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# Crop Diversification and Resilience of Drought-Resistant Species in Semi-Arid Areas: An Economic and Environmental Analysis

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**Abstract:** Specialization and intensification in agriculture have increased productivity but have also led to the spread of monocultural systems, simplifying production but reducing genetic diversity. The purpose of this study was to propose crop diversification as a tool to increase biodiversity and achieve sustainable and resilient intensive agriculture, particularly in areas with water scarcity. In this paper, a combined life cycle assessment (LCA) and life cycle costing (LCC) applied to evaluate the environmental and economic sustainability of a differentiated system of cultivation were (pomegranates, almonds and olives), according to modern intensive and super-intensive cropping systems. Based on the results obtained, it is deduced that pomegranate cultivation generated the highest environmental load, followed by almonds and olives. From the financial analysis, it emerged that almond farming is the most profitable, followed by pomegranate and olive farming.

**Keywords:** crop diversification; resilience; water management; water efficiency



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## 1. Introduction

The growing worldwide food demand requires an increase in agricultural production, pushing farmers toward crop specialization and input intensification. It has contributed to the yield gains but has also enhanced the decline in crop diversity [1]. This simplification of farming systems and the consequent burdening of environmental constraints have increased concerns regarding the future functionality of ecosystems with regard to biodiversity, pathogen diffusion and adaptation potential to climate change [2,3].

The adoption of drought-tolerant crops [4,5] integrated into the different and well-established strategies for saving water in agriculture (e.g., regulated deficit irrigation, drip irrigation systems, etc.) may contribute to improving biodiversity, solve the problems of water scarcity and make the agroecosystems more resilient. Environmental changes and the spread of plant-related pathogens greatly influence food production and safety. There is a clear need to develop strategies to manage agroecosystem resilience; integration with different species could be a possible option [6]. Therefore, the need to innovate agricultural production models could generate new market opportunities for farms.

Although in the literature it has been widely demonstrated that the implementation of increased agricultural crop diversification reduces biodiversity loss by making the agroecosystem more resilient [7,8], most of the research has focused on cereals and horticultural crops [1,9]; therefore, there is the lack of a concept of diversification related to tree crops. The olive-growing sector, which, due to its low water requirement, is widespread throughout the Mediterranean region, plays an important social, economic, and environmental role in olive-producing countries; moreover, in the Mediterranean area, traditional systems faced problems linked to monoculture and farmers showed concerns about its negative effects in term of pests and abiotic diseases, water scarcity, and a strong decrease in the level of income [10,11].

A diversity of organisms is required for ecosystem functionality and its capability to supply services, in addition to food production [6]. Renewal processes through the diversification of agroecosystems, in the form of polycultures, are needed to achieve this goal. In this study, agricultural diversification refers to the transition from the exclusive and repeated cultivation over time of a single tree crop in a certain area toward the introduction of several different tree species that were formerly underutilized or neglected. Crop diversification has been lauded as a tool to suppress pest outbreaks, preserve biodiversity, and optimize water management when facing water scarcity problems.

Moreover, in the last few years, a change in dietary habits has been observed that tends to privilege the nutritional properties of products [12–14], especially if they are obtained from sustainable crop systems (e.g., integrated and organic systems).

In this regard, studies have shown that some tree crops, such as almond and pomegranate, may represent a significant source of health-promoting substances that are considered fundamental to a healthy diet [15,16] improving the ecosystem quality, farm income and employment opportunities [17–19]. According to trade statistics, the domestic consumption of almonds and pomegranates has increased, mainly due to their classification as 'superfoods', resulting in worldwide commercial success [20–22].

The aim of the study was to evaluate the environmental and economic sustainability of crop diversification, concerning the possibility of combining an existing monocultural cropping system (olive orchards) with low-water-demanding crops (almond and pomegranate) that are able to withstand deficit irrigation [23,24], considering, as a case study, a particular area of the Mediterranean, the Salento Peninsula (dark grey in Figure 1). The Salento Peninsula is a sub-region that extends over the southern part of Apulia and is in the easternmost area of Italy.

**Figure 1.** Study area: the Salento Peninsula (Apulia region, Southern Italy).

In this paper, we performed an integrated environmental and economic assessment of a local intensive cropping system, involving olives, pomegranates and almonds, which is considered highly efficient in terms of productivity and management [17,25–27]. In particular, life cycle assessment (LCA) was integrated with life cycle costing (LCC) analysis, through the adoption of a common database of employed inputs, considering the same functional unit (1 ha of cultivation) and the system boundary (from cradle to farm gate) [28].

## 2. Materials and Methods

### 2.1. Study Area and Data Collection

Italy is the second most important country in the world for olive production (Spain 45%, Italy 15%) and export (Spain 60%, Italy 20%) [29]. The most important olive cultivation areas are mainly in Southern Italy, particularly in Apulia, which accounts for 45% of the total olive national growing area, Calabria (19%) and Sicily (10%). The olive farming sector has to face growing competition in the international olive oil market [30]. Nowadays, the Italian sector is mainly represented by traditional olive orchards (80%) with fewer than 200 trees/ha, where production costs are higher than revenues, due to low productivity and a low level of mechanization for pruning and harvesting operations [31,32]. Moreover, in Apulia, a disease known as "Olive Quick Decline Syndrome" (OQDS) destroyed about 40% of the regional olive orchards in the last ten years. The causal agent is *Xylella fastidiosa*, a Gram-negative bacterium for which no cure is known [33]; the high concentrations of olive cultivation worsened the spread of the pathogen and the associated disease [34]. The bacterium invades the xylem of a wide range of hosts; it has wrought havoc on vineyards in California and citrus trees in Brazil. Affected areas have been reported in other European countries: Corsica (2015), France (2015), the Balearic Islands (2016), Spain (2017) and Portugal (2019) [35]. Regeneration strategies concern the replanting of *X. fastidiosa*-resistant olive tree cultivars [36,37], through the adoption of intensive and super-intensive olive-growing models, since they increase yield and reduce operating costs [32] with an enhancement of the level of income. As an alternative, a substitution of an olive orchard with other crops that are similar in soil, climate and technical requirements, has been taken into consideration in the development plans [38].

Globally, almond (*Prunus dulcis*) cultivation is experiencing a period of renewed interest, mainly due to a strong interest in the health properties of the fruits. According to the Food and Agriculture Organization (FAO) statistical data, the global production of almonds in their shells is estimated to be just over 3,200,000 t in an area of over 2,000,000 hectares. The United States, with a production of over 1,000,000 t of shelled almonds, has now consolidated its leadership (78%) of the world's almond production, which was followed by Australia (8%), Spain (6%), Turkey (3%), and Italy (2%) [1]. After a constant contraction of areas and production in the second half of the last century, the farming community in the Mediterranean Basin is revaluing this crop, which provides significant results if the farmer abandons traditional cultivation models to adopt more modern and profitable ones. The implementation of almond cultivation involves an evolutionary process of cultivation techniques compared to the past, through the mechanization of pruning and harvesting, in order to reduce production costs and maximize productivity. In this study, the almond tree that is cultivated with super-intensive management has been considered for analysis because it is part of a highly efficient system in terms of productivity and management [17,27].

Pomegranate (*Punica granatum* L.) is a temperate species that requires high summer temperatures to ripen the fruits properly. For this reason, its cultivation is relegated to the Mediterranean Basin, southern Asia, and several countries in North and South America [2]. Its cultivation is attracting increasing commercial interest thanks to its recognized health properties, including pomegranates among the functional fruits [3]. The processing of the fruit, destined for the "ready to eat" market, has contributed to the increase in crop areas in the world, reaching a cultivation area that is wider than 300,000 ha and a world production that is higher than 3,000,000 t [4].

Almond and pomegranate are two water-stress-tolerant species and for these crops, different water strategies have been studied and developed: one of the main water-saving strategies is regulated deficit irrigation (RDI), based on reducing and supplying irrigation according to water stress (tolerant or sensitive) phenological periods [38]. In particular:

- In pomegranate orchards, a mild water deficit during the flowering–fruit set period, considered a non-critical period, allows water saving of up to 30% without affecting the marketable yield [39,40]; a drip irrigation system, in an arid region, saved about

32% of the water compared to surface irrigation practices [41] and reduced energy consumption and greenhouse gas emissions by approximately 15.6% [42].

- In almond orchards, regulated deficit irrigation strategies and subsurface drip irrigation have allowed a 45% water saving, while production was reduced by 17% [43]; deficit irrigation has improved almond quality and water saving without significant yield loss [44].

A crucial requirement for performing an LCA and LCC is the availability of a complete and accurate technical and economic data set regarding the full cultural cycle. This need was provided for by performing a focus-group study among key informants (practitioners, the representatives of farmers' associations and technical assistants) with a deep knowledge of Mediterranean agriculture systems. Their suggestions allowed us to select and contact a convenience sample of 20 farms that are representative of the most common types of innovative enterprises in the area. These innovative farms were chosen, taking care that for the three considered crops, differences in terms of dimension and production techniques were represented. The samples were drawn from six farms for pomegranate, six for almond and eight for olive cultivation; the farmers providing the samples were directly interviewed, reported their own structural features and cultivation practices (Table 1) and filled in a structured questionnaire, including all cultivation input and output data that were related to the study period. The farms that were analyzed declared that they would adhere to integrated production (IP) principles [45], as confirmed by the data collected during the interviews.

**Table 1.** Main features and practices of the three analyzed cultivation systems.

| Characteristics | Cultivation System<br>Pomegranate | Almond | Olive |
|---|---|---|---|
| Reference area | 1 ha | 1 ha | 1 ha |
| Planting density (orchard layout) | 800 trees ha$^{-1}$<br>(5 m × 2.5 m) | 2083 trees ha$^{-1}$<br>(4 m × 1.2 m) | 1000 trees ha$^{-1}$<br>(4.0 m × 2.5 m) |
| Irrigation | Drip irrigation | Drip irrigation | Drip irrigation |
| Fertilization technique | Conventional and fertirrigation | Conventional and fertirrigation | Conventional and fertirrigation |
| Pruning | Manual | Mechanical, trimming machine | Mechanical, trimming machine |
| Pest control | Conventional<br>(tractor and atomizer) | Conventional<br>(tractor and atomizer) | Conventional<br>(tractor and atomizer) |
| Harvest | Manual | Straddle harvester | Straddle harvester |
| Economic life | 15 years | 15 years | 15 years |
| Yield | 25.0 t ha$^{-1}$ | 2.0 t ha$^{-1}$ | 12.0 t ha$^{-1}$ |

## *2.2. LCA Analysis*

Life cycle assessment (LCA) is a methodology applied to estimate the environmental impacts of products or processes [46–48]; this analysis allows us to detect the stages of the crop cycle and the inputs that most influence the total impact, using a systematic approach; the results allow us to compare alternative production methods and processes, in order to suggest improvements for increasing sustainability [49–52].

The International Standardization Organization (ISO) has standardized the LCA practice, identifying four interrelated phases: defining the goal and scope of the study; compiling a life cycle inventory; evaluating potential environmental impacts; interpreting the results.

### 2.2.1. Goal and Scope Definition

One of the aims of the present research was to estimate and compare the environmental impacts and the water consumption of the three orchards, managed according to integrated systems of cultivation rules. The economic life of all the three models in the study area was set to 15 years, which is equal to the average economic life for the analyzed orchards. The identification of all the life stages of the orchard is necessary due to changeable levels of inputs, costs and yield; therefore, the following three main farming phases were taken into account: planting, growing and the full production phase. As a functional unit (FU), namely, the reference unit to which the inventory data is normalized, 1 ha of cultivated land was chosen. All the impacts were assessed using the SimaPro 7.3 software, based on the Ecoinvent database 3.0. The environmental impact indicators considered in the study were selected according to ISO 14040; system boundaries were defined as being from the production of the inputs to the harvested products at the farm gate. The Environmental Product Declaration 2008 (EPD 2008) method was selected to investigate the main environmental impact categories [53], i.e., water consumption (WC), expressed in $m^3$; global warming potential, with a time frame of 100 years (GWP), in kg $CO_2$-eq.; ozone depletion potential (ODP) in kg CFC-11 eq.; eutrophication potential (EP) in kg $PO_4$-eq.; acidification potential (AP) in kg $SO_2$-eq.; and non-renewable fossil fuels (NRF), in MJ. This method was chosen because it allows us to evaluate the main impact categories involved in the fruit-growing sector [54]. The EPD method is based on principles inherent in the ISO standard for Type III environmental declarations (ISO 14025), giving them widespread international acceptance [55].

#### 2.2.2. Life-Cycle Inventory

The data were collected in integrated orchards; the International Organization for Biological and Integrated Control (IOBC) describes integrated farming according to the UNI 11233-2009 European standard as a farming system where high-quality products are produced by using resources sustainably and by using polluting inputs as little as possible.

For the life cycle inventory, primary data were collected through interviews with the farmers, using a questionnaire, and were used for both environmental and economic analysis. Data associated with the studied systems concerned were grouped as follows: orchard characteristics; cultivation techniques; types and number of agricultural inputs, water for irrigation and phytosanitary treatments; electricity consumption for water extraction and handling; machinery used for farm management; production costs (considering expenses related to materials, labor and services, quotas, and other duties); crop production.

The selected farmers declared that they adhered to the regional integrated production specification; therefore, the management systems for each of the three scenarios did not differ significantly. The almond and olive groves involved in the study were mechanically pruned, so the farmers declared the same average consumption of diesel fuel. All pomegranate orchards were pruned manually, with similar labor needs. Fertilizers, pesticides and water supply results were very similar and were always within the range reported on the regional production specification, considering the high homogeneity of soil and climatic conditions for farms in the same area. Therefore, the average data were used in the life cycle inventory. According to the farmers' declarations, the following actions had been considered: three fungicidal and two insecticide treatments; two tillage and one weed-mowing treatment; an average irrigation water volume.

The average inputs used by the sample of farms are reported in Tables 2–4.

**Table 2.** Inputs and outputs of 1 hectare of pomegranate cultivation during the reference period (15 years).

| Input | Short Description | Unit of Measure | Total |
|---|---|---|---|
| Fungicides (as active principle) | copper oxychloride | kg | 31.02 |
| | sulfur | kg | 145.60 |
| Insecticides (as active principle) | pyrethrin | kg | 1.46 |
| | Spinosad | kg | 0.02 |
| Fertilizers | ammonium sulfate | kg | 3900.00 |
| | phosphoric acid | kg | 1203.70 |
| | potassic nitrate | kg | 3673.91 |
| Water | water for irrigation | $m^3$ | 55,000.00 |
| | water for phytosanitary | $m^3$ | 130.00 |
| Fuel | fuel | kg | 4630.74 |
| | lubrication oil | kg | 27.85 |
| Electricity | for water extraction and handling | kWh | 25,233.00 |
| Yield | pomegranate | t | 325.00 |

**Table 3.** Inputs and outputs of 1 hectare of almond cultivation during the reference period (15 years).

| Input | Short Description | Unit of Measure | Total |
|---|---|---|---|
| Fungicides (as active principle) | copper oxychloride | kg | 44.46 |
| | boscalid | kg | 6.76 |
| | pyraclostrobin | kg | 1.74 |
| | myclobutanil | kg | 1.56 |
| Insecticides (as active principle) | deltamethrin | kg | 0.53 |
| | Spinosad | kg | 7.49 |
| Fertilizers | ammonium sulfate | kg | 3714.29 |
| | phosphoric acid | kg | 1444.44 |
| | potassic nitrate | kg | 1978.26 |
| Water | water for irrigation | $m^3$ | 42,000.00 |
| | water for phytosanitary | $m^3$ | 117.00 |
| Fuel | fuel | kg | 5608.21 |
| | lubrication oil | kg | 31.41 |
| Electricity | water extraction and handling | kWh | 25,233.00 |
| Yield | almond | t | 26.00 |

**Table 4.** Inputs and outputs of 1 hectare of olive cultivation during the reference period (15 years).

| Input | Short Description | Unit of Measure | Total |
|---|---|---|---|
| Fungicides (as active principle) | copper sulfate | kg | 39.00 |
| | copper ion (Cu++) | kg | 39.00 |
| Insecticides (as active principle) | phosmet | kg | 22.88 |
| | dimethoate | kg | 22.23 |
| Fertilizers | ammonium sulfate | kg | 5330.00 |
| | phosphoric acid | kg | 650.00 |
| | potassic nitrate | kg | 3380.00 |
| Water | water for irrigation | $m^3$ | 29,000.00 |
| | water for phytosanitary | $m^3$ | 65.00 |
| Fuel | fuel | kg | 4537.39 |
| | lubrication oil | kg | 16.58 |
| Electricity | water extraction and handling | kWh | 16,770.00 |
| Yield | olive | t | 156.00 |

### *2.3. LCC Analysis*

The life cycle costing (LCC) analysis is an economic evaluation technique that takes into consideration all cash flows that appear during the life cycle of a product, project or service [56]. The principal application is to quantify the cost-effectiveness of ranking different alternative investments inside a decision-making or evaluation process [57,58]. The LCC analysis was based on the following assumptions:

1. Costs concerning manual operations were assessed, considering the current union hourly wage of agricultural workers;
2. Tariffs charged by local agricultural service providers were considered for mechanical operations;
3. The average water tariff of the Apulian consortia was considered for irrigation costs;
4. The revenues were calculated considering the average producer prices for olives, pomegranates and almonds, established via a direct survey carried out during the month of June, July and August 2021, among local producers and sellers, and reflecting the market prices.
5. For the comparison of the internal rate of return (IRR) obtained for different crops, a rate of 5% was assumed, which is realistic for Mediterranean tree crops [59,60] and is recommended by the European Commission [61].

To assess the cost-effectiveness of the investment, a conventional LCC was carried out, based on the following financial indexes: the gross margin (GM), the internal rate of return (IRR), and the discounted payback time (DPBT).

The internal rate of return (IRR)(1) is the discount rate at which discounted cash inflows are equal to discounted cash outflows, meaning the discount rate at which the net present value (NPV) of the investment equals zero [61,62].

$$\text{IRR} = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+r)^t} = 0 \quad (1)$$

The NPV indicator (2) was calculated as the difference between discounted annual revenues and costs, and it represents the present value of the net benefits generated by an investment over its economic life. An investment is convenient if the NPV is positive. Among two or more alternative investments, the higher NPV value identifies the more profitable option [37]:

$$\text{NPV} = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+r)^t} \quad (2)$$

Discounted payback time (DPBT) measures the period at the end of which the cumulative discounted cash flows equal the investment costs [63,64]. Therefore, one investment becomes more viable than another with the decrease in the necessary period.

## 3. Results and Discussion

### *3.1. LCA Results*

Table 5 shows the results for the characterization of the impact of the three orchards per functional unit. Impact categories linked to energy supply use (GWP, ODP, NRF) were mostly affected by fuel consumption. Fertilizers impacted particularly on the AP and EP impact categories, due to their high emissions of nitrogen compounds in the air, phosphates in water pollution and copper releases into the soil. These results are in line with other LCA insights [54,65,66]. Pomegranates showed the worst environmental performance: the steel support structure and the energy requirement for their higher irrigation needs (4000 $m^3$ vs. 3000 $m^3$ and 2000 $m^3$ for almonds and olives in a year, respectively) were the main contributors to the impact. GWP, AP and NRF values were almost double compared to the other two crops. The great need for ammonium- and phosphorous-based fertilizers also affected the EP, which resulted in triple values compared to the other crops; the fuel requirements were lower than other crops due to hand-harvesting and manual pruning.

**Table 5.** Results of the life cycle impact assessment related to the functional unit of 1 ha of cultivated area, during the reference period (15 years).

| Impact Categories | Units | Pomegranate | Almond | Olive |
|---|---|---|---|---|
| Water consumption (WC) | $m^3$ | $5.50 \times 10^4$ | $4.20 \times 10^4$ | $2.90 \times 10^4$ |
| Global warming potential (GWP) | kg $CO_2$ eq | $12.7 \times 10^3$ | $6.15 \times 10^3$ | $5.28 \times 10^3$ |
| Ozone depletion potential (ODP) | kg CFC-11 eq | $3.17 \times 10^{-3}$ | $4.46 \times 10^{-3}$ | $3.76 \times 10^{-3}$ |
| Acidification potential (AP) | kg $SO_2$ eq | $4.66 \times 10^1$ | $2.47 \times 10^1$ | $2.08 \times 10^1$ |
| Eutrophication potential (EP) | kg $PO_4$ eq | 21.9 | 6.08 | 5.66 |
| Non-renewable fossil fuels (NRF) | MJ | $2.09 \times 10^5$ | $1.24 \times 10^5$ | $1.12 \times 10^5$ |

Olives showed the best environmental performance, due to having the lowest water and energy requirements.

In terms of almonds and olives, pruning and harvesting mechanization had the greatest impact, affecting mainly AP and GWP.

Basically, the life cycle impact assessment (LCIA) showed that the greatest environmental loads came from fuel consumption for mechanical practices and from the use of electricity for irrigation.

The environmental analysis highlighted the fact that olive cultivation generated the lowest overall environmental load, followed by almond and pomegranate cultivation. The obtained results suggest that water-saving measures and advanced and smart irrigation methods may reduce environmental emissions.

### 3.2. LCC Results

A cost-benefit analysis was employed to compare the yearly economic results of farms, to better evaluate the profitability of the three crops (Table 6). For the full production phase yearly gross revenue, the operating costs and gross margin were calculated. Pomegranate cultivation was the most expensive, averaging EUR 13,267.80/ha$^{-1}$, while manual operations such as harvesting and pruning had the greatest impact, accounting for approximately 82.3% of the total cost, while irrigation accounted for 9.7%. Regarding almond and olive orchards, the obtained results showed that the cost of irrigation has an incidence of 42.6% and 32.6%, respectively. Cultivation operations have had minor impacts in terms of costs and labor; the incidence of harvesting and pruning is very similar for both orchards, at around 26% of the total cost. In addition, the integrated production technique optimizes the use of resources, especially energy and chemicals, allowing farmers to reduce costs and to obtain more sustainable production [64,65]. In fact, the production costs of integrated farms, related to utilized products (fertilizers, pesticides, herbicides, fuel), have a lower incidence compared to conventional farms. Fertilizers, pesticides, herbicides and fuel accounted for 5.8%, 13.8% and 23.3% for pomegranate, almond and olive cultivation, respectively.

**Table 6.** Results of the average yearly cost-benefit analysis during the full production phase.

| Crop | Yield (t ha$^{-1}$) | Gross Revenue (EUR/ha$^{-1}$) | Operating Costs (EUR/ha$^{-1}$) | Gross Margin (EUR/ha$^{-1}$) |
|---|---|---|---|---|
| Pomegranate | 25.00 | 20,000.00 | 13,267.80 | 6732.20 |
| Almond | 2.00 | 10,000.00 | 3806.45 | 6193.55 |
| Olive | 12.00 | 6000.00 | 2635.45 | 3364.55 |

The financial performance of the three cultivation systems was evaluated through a life-cycle costing methodology, estimating the following indexes: gross margin (GM) internal rate of return (IRR), and discounted payback period (DPBP). The results are summarized in Table 7.

**Table 7.** Life cycle costing (LCC) results.

| Crop | Gross Margin (EUR) ha$^{-1}$) | IRR (%) | DPBP (y) |
|---|---|---|---|
| Pomegranate | 6732.20 | 9.4 | 9.1 |
| Almond | 6193.55 | 22.7 | 5.1 |
| Olive | 3364.55 | 11.2 | 8.7 |

Results show the economic feasibility of all three alternatives, recording an IRR higher than the discount rate that was assumed of 5%. The significant differences between the economic performances of the tree crops are affected by the discrepancy of yields and the market prices: for pomegranates, a yield of 25.0 t/ha and a market price of EUR 800/t has been considered; the yield of shelled almonds was 2.0 t/ha and a market price of EUR 5000/t; while for an olive crop, a yield of 12.0 t/ha and a market price of EUR 500/t has been assumed. Indeed, even if the almond yield is lower (2.0 t ha$^{-1}$) than the olive yield (12.0 t/ha$^{-1}$), its higher market price of production generates a significant financial performance. Pomegranate cultivation showed an economic performance better than other crops, with a GM of EUR 6732.20, almost double that of the olive crop and greater than 9% with respect to almonds. The IRR values demonstrate the best efficiency of almond cultivation in terms of the return of capital (IRR = 22.7%), while the other two crops show significantly lower IRRs at 11.2% and 9.4%, respectively, for olive and pomegranate. The

DPBP indexes show that discounted cash flows equaled the expenses in just 5.1 years in the almond crop, while the return periods are similar and almost double for olive (8.7 years) and pomegranate (9.1 years). The comparison among IRR and DPBP for the three crops unequivocally demonstrates the superiority of the almond crop in ensuring profitability and return on investments but is less consistent regarding olive and pomegranate. The olive crop, compared to pomegranate, has a higher IRR (11.2% vs. 9.4%) but the GM value is half the GM of pomegranate (EUR 3364.55 vs. EUR 6732.20) in the face of very similar return times. The differences are not surprising, as has been underlined by other authors [67,68]: this is due to the different distribution of costs during the crop's life cycle. In the pomegranate crop, the plant costs are higher than in the olive crop, due to the higher price of trees needing support structures; the higher incidence of costs in the early years affects the value of the indicators. In the later cultivation stages, the higher GM values are mainly due to the more profitable market price and the earlier entry into production.

The superior result despite very similar DPBPs demonstrates to what extent the pomegranate crops that are managed by innovative and intensive techniques can represent a valid alternative to olive cultivation, especially in areas with critical issues with respect to the availability of water resources.

Therefore, it is possible to argue that in terms of financial performance, almond cultivation is the best choice, followed by pomegranate and olive cultivation.

It must be said that the tree crops present different technical and financial risk profiles, despite the fact that the results in terms of profitability could represent good guidance in terms of crop diversification strategy. Olive and almond super-intensive cultivation cannot overlook the availability of farm equipment for pruning and harvesting. The farmers have to carefully evaluate the convenience of purchasing the machinery or the possibility of recourse to farm contracting.

Pomegranate cultivation is not widespread in the Apulia region; therefore, farmers should critically take into account their own expertise and the availability of skilled labor. On the other hand, the recognized nutritional properties of these crops, especially for almond and pomegranate cultivation, could suggest market opportunities and profitable prices for entrepreneurs.

### *3.3. Irrigation Performance Indicators*

Agriculture is acknowledged worldwide to be a major contributor to the global emissions of greenhouse gases (GHGs) [69]. Agriculture is also the largest freshwater consumer, accounting for almost 70% of the world's water withdrawals [70]. Water is an essential environmental factor in increasing crop yield [71], thereby contributing to economic growth, but its scarcity, especially in particular areas, recalls the need to optimize this resource with the careful choice of techniques and crops.

Defining irrigation performance indicators is essential to assess the sustainability of irrigated agriculture. Performance is assessed for a variety of reasons: to improve system operations, to assess progress in meeting strategic goals, to assess the impacts of interventions, to better understand the determinants of performance, and to compare the performance of a system with others or with the same irrigation system over time [72]. The type of selected performance measures depends on the purpose of the performance assessment evaluation.

In this paper, two comparative performance indicators were developed, with the objective of providing a means of comparing irrigation system performance for the three analyzed crops. The two indicators relate global warming potential (GWP) and profitability (gross margin) to the irrigation water supplied (Table 8. They can provide a valuable contribution to environmental and economic sustainability assessment.

**Table 8.** Global warming potential (GWP) and profitability, related to the irrigation supply.

| Crops | GWP/unit Irrigation Supply (kg $CO_2/m^3$) | Gross Margin/Unit Irrigation Supply (EUR/$m^3$) |
|---|---|---|
| Pomegranate | 0.23 | 1.59 |
| Almond | 0.15 | 2.16 |
| Olive | 0.18 | 1.51 |

Where water is a constraining resource, output per water unit may be important. The difficulty arises when comparing different crops for which production, in terms of mass, is not directly comparable. Since, in this study, only one irrigation system is considered (drip irrigation), production was measured in terms of the value of the product, using local market prices.

The GWP index provides useful information on the environmental sustainability of production methods and on agricultural systems. It is used to evaluate the environmental impact of production systems [73]: the lower the value of this index, the more environmentally sustainable a system is.

As shown in Table 8, pomegranate cultivation resulted in the highest contribution to GWP as it generated 0.23 kg $CO_{2eq}/m^3$ of water supplied. This is mainly due to the higher water needs, strongly affecting electricity consumption for water handling; moreover, the steel support structure, compulsory in the first phases of cultivation, negatively affected the total environmental impact. On the other hand, almond and olive cultivation demanded 0.15 and 0.18 kg $CO_{2eq}/m^3$ of water supplied, respectively, with a greater contribution due to the fuel consumption for the mechanization of pruning and harvesting.

Therefore, irrigation sustainability was estimated in terms of profitability per cubic meter of water applied: the higher the value of this indicator, the greater the economic productivity of water.

Profitability depends mainly on the market price per ton of product; the higher local price of almonds generates higher incomes than the other two crops, thus yielding better water economic efficiency. Table 8 shows that a cubic meter of water is able to generate a profit of EUR 2.16 if used for almond irrigation, and a profit of EUR 1.5 and EUR 1.51 if employed, respectively, in pomegranate and olive cultivation.

Overall, for the same water consumption, almond cultivation allows the best environmental and economic performance; meanwhile, pomegranate cultivation showed a gross margin lower by 35% and a GWP higher by 53% compared to almond cultivation. Finally, the olive gross margin was the lowest, at 5% lower than pomegranate and 43% lower than almond cultivation; regarding GWP, the LCA for olive cultivation resulted in an intermediate value between the other two crops.

Obviously, these values may have more relevance if interpreted in the context of the studied area, e.g., in the light of other indicators related to landscape, labor supply and social instances.

## 4. Conclusions

Farms specializing in monoculture are more vulnerable than those where more species are cultivated, particularly with the intensification of competitive pressure. The world's emerging scenario is dominated by specialized and mechanized farms with an average farm size greater than 5 hectares, while the Mediterranean tree farming sector is mainly composed of small farms. The productivity of these systems is relatively low and, as a result, the production costs are significantly higher than in other countries with better structural conditions (e.g., for the olive sector, Spain is the biggest producer of olive oil in the world).

Moreover, climate change adaptation, the spread of new pathogens, the loss of resilience and water restrictions [74] require producers to invest in crops that can overcome these challenges.

Agricultural landscapes could be redesigned through crop diversity and the cultivation of resistant and resilient species, reducing the risks associated with extreme weather events and pest infestations [75,76]. Crop differentiation could be able to increase the resilience of agroecosystems and reduce production costs without increasing the pressure on natural resources, especially on water supply.

The results of the environmental analysis highlighted the fact that olive cultivation generated the lowest total environmental load, followed by almond and pomegranate cultivation. The results showed that the main impacts are due to fuel combustion, electricity for irrigation and the use of chemicals. Therefore, since plant protection and weed control are necessary for farmers, organic fertilizers should be favored instead of synthetic products [77–79]; it would also be necessary to implement the practice of grassing [80] to reduce mechanical intervention.

From the financial analysis, on the other hand, it emerged that almond cultivation is the most profitable, followed by pomegranate and olive cultivation. The economic analysis shows that pomegranate and almond cultivation would allow profitability. Several studies demonstrated the health properties of these fruits [16,81], which is reflected in the increase in demand and the average market price.

However, the findings of the analysis could not be exhaustive because of some limitations. The first limitation is the low availability of representative farms: a wider range of case studies could increase the accuracy of the profitability and environmental impact evaluation. A further limitation of the study was the system boundary for LCA: the extension behind the farm gate, made by including the transportation phases, could be relevant for the environmental impact assessment. Finally, the economic analysis did not contemplate all the possible future market dynamics of the average prices of inputs and outputs, due to the recent introduction of pomegranate cultivation and innovative techniques in almond orchard cultivation; these changes might affect the results.

To maintain adequate levels of production, the results from the literature lead us to the conclusion that the adoption of water management strategies for water saving would reduce the environmental and economic burden by allowing sustainable intensive agriculture in areas with water shortages.

The combined use of LCA and LCC methodologies allowed the analysis and quantification of the effects of sustainable resource use and management practices, with the aim of suggesting improvements to achieve sustainable intensive agriculture, especially in areas with water shortages.

The results obtained can be used in similar arid and semi-arid environments in the Mediterranean region and elsewhere; such agricultural landscapes should be redesigned on the basis of crop diversity over space and time and on the cultivation of drought-tolerant species, facing the challenges related to water shortage and pest infestations. This paper's insights may represent a framework that will be useful to support policymakers [82] in defining strategies for the development of Mediterranean rural areas and models for the best management of scarce resources, in particular the use of water for irrigation.

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