and nutrients in the soil. For example, considering an addition of manure every 3 years, the amount required to achieve the appropriate fertilizer balance would be 6480 kg ha^{-1} in barley, 4854 kg ha^{-1} in almond trees, and 8910 kg ha^{-1} in olive trees. These amounts can be applied easily with medium–small sized trailers and, therefore, using low-power, low-consumption, and low-cost equipment. These values, in the specific case of the almond tree, are in line with those reported in the work of [3], also in SE Spain; they added 4800 kg of manure per hectare in one of their soil management treatments (called CM). Furthermore, this treatment had a cost of EUR 1182 ha^{-1}, quite close to our calculated value (EUR 1347 ha^{-1}, Table 5), and closer still if we consider the effect of inflation in the period 2020 to 2023.

The sheep/goat manure has good average values of macronutrients and a fertilizer balance that is very adaptable to various rainfed crops, such as those studied here. Only in the case of barley and other cereals are the phosphorus requirements, which are relatively high, not covered, so it would be necessary to provide phosphorus amendments every few years. The rainfed vineyard is another representative case in SE Spain for which this type of fertilization can be recommended, both from the economic perspective, due to the reduction in costs, and from the environmental perspective, due to the minimization of environmental impacts [28,33].

In relative terms, the decrease in cost is low in the case of almond and olive trees, but it is more important in barley, which is the crop with the highest annual nutritional requirements (Table 9) and, therefore, with a higher relative cost allocated to fertilization (Table 5).

Table 9. Sensitivity analysis of total costs.

Scenarios	Almond	Olive	Barley
Total Costs (€ ha^{-1})			
S1 (conventional)	1347	1603	491
S2 (manure)	1302	1558	460
S3 (compost)	1317	1515	426
Absolute difference (€ ha^{-1})			
S1 vs. S2	45	45	31
S1 vs. S3	30	88	65
Relative difference (%)			
S1 vs. S2	3.34	3.81	6.31
S1 vs. S3	2.23	5.49	13.24

AD = S1 − Sn; RD = 100 × (S1 − Sn)/S1.

The positive economic balance is greater in the case of applying locally sourced compost for all three crops analyzed. There is no market price for this local compost, but we calculated the cost of production and of transportation from the farm of origin to the site of use, considering a 20 km radius as a proximity criterion; the unit cost is EUR 0.023 per kg of compost (Table 4). The balance is high, especially for the woody crops; in particular, for olive trees a value of EUR 88 per hectare and year is reached. On the negative side, the balance reached (when all the nitrogen fertilizer units required are supplied) in the case of the olive tree is approximately 44-12-26; therefore, the needs are not fully covered for phosphorus (especially) or potassium (to a lesser extent). The crop with the second best economic balance is barley (EUR 65 ha^{-1}), confirming that the crops with higher requirements (barley and olive) respond better to this practice. The olive tree pattern is repeated for barley since this cereal does not have high potassium requirements (19 of the 20 fertilizer units required are supplied), and so, in the same way, the deficit is linked to phosphorus.

The almond tree, due to its greater need for potassium, requires extra applications of compost and this extra cost makes it the crop with the lowest positive balance (EUR 30 ha^{-1}). As in the case of sheep/goat manure, the quantities to be provided are relatively low, which would allow even more economically and environmentally efficient management, supplying them every 2–4 years. For example, considering an addition of compost every 3 years, the quantities to be provided would be 5280 kg ha^{-1} in barley, 3954 kg ha^{-1} in almond trees, and 7248 kg ha^{-1} in olive trees. These quantities are somewhat smaller than in the case of sheep/goat manure.

The compost has good average values of macronutrients and a fertilizer balance adaptable to various rainfed crops, in particular barley and olive trees, while it is not so appropriate for almond trees or grape vines—that is, crops with high potassium requirements. The economic balance is greater for the practice of providing local compost to crops with low potassium needs. The unit cost of the compost means that its use reduces costs, while also improving the structure and fertility of the soil and achieving the reuse of excess plant and animal waste (for example, pruning waste and slurry).

The relative differences shown in Table 9 indicate that in the case of barley, applying local compost achieves a 13.24% reduction in the production cost. In general, in rainfed crops, with low or no profitability and high vulnerability to limiting climate and soil conditions, these cost reductions can make the difference between economic viability and non-viability, since they have a direct impact on the net operating margin (income minus costs).

The addition of an organic amendment, be it sheep/goat manure or a compost derived from a mixture of several components, as in our case, is a practice that can achieve good economic results, especially in areas with soils that are very poor in organic matter. According to De Leijster et al. [3], in the case of almond trees in SE Spain, the addition of manure combined with conventional tillage is the treatment that gives the highest income for almond production as well as the highest net income, relative to green manure or no-tillage with a vegetation cover. Of course, the no-till option in rainfed lands in SE Spain is the least advantageous and is even economically unviable, since it reduces yields, and therefore income, in crops that already have very narrow viability margins [3,5].

In some work on soil management practices, financial compensation for environmental externalities related to soil carbon stocks and soil erosion has been proposed, as these are considered the externalities with the greatest effect on biophysical land degradation in the region [3,70]. In this sense, the evaluation of ecosystem services associated with agricultural practices is a necessary component, although it is not within the scope of this work. According to De Leijster et al. [3], the implementation of a public "green payment" for agroecological management of rainfed almond trees would increase the economic advantages of the combination of tillage with the addition of manure or compost, compared to other soil management strategies (green manure or no-till with a vegetation cover).

3.3.2. Life Cycle Assessment

The replacement of inorganic fertilizers with organic ones (manure S2 and compost S3) in the conventional woody crops (almond and olive) (S1) represents a decrease of around 50% in HT, FWAE, and MAE, and 20% in ADFF (Figure 1, Tables A1 and A2). For AD, the decrease is different depending on the type of organic fertilizer, being 40–50% with manure and 25–30% with compost. In barley, this impact profile is similar but the decrease in the values of the impacts is greater (Figure 1, Table A3).

In the woody crops, the differences in GW, OLD, and PO are very small; this is also the case for barley, except for PO where the decrease in the two scenarios with organic fertilizers is 50%.

However, the organic fertilizers give a notable increase in TE, A, and E. This increase in the values of these impact categories, especially in TE, due to organic fertilizers, when compared to inorganic fertilizers, has been described in different crops, such as apple [71], grape vines [25], and barley [72]. The NH_3 emissions associated with the application of organic fertilizers play an important role in these increases [25,71].

In some previous studies, the differences in GW, or greenhouse gas emissions, between conventional and organic cultivation are not very relevant and the value for organic cultivation has even been found to be higher [71,73]; on the contrary, in other work, the difference is significant and in favor of organic cultivation [54,74–76]. These discrepancies, however, are due in part to different agronomic factors, for which inputs and outputs are actually taken into account, and to the databases used in each LCA [73].

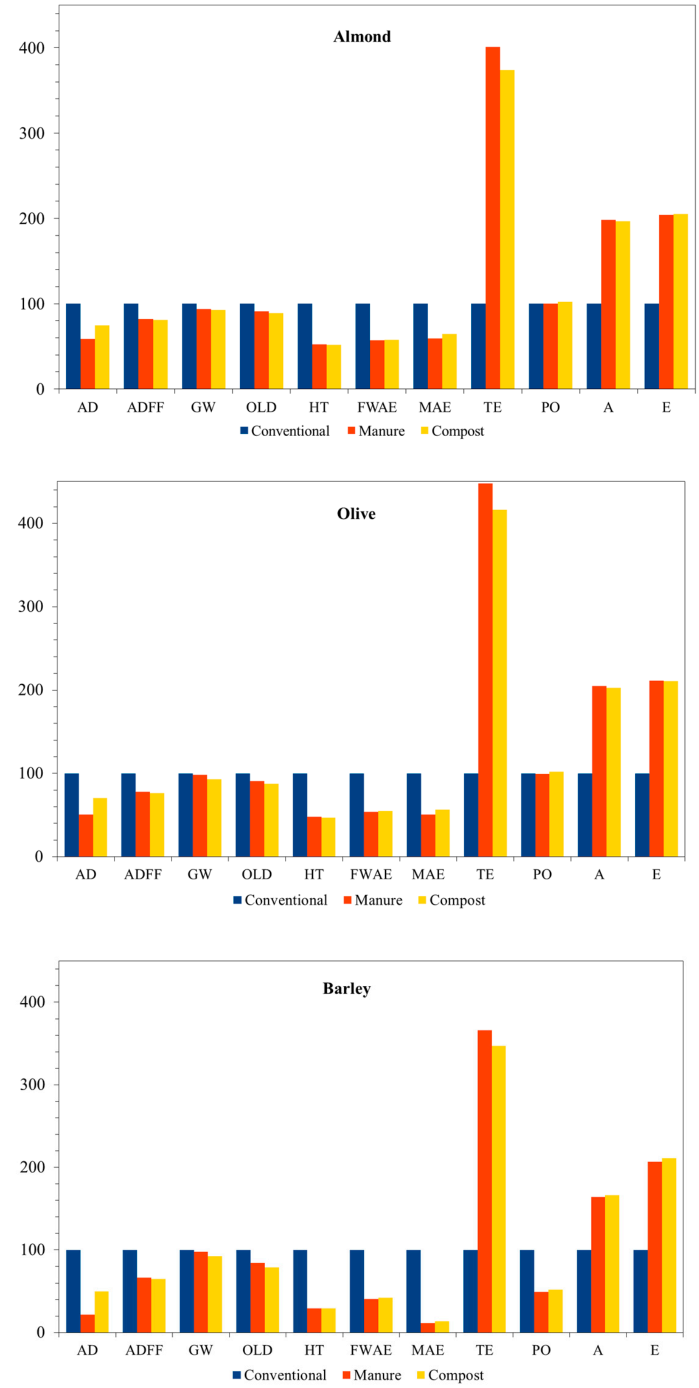

Figure 1. Differences between the conventional crop (S1) and those receiving manure (S2) or compost (S3), for almond, olive, and barley.

Be that as it may, as some authors indicate [77], the LCA results may not be sufficiently exhaustive to completely define the environmental profile of an organic production system. There are environmental aspects that are not evaluated in an LCA: for instance, organic fertilization, compared to inorganic, improves soil quality and increases soil organic matter [9–13]. This is especially important in the soils in which the crops studied here are grown since they are poor in organic matter.

3.3.3. The Use of Manure or Compost Avoids the Use of Inorganic Fertilizers

When the manure and compost are applied as fertilizers (scenarios S5 and S6), and they cease to be waste and the production and use of inorganic fertilizers is unnecessary, as suggested by Salomone et al. [58], then all the impacts decrease for the three crops (Figure 2, Tables A4–A6). Furthermore, the impact categories HT, FWAE, and MAE have negative values for the three crops and both organic fertilizers. In barley cultivation, in which phytosanitary products are not used, AD also has negative values.

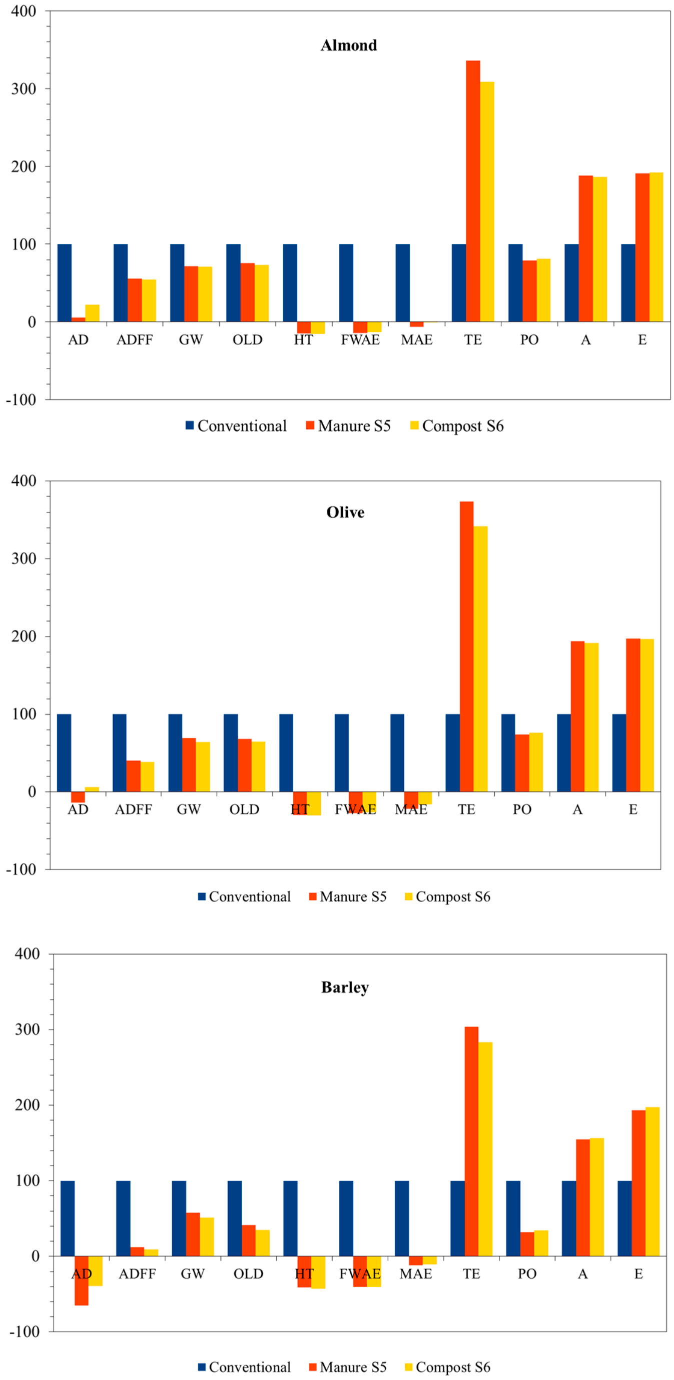

Figure 2. Differences between the conventional crop (S1) and those receiving manure (S5) or compost (S6), for almond, olive, and barley. In scenarios S5 and S6, the production and use of inorganic fertilizers is avoided.

In scenarios S5 and S6, the decrease in GW with respect to scenario 1 is notable, varying from 28 to 49% (Tables A4–A6).

It seems that this calculation option would be appropriate since manure and compost cease to be waste from the agricultural and livestock sector and are economically revalued by becoming a source of nutrients for agricultural soil. At the same time, this avoids the production of inorganic fertilizers for the sole purpose of nourishing agricultural soil, which, as indicated, is one of the most impactful elements in all categories.

4. Conclusions

For rainfed crops in semi-arid areas, such as SE Spain, the combination of tillage practices with manure or compost application is an alternative to inorganic fertilization. It reduces costs and maintains productivity, which in these scenarios can translate into the difference between economic viability and unviability. The values of all impact categories decrease significantly—except for those of TE, A, and E, which increase due to the greater emission of NH_3 associated with organic fertilizers. Also, it must be taken into account that these practices take advantage of and add value to waste from the agro-livestock sector while removing the need for the production of inorganic fertilizers, which further reduces environmental impacts and favors a circular economy.

In agreement with the views of other authors, we consider that the environmental advantages provided when farmers use tillage together with a supply of manure or compost could be rewarded through a "green" public payment that would increase the economic advantages of such practices and thus promote them. This is in line with the policies promoted by the EU that advocate a reduction in inorganic fertilization in order to reduce dependence on fertilizers from third countries and achieve a sustainable production system.

Author Contributions: B.G.C., B.G.G. and J.G.G. conceived and designed the present study. B.G.C. and J.G.G. collected the data, made calculations and performed the economic analysis. B.G.C. and B.G.G. performed the Life Cycle Assessment. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Table A1. Almond crop. Potential environmental impacts in the three scenarios evaluated and relative differences.

	Conventional (S1)	**Manure (S2)**	**Compost (S3)**	**S1 vs. S2 RD (%)**	**S1 vs. S3 RD (%)**
AD (kg Sb-eq)	2.36×10^{-5}	1.38×10^{-5}	1.76×10^{-5}	41.56	25.35
ADFF (MJ)	3.53×10^{1}	2.91×10^{1}	2.87×10^{1}	17.73	18.82
GW (kg CO_2-eq)	2.66×10^{0}	2.48×10^{0}	2.46×10^{0}	6.52	7.27
OLD (kg CFC-11-eq)	4.52×10^{-7}	4.12×10^{-7}	4.02×10^{-7}	8.71	10.90
HT (kg 1,4-DB-eq)	8.80×10^{-1}	4.61×10^{-1}	4.56×10^{-1}	47.58	48.15
FWAE (kg 1,4-DB-eq)	5.00×10^{-1}	2.84×10^{-1}	2.88×10^{-1}	43.12	42.29
MAE (kg 1,4-DB-eq)	8.43×10^{2}	5.00×10^{2}	5.46×10^{2}	40.71	35.29
TE (kg 1,4-DB-eq)	2.36×10^{-3}	9.47×10^{-3}	8.82×10^{-3}	−301.14	−273.80
PO (kg C_2H_4-eq)	4.71×10^{-4}	4.72×10^{-4}	4.82×10^{-4}	−0.17	−2.25
A (kg SO_2-eq)	2.81×10^{-2}	5.57×10^{-2}	5.52×10^{-2}	−98.39	−96.68
E (kg PO_4-eq)	6.37×10^{-3}	1.30×10^{-2}	1.31×10^{-2}	−104.02	−105.04

RD = 100 × (S1 − Sn)/S1.

Table A2. Olive crop. Potential environmental impacts in the three scenarios evaluated and relative differences.

	Conventional (S1)	Manure (S2)	Compost (S3)	S1 vs. S2 RD (%)	S1 vs. S3 RD (%)
AD (kg Sb-eq)	3.42×10^{-6}	1.74×10^{-6}	2.41×10^{-6}	49.09	29.37
ADFF (MJ)	4.35×10^{0}	3.40×10^{0}	3.33×10^{0}	21.95	23.54
GW (kg CO_2-eq)	3.54×10^{-1}	3.48×10^{-1}	3.30×10^{-1}	1.72	6.81
OLD (kg CFC-11-eq)	5.53×10^{-8}	5.02×10^{-8}	4.84×10^{-8}	9.25	12.45
HT (kg 1,4-DB-eq)	1.35×10^{-1}	6.46×10^{-2}	6.36×10^{-2}	52.13	52.84
FWAE (kg 1,4-DB-eq)	7.73×10^{-2}	4.16×10^{-2}	4.23×10^{-2}	46.13	45.25
MAE (kg 1,4-DB-eq)	1.34×10^{2}	6.84×10^{1}	7.63×10^{1}	49.17	43.24
TE (kg 1,4-DB-eq)	3.64×10^{-4}	1.63×10^{-3}	1.52×10^{-3}	−348.03	−316.05
PO (kg C_2H_4-eq)	6.82×10^{-5}	6.80×10^{-5}	6.96×10^{-5}	0.38	−2.06
A (kg SO_2-eq)	4.66×10^{-3}	9.55×10^{-3}	9.45×10^{-3}	−105.00	−102.85
E (kg PO_4-eq)	1.08×10^{-3}	2.27×10^{-3}	2.26×10^{-3}	−111.19	−110.56

RD = 100 × (S1 − Sn)/S1.

Table A3. Barley crop. Potential environmental impacts in the three scenarios evaluated and relative differences.

	Conventional (S1)	Manure (S2)	Compost (S3)	S1 vs. S2 RD (%)	S1 vs. S3 RD (%)
AD (kg Sb-eq)	2.25×10^{-6}	4.90×10^{-7}	1.12×10^{-6}	78.26	50.46
ADFF (MJ)	2.69×10^{0}	1.79×10^{0}	1.75×10^{0}	33.36	35.00
GW (kg CO_2-eq)	2.29×10^{-1}	2.24×10^{-1}	2.11×10^{-1}	2.17	7.68
OLD (kg CFC-11-eq)	2.58×10^{-8}	2.18×10^{-8}	2.04×10^{-8}	15.64	21.09
HT (kg 1,4-DB-eq)	1.32×10^{-1}	3.88×10^{-2}	3.88×10^{-2}	70.59	70.60
FWAE (kg 1,4-DB-eq)	6.93×10^{-2}	2.80×10^{-2}	2.93×10^{-2}	59.59	57.74
MAE (kg 1,4-DB-eq)	3.69×10^{2}	4.23×10^{1}	5.05×10^{1}	88.55	86.32
T × 10 (kg 1,4-DB-eq)	3.86×10^{-4}	1.41×10^{-3}	1.34×10^{-3}	−265.85	−247.38
PO (kg C_2H_4-eq)	8.98×10^{-5}	4.43×10^{-5}	4.67×10^{-5}	50.67	47.96
A (kg SO_2-eq)	4.99×10^{-3}	8.19×10^{-3}	8.30×10^{-3}	−63.96	−66.18
E (kg PO_4-eq)	9.59×10^{-4}	1.98×10^{-3}	2.03×10^{-3}	−106.74	−111.23

RD = 100 × (S1 − Sn)/S1.

Table A4. Almond crop. Potential environmental impacts when it is assumed that the application of manure (S5) and compost (S6) avoids the production of inorganic fertilizers and relative differences.

	Conventional (S1)	Manure (S5)	Compost (S6)	S1 vs. S5 RD (%)	S1 vs. S6 RD (%)
AD (kg Sb-eq)	2.36×10^{-5}	1.35×10^{-6}	5.15×10^{-6}	94.28	78.16
ADFF (MJ)	3.53×10^{1}	1.97×10^{1}	1.93×10^{1}	44.19	45.33
GW (kg CO_2-eq)	2.66×10^{0}	1.90×10^{0}	1.88×10^{0}	28.32	29.11
OLD (kg CFC-11-eq)	4.52×10^{-7}	3.42×10^{-7}	3.32×10^{-7}	24.31	26.53
HT (kg 1,4-DB-eq)	8.80×10^{-1}	-1.30×10^{-1}	-1.36×10^{-1}	114.74	115.43
FWAE (kg 1,4-DB-eq)	5.00×10^{-1}	-7.06×10^{-2}	-6.71×10^{-2}	114.13	113.43
MAE (kg 1,4-DB-eq)	8.43×10^{2}	-5.21×10^{1}	-7.46×10^{1}	106.18	100.88
TE (kg 1,4-DB-eq)	2.36×10^{-3}	7.94×10^{-3}	7.29×10^{-3}	−236.29	−208.83
PO (kg C2H4-eq)	4.71×10^{-4}	3.73×10^{-4}	3.82×10^{-4}	20.85	18.80
A (kg SO2-eq)	2.81×10^{-2}	5.28×10^{-2}	5.23×10^{-2}	−88.00	−86.27
E (kg PO4-eq)	6.37×10^{-3}	1.22×10^{-2}	1.22×10^{-2}	−90.93	−91.92

RD = 100 × (S1 − Sn)/S1.

Table A5. Olive crop. Potential environmental impacts when it is assumed that the application of manure (S5) and compost (S6) avoids the production of inorganic fertilizers, and relative differences.

	Conventional (S1)	Manure (S5)	Compost (S6)	S1 vs. S5 RD (%)	S1 vs. S6 RD (%)
AD (kg Sb-eq)	3.42×10^{-6}	-4.57×10^{-7}	2.16×10^{-7}	113.38	93.67
ADFF (MJ)	4.35×10^{0}	1.74×10^{0}	1.67×10^{0}	59.90	61.50
GW (kg CO_2-eq)	3.54×10^{-1}	2.45×10^{-1}	2.27×10^{-1}	30.62	35.71
OLD (kg CFC-11-eq)	5.53×10^{-8}	3.77×10^{-8}	3.60×10^{-8}	31.77	34.97
HT (kg 1,4-DB-eq)	1.35×10^{-1}	-3.98×10^{-2}	-4.08×10^{-2}	129.52	130.24
FWAE (kg 1,4-DB-eq)	7.73×10^{-2}	-2.11×10^{-2}	-2.04×10^{-2}	127.24	126.36
MAE (kg 1,4-DB-eq)	1.34×10^{2}	-2.92×10^{1}	-2.12×10^{1}	121.71	115.78
TE (kg 1,4-DB-eq)	3.64×10^{-4}	1.36×10^{-3}	1.25×10^{-3}	−273.81	−241.83
PO (kg C2H4-eq)	6.82×10^{-5}	5.05×10^{-5}	5.22×10^{-5}	26.01	23.57
A (kg SO2-eq)	4.66×10^{-3}	9.04×10^{-3}	8.94×10^{-3}	−93.93	−91.78
E (kg PO4-eq)	1.08×10^{-3}	2.12×10^{-3}	2.12×10^{-3}	−97.50	−96.87

RD = 100 × (S1 − Sn)/S1.

Table A6. Barley crop. Potential environmental impacts when it is assumed that the application of manure (S5) and compost (S6) avoids the production of inorganic fertilizers, and relative differences.

	Conventional (S1)	Manure (S5)	Compost (S6)	S1 vs. S5 RD (%)	S1 vs. S6 RD (%)
AD (kg Sb-eq)	2.25×10^{-6}	-1.46×10^{-6}	-8.87×10^{-7}	164.99	139.38
ADFF (MJ)	2.69×10^{0}	3.24×10^{-1}	2.43×10^{-1}	87.97	90.99
GW (kg CO_2-eq)	2.29×10^{-1}	1.33×10^{-1}	1.18×10^{-1}	41.96	48.47
OLD (kg CFC-11-eq)	2.58×10^{-8}	1.07×10^{-8}	9.00×10^{-9}	58.58	65.11
HT (kg 1,4-DB-eq)	1.32×10^{-1}	-5.41×10^{-2}	-5.65×10^{-2}	141.04	142.82
FWAE (kg 1,4-DB-eq)	6.93×10^{-2}	-2.78×10^{-2}	-2.79×10^{-2}	140.15	140.32
MAE (kg 1,4-DB-eq)	3.69×10^{2}	-4.45×10^{1}	-3.85×10^{1}	112.05	110.41
TE (kg 1,4-DB-eq)	3.86×10^{-4}	1.17×10^{-3}	1.09×10^{-3}	−203.53	−183.49
PO (kg C_2H_4-eq)	8.98×10^{-5}	2.87×10^{-5}	3.08×10^{-5}	68.00	65.72
A (kg SO_2-eq)	4.99×10^{-3}	7.73×10^{-3}	7.83×10^{-3}	−54.77	−56.76
E (kg PO_4-eq)	9.59×10^{-4}	1.85×10^{-3}	1.89×10^{-3}	−93.08	−97.23

RD = 100 × (S1 − Sn)/S1.

References

1. Wezel, A.; Casagrande, M.; Celette, F.; Vian, J.F.; Ferrer, A.; Peigné, J. Agroecological Practices for Sustainable Agriculture. A Review. *Agron. Sustain. Dev.* **2014**, *34*, 1–20. [CrossRef]
2. Aguilera, E.; Díaz-Gaona, C.; García-Laureano, R.; Reyes-Palomo, C.; Guzmán, G.I.; Ortolani, L.; Sánchez-Rodríguez, M.; Rodríguez-Estévez, V. Agroecology for Adaptation to Climate Change and Resource Depletion in the Mediterranean Region. A Review. *Agric. Syst.* **2020**, *181*, 102809. [CrossRef]
3. De Leijster, V.; Verburg, R.W.; Santos, M.J.; Wassen, M.J.; Martínez-Mena, M.; de Vente, J.; Verweij, P.A. Almond Farm Profitability under Agroecological Management in South-Eastern Spain: Accounting for Externalities and Opportunity Costs. *Agric. Syst.* **2020**, *183*, 102878. [CrossRef]
4. Kremen, C.; Iles, A.; Bacon, C. Diversified Farming Systems: An Agroecological, Systems-Based Alternative to Modern Industrial Agriculture. *Ecol. Soc.* **2012**, *17*, 44. [CrossRef]
5. Martin-Gorriz, B.; Maestre-Valero, J.F.; Boix-Fayos, C.; Martínez-Mena, M. Carbon Emissions and Economic Assessment of Farm Operations under Different Tillage Practices in Organic Rainfed Almond Orchards in Semiarid Mediterranean Conditions. *Sci. Hortic.* **2020**, *261*, 108978. [CrossRef]
6. Testa, R.; Foderâ, M.; Di Trapani, A.M.; Tudisca, S.; Sgroi, F. Choice between Alternative Investments in Agriculture: The Role of Organic Farming to Avoid the Abandonment of Rural Areas. *Ecol. Eng.* **2015**, *83*, 227–232. [CrossRef]
7. Sgroi, F.; Candela, M.; Di Trapani, A.M.; Foderà, M.; Squatrito, R.; Testa, R.; Tudisca, S. Economic and Financial Comparison between Organic and Conventional Farming in Sicilian Lemon Orchards. *Sustainability* **2015**, *7*, 947–961. [CrossRef]
8. Jezeer, R.E.; Verweij, P.A.; Santos, M.J.; Boot, R.G.A. Shaded Coffee and Cocoa—Double Dividend for Biodiversity and Small-Scale Farmers. *Ecol. Econ.* **2017**, *140*, 136–145. [CrossRef]

9. Cirigliano, P.; Chiriacò, M.V.; Nuñez, A.; Dal Monte, G.; Labagnara, T. Combined Effect of Irrigation and Compost Application on Montepulciano Berry Composition in a Volcanic Environment of Latium Region (Central Italy). *Cien. Inv. Agr.* **2017**, *44*, 195–206. [CrossRef]
10. Bai, Z.; Caspari, T.; Ruiperez Gonzalez, M.; Batjes, N.H.; Mäder, P.; Bünemann, E.K.; de Goede, R.; Brussaard, L.; Xu, M.; Santos Ferreira, C.S.; et al. Effects of Agricultural Management Practices on Soil Quality: A Review of Long-Term Experiments for Europe and China. *Agric. Ecosyst. Environ.* **2018**, *265*, 1–7. [CrossRef]
11. Pinto-Morales, F.; Retamal-Salgado, J.; López, M.D.; Zapata, N.; Vergara-Retamales, R.; Pinto-Poblete, A. The Use of Compost Increases Bioactive Compounds and Fruit Yield in Calafate Grown in the Central South of Chile. *Agriculture* **2022**, *12*, 98. [CrossRef]
12. Mugnai, S.; Masi, E.; Azzarello, E.; Mancuso, S. Influence of Long-Term Application of Green Waste Compost on Soil Characteristics and Growth, Yield and Quality of Grape (*Vitis vinifera* L.). *Compost. Sci. Util.* **2012**, *20*, 29–33. [CrossRef]
13. Marín-Martínez, A.; Sanz-Cobeña, A.; Bustamante, M.A.; Agullo, E.; Paredes, C. Effect of Organic Amendment Addition on Soil Properties, Greenhouse Gas Emissions and Grape Yield in Semi-Arid Vineyard Agroecosystems. *Agronomy* **2021**, *11*, 1477. [CrossRef]
14. Bittenbender, H.C.; Hue, N.V.; Fleming, K.; Brown, H. Sustainability of Organic Fertilization of Macadamia with Macadamia Husk-manure Compost. *Commun. Soil. Sci. Plant Anal.* **2008**, *29*, 409–419. [CrossRef]
15. Morlat, R.; Chaussod, R. Long-Term Additions of Organic Amendments in a Loire Valley Vineyard. I. Effects on Properties of a Calcareous Sandy Soil. *Am. J. Enol. Vitic.* **2008**, *59*, 353–363. [CrossRef]
16. Celik, I.; Ortas, I.; Kilic, S. Effects of Compost, Mycorrhiza, Manure and Fertilizer on Some Physical Properties of a Chromoxerert Soil. *Soil. Tillage Res.* **2004**, *78*, 59–67. [CrossRef]
17. Vásquez, H.; Maravi, C. The Effect of Organic Fertilization (Biol and Compost) on the Establishment of Morera (*Morus alba*). *RICBA* **2017**, *1*, 33–39. [CrossRef]
18. Wang, S.Y.; Lin, H.S. Compost as a Soil Supplement Increases the Level of Antioxidant Compounds and Oxygen Radical Absorbance Capacity in Strawberries. *J. Agric. Food Chem.* **2003**, *51*, 6844–6850. [CrossRef]
19. Zhong, W.; Gu, T.; Wang, W.; Zhang, B.; Lin, X.; Huang, Q.; Shen, W. The Effects of Mineral Fertilizer and Organic Manure on Soil Microbial Community and Diversity. *Plant Soil.* **2010**, *326*, 511–522. [CrossRef]
20. Donia, E.; Mineo, A.M.; Sgroi, F. A Methodological Approach for Assessing Business Investments in Renewable Resources from a Circular Economy Perspective. *Land. Use Policy* **2018**, *76*, 823–827. [CrossRef]
21. COM. *The European Green Deal. Communication from the Commission to the European Parliament*; European Commission: Brussels, Belgium, 2019.
22. EU. *Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 Establishing Rules on Support for Strategic Plans to Be Drawn up by Member States under the Common Agricultural Policy (CAP Strategic Plans) and Financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and Repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013*; EUR-Lex: Brussels, Belgium, 2021.
23. Soto García, M.; Martínez Álvarez, V.; Martín Górriz, B. *El regadío en la Región de Murcia. Caracterización y Análisis Mediante Indicadores de Gestión*; Sindicato Central de Regantes del Acueducto Tajo-Segura: Murcia, Spain, 2014; ISBN 978-84-697-0372-4.
24. Martin-Gorriz, B.; Martínez-Alvarez, V.; Maestre-Valero, J.F.; Gallego-Elvira, B. Influence of the Water Source on the Carbon Footprint of Irrigated Agriculture: A Regional Study in South-Eastern Spain. *Agronomy* **2021**, *11*, 351. [CrossRef]
25. García Castellanos, B.; García García, B.; García García, J. Evaluation of the Sustainability of Vineyards in Semi-Arid Climates: The Case of Southeastern Spain. *Agronomy* **2022**, *12*, 3213. [CrossRef]
26. Romero, P.; Gil Muñoz, R.; Fernández-Fernández, J.I.; del Amor, F.M.; Martínez-Cutillas, A.; García-García, J. Improvement of Yield and Grape and Wine Composition in Field-Grown Monastrell Grapevines by Partial Root Zone Irrigation, in Comparison with Regulated Deficit Irrigation. *Agric. Water Manag.* **2015**, *149*, 55–73. [CrossRef]
27. Romero, P.; Botía, P.; Navarro, J.M. Selecting Rootstocks to Improve Vine Performance and Vineyard Sustainability in Deficit Irrigated Monastrell Grapevines under Semiarid Conditions. *Agric. Water Manag.* **2018**, *209*, 73–93. [CrossRef]
28. García-Castellanos, B.; García-García, B.; García-García, J. Evaluación de la sostenibilidad de tres sistemas de cultivo de viña característicos de la Región de Murcia. *ITEA* **2021**, *118*, 137–157. [CrossRef]
29. Fraga, H.; García de Cortazar, I.; Malheiro, A.C.; Santos, J.A. Modelling Climate Change Impacts on Viticultural Yield, Phenology and Stress Conditions in Europe. *Glob. Chang. Biol.* **2016**, *22*, 3774–3788. [CrossRef] [PubMed]
30. Resco, P.; Iglesias, A.; Bardají, I.; Sotés, V. Exploring Adaptation Choices for Grapevine Regions in Spain. *Reg. Environ. Chang.* **2016**, *16*, 979–993. [CrossRef]
31. CARM. *Estadística Agraria de Murcia 2019/20*; Comunidad Autónoma de la Región de Murcia. Consejería de Agua, Agricultura, Ganadería, Pesca, Medio Ambiente y Emergencias: Murcia, Spain, 2021.
32. García García, J. Evaluación económica del cultivo de almendro en secano en la Región de Murcia: Situación actual y retos de futuro. *Fruticultura* **2015**, *44*, 26–36.
33. García García, J.; García García, B.; García Castellanos, B. *Manual de Buenas Prácticas Para el Cultivo de la Viña en la Región de Murcia*; Grupo operativo QVALITAS: Murcia, Spain, 2021; ISBN 978-84-09-32135-3.

34. García García, J.; García García, B. Aspectos socioeconómicos y ambientales del cultivo de la uva Monastrell. In *El libro de la Monastrell*; Riquelme, F., Martínez-Cutillas, A., Eds.; Consejería de Agua, Agricultura, Ganadería y Pesca de la Región de Murcia: Murcia, Spain, 2018; pp. 71–88, ISBN 978-84-09-06249-2.
35. Ministerio de Agricultura, Alimentación y Medio Ambiente. *Manual Para el Cumplimiento de la Condicionalidad Otros Cultivos Herbáceos*; Ministerio de Agricultura, Alimentación y Medio Ambiente: Madrid, Spain, 2020.
36. MAPA. *Anuario de Estadística 2021*; Ministerio de Agricultura, Pesca y Alimentación (MAPA): Madrid, Spain, 2021.
37. García García, J. *Estructura de Costes de las Orientaciones Productivas Agrícolas de la Región de Murcia: Frutos Secos, Frutales de Pepita, Vid y Olivo*; Técnica; Consejería de Agua, Agricultura, Ganadería y Pesca de la Región de Murcia: Murcia, Spain, 2019; ISBN MU 422-2019.
38. García García, J.; Payá Pina, D. Análisis socioeconómico del cultivo del almendro en la Región de Murcia. *Fruticultura* **2020**, *78*, 136–144.
39. García García, J. *Estructura de Costes de los Principales Cultivos en Agricultura Ecológica de la Región de Murcia*; Técnica; Consejería de Agua, Agricultura, Ganadería y Pesca de la Región de Murcia: Murcia, Spain, 2023; ISBN MU 132-2023.
40. MAPA. *Secuestro de Carbono y Mejora de los Suelos en Cultivos Agrícolas Mediterráneos*; Guía de Buenas Prácticas Agrarias CARBOCERT; Unión Europea. Ministerio de Agricultura, Pesca y Alimentación (MAPA): Madrid, Spain, 2020.
41. *MAGRAMA Guía Práctica de la Fertilización Racional de los Cultivos en España*; Ministerio de Medio Ambiente y Medio Rural y Marino (MAGRAMA): Madrid, Spain, 2010; ISBN 978-84-491-0997-3.
42. García García, J.; García García, B. Sustainability Assessment of Greenhouse Pepper Production Scenarios in Southeastern Spain. *Agronomy* **2022**, *12*, 1254. [CrossRef]
43. ISO. *ISO 14040*; Environmental Management-Life Cycle Assessment: Principles and Framework. International Organization for Standards (ISO): Geneva, Switzerland, 2006.
44. ISO. *ISO 14044*; Environmental Management –Life Cycle Assessment: Requirements and Guidelines. International Organization for Standards (ISO): Geneva, Switzerland, 2006.
45. Dijkman, T.; Birkved, M.; Saxe, H.; Wenzel, H.; Hauschild, M.Z. Environmental Impacts of Barley Cultivation under Current and Future Climatic Conditions. *J. Clean. Prod.* **2017**, *140*, 644–653. [CrossRef]
46. PRé. *Introduction to LCA with SimaPro*; PRé: Amersfoort, The Netherlands, 2016.
47. EEA. *EMEP/EEA Air Pollution Emission Inventory Guidebook 2019. Technical Guidance to Prepare National Emission Inventories*; EEA Report; Publications Office of the European Union: Luxenbourg, 2019; ISBN 978-92-9213-806-6.
48. del Hierro, Ó.; Gallejones, P.; Besga, G.; Artetxe, A.; Garbisu, C. A Comparison of IPCC Guidelines and Allocation Methods to Estimate the Environmental Impact of Barley Production in the Basque Country through Life Cycle Assessment (LCA). *Agriculture* **2021**, *11*, 1005. [CrossRef]
49. IPCC. *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*; Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenco, Y., Shermanau, P., Federici, S., Eds.; IPCC: Geneva, Switzerland, 2019; ISBN 978-4-88788-232-4.
50. Pergola, M.; D'Amico, M.; Celano, G.; Palese, A.M.; Scuderi, A.; Di Vita, G.; Pappalardo, G.; Inglese, P. Sustainability Evaluation of Sicily's Lemon and Orange Production: An Energy, Economic and Environmental Analysis. *J. Environ. Manag.* **2013**, *128*, 674–682. [CrossRef]
51. Beccali, M.; Cellura, M.; Iudicello, M.; Mistretta, M. Resource Consumption and Environmental Impacts of the Agrofood Sector: Life Cycle Assessment of Italian Citrus-Based Products. *Environ. Manag.* **2009**, *43*, 707–724. [CrossRef]
52. Gazulla, C.; Raugei, M.; Fullana-i-Palmer, P. Taking a Life Cycle Look at Crianza Wine Production in Spain: Where Are the Bottlenecks? *Int. J. Life Cycle Assess.* **2010**, *15*, 330–337. [CrossRef]
53. Bosco, S.; Di Bene, C.; Galli, M.; Remorini, D.; Massai, R.; Bonari, E. Greenhouse Gas Emissions in the Agricultural Phase of Wine Production in the Maremma Rural District in Tuscany, Italy. *Ital. J. Agron.* **2011**, *6*, 15. [CrossRef]
54. Villanueva-Rey, P.; Vázquez-Rowe, I.; Moreira, M.T.; Feijoo, G. Comparative Life Cycle Assessment in the Wine Sector: Biodynamic vs Conventional Viticulture Activities in NW Spain. *J. Clean. Prod.* **2014**, *65*, 330–341. [CrossRef]
55. De Luca, A.I.; Falcone, G.; Iofrida, N.; Stillitano, T.; Strano, A.; Gulisano, G. Life Cycle Methodologies to Improve Agri-Food Systems Sustainability. *Life Cycle Methodol. Improv. Agri-Food Syst. Sustain.* **2015**, *1*, 135–150. [CrossRef]
56. Falcone, G.; De Luca, A.I.; Stillitano, T.; Strano, A.; Romeo, G.; Gulisano, G. Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. *Sustainability* **2016**, *8*, 793. [CrossRef]
57. Barrós Torres, A.; Bruna Lavilla, P.; Vallés López, M.; Castillo Aranda, A.; López Elbaile, L.; Iguácel Soteras, F.; Betrán Aso, J.A. *Estiércoles Caracterización, Análitica e Implicaciones Sobre su Aprovechamiento Fertilizante*; Informaciones Técnicas; Gobierno de Aragón Departamento de Desarrollo Rural y Sostenibilidad: Zaragoza, Spain, 2018; Volume 268.
58. Salomone, R.; Saija, G.; Mondello, G.; Giannetto, A.; Fasulo, S.; Savastano, D. Environmental Impact of Food Waste Bioconversion by Insects: Application of Life Cycle Assessment to Process Using Hermetia Illucens. *J. Clean. Prod.* **2017**, *140*, 890–905. [CrossRef]
59. Navarro, A.; Puig, R.; Kılıç, E.; Penavayre, S.; Fullana-i-Palmer, P. Eco-Innovation and Benchmarking of Carbon Footprint Data for Vineyards and Wineries in Spain and France. *J. Clean. Prod.* **2017**, *142*, 1661–1671. [CrossRef]
60. Bartzas, G.; Vamvuka, D.; Komnitsas, K. Comparative Life Cycle Assessment of Pistachio, Almond and Apple Production. *Inf. Process Agric.* **2017**, *4*, 188–198. [CrossRef]

61. Sottile, F.; Massaglia, S.; Peano, C. Ecological and Economic Indicators for the Evaluation of Almond (*Prunus dulcis* L.) Orchard Renewal in Sicily. *Agriculture* **2020**, *10*, 301. [CrossRef]
62. Venkat, K. Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. *J. Sustain. Agr.* **2012**, *36*, 620–649. [CrossRef]
63. Kendall, A.; Marvinney, E.; Brodt, S.; Zhu, W. Life Cycle–Based Assessment of Energy Use and Greenhouse Gas Emissions in Almond Production, Part I: Analytical Framework and Baseline Results. *J. Ind. Ecol.* **2015**, *19*, 1008–1018. [CrossRef]
64. Aguilera, E.; Guzmán, G.; Alonso, A. Greenhouse Gas Emissions from Conventional and Organic Cropping Systems in Spain. II. Fruit Tree Orchards. *Agron. Sustain. Dev.* **2015**, *35*, 725–737. [CrossRef]
65. Espadas-Aldana, G.; Vialle, C.; Belaud, J.P.; Vaca-Garcia, C.; Sablayrolles, C. Analysis and Trends for Life Cycle Assessment of Olive Oil Production. *Sustain. Prod. Consum.* **2019**, *19*, 216–230. [CrossRef]
66. Rahmani, A.; Parashkoohi, M.G.; Zamani, D.M. Sustainability of Environmental Impacts and Life Cycle Energy and Economic Analysis for Different Methods of Grape and Olive Production. *Energy Rep.* **2022**, *8*, 2778–2792. [CrossRef]
67. Romero-Gámez, M.; Castro-Rodríguez, J.; Suárez-Rey, E. Optimization of Olive Growing Practices in Spain from a Life Cycle Assessment Perspective. *J. Clean. Prod.* **2017**, *149*, 25–37. [CrossRef]
68. El Joumri, L.; Labjar, N.; Dalimi, M.; Harti, S.; Dhiba, D.; El Messaoudi, N.; Bonnefille, S.; El Hajjaji, S. Life Cycle Assessment (LCA) in the Olive Oil Value Chain: A Descriptive Review. *Environ. Dev.* **2023**, *45*, 100800. [CrossRef]
69. Khorramdel, S.; Ghorbani, R.; Ghafori, A.A. Comparison of Environmental Impacts for Dryland and Irrigated Barley Agroecosystems by Using Life Cycle Assessment (LCA) Methodology. *J. Plant Prod.* **2015**, *22*, 243–264.
70. Montanaro, G.; Xiloyannis, C.; Nuzzo, V.; Cichio, B. Orchard Management, Soil Organic Carbon and Ecosystem Services in Mediterranean Fruit Tree Crops. *Sci. Hortic.* **2017**, *2017*, 92–101. [CrossRef]
71. Keyes, S.; Tyedmers, P.; Beazley, K. Evaluating the Environmental Impacts of Conventional and Organic Apple Production in Nova Scotia, Canada, through Life Cycle Assessment. *J. Clean. Prod.* **2015**, *104*, 40–51. [CrossRef]
72. Stylianou, M.; Papamichael, I.; Voukkali, I.; Tsangas, M.; Omirou, M.; Ioannides, I.M.; Zorpas, A.A. LCA of Barley Production: A Case Study from Cyprus. *J. Environ. Res. Public. Health* **2023**, *20*, 2417. [CrossRef] [PubMed]
73. Meier, M.S.; Stoessel, F.; Jungbluth, N.; Juraske, R.; Schader, C.; Stolze, M. Environmental Impacts of Organic and Conventional Agricultural Products—Are the Differences Captured by Life Cycle Assessment? *J. Environ. Manag.* **2015**, *149*, 193–208. [CrossRef]
74. Meisterling, K.; Samaras, C.; Schweizer, V. Decisions to Reduce Greenhouse Gases from Agriculture and Product Transport: LCA Case Study of Organic and Conventional Wheat. *J. Clean. Prod.* **2009**, *17*, 222–230. [CrossRef]
75. Ribal, J.; Ramírez-Sanz, C.; Estruch, V.; Clemente, G.; Sanjuán, N. Organic versus Conventional Citrus. Impact Assessment and Variability Analysis in the Comunitat Valenciana (Spain). *Int. J. Life Cycle Assess.* **2016**, *22*, 571–586. [CrossRef]
76. Chatzisymeon, E.; Foteinis, S.; Borthwick, A.G.L. Life Cycle Assessment of the Environmental Performance of Conventional and Organic Methods of Open Field Pepper Cultivation System. *Int. J. Life Cycle Assess.* **2017**, *22*, 896–908. [CrossRef]
77. Petti, L.; Arzoumanidis, I.; Benedetto, G.; Bosco, S.; Cellura, M.; De Camillis, C.; Fantin, V.; Masotti, P.; Pattara, C.; Raggi, A.; et al. Life Cycle Assessment in the Wine Sector. In *Life Cycle Assessment in the Agri-Food Sector*; Notarnicola, B., Salomone, R., Petti, L., Renzulli, P.A., Roma, R., Cerutti, A.K., Eds.; Springer International Publishing: Cham, Switzerland, 2015; pp. 123–184, ISBN 978-3-319-11939-7.