Article

Crop diversification and resilience of drought-resistant species in semi-arid areas: an economic and environmental analysis

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Abstract: The specialisation and intensification in agriculture have increased the productivity but have also led to the spread of monocultural systems, simplifying production and 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) was applied to evaluate the environmental and economic sustainability of a differentiated system of cultivation (pomegranate, almond and olive), according to modern intensive and superintensive cropping systems. Based upon the results obtained, it is deduced that pomegranate cultivation generated the highest environmental load, followed by almond and olive. From the financial analysis, it emerged that almond is the most profitable, followed by pomegranate and olive.

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

1. Introduction

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

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

Although in literature it has been widely demonstrated that the implementation of increased agricultural crop diversification reduces biodiversity loss by making the agroecosystem resilient [7,8], most research has focused on cereals and horticultural crops [1,9], therefore there is a 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 producing countries; moreover, in Mediterranean area traditional systems called on problems linked to the monocolture and farmers showed concerns about negative effects in term of pest and abiotic diseases, water scarcity, and strong decrease of level of income [10,11].

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A diversity of organisms is required for ecosystems functionality and capability to supply services, in addition to food production [6]. Renewal processes through 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 over time cultivation of a single tree crop in a certain area towards the introduction of several different tree species formerly underutilised or neglected. Crop diversification has been intended as a tool to suppress pest outbreaks, preserve biodiversity, and optimize water management facing water scarcity problems.

Moreover, in the last years, it has been observed a change in dietary habits, which 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, as almond and pomegranate, may represent a significant source of health-promoting substances considered fundamental for a healthy diet [15,16] improving ecosystem quality, farm income and employment opportunities [17–19]. According to trade statistics, domestic consumption of almonds and pomegranates increased, mainly due to classification as 'super fruits' resulting in a worldwide commercial success [20–22].

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

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

In this paper an integrated environmental and economic assessment of a local intensive cropping system, involving olive, pomegranate and almond, considered highly efficient in terms of productivity and management [25–28], was performed. In particular, Life Cycle Assessment (LCA) was integrated with a 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 system boundary (from cradle to farm gate) [29].

2. Materials and Methods

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2.1. Study area and data collection

Italy is the second country in the world for olive production (45% Spain, 15% Italy) and export (60% Spain, 20% Italy) [30] . 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 a growing competition on the international olive oil market [31]. Nowadays the Italian sector is mainly represented by traditional olive orchards (80%), with less than 200 trees/ha, where production costs are higher than revenues, due to low productivity and low level of mechanization for pruning and harvesting operations [32,33]. Moreover, in Apulia, a disease denoted "Olive Quick Decline Syndrome" (OQDS) destroyed, in the last ten years, about 40% of the regional olive orchards. The causal agent is Xylella fastidiosa, a Gram-negative bacterium, for which no cure is known [34] and, the high concentration of olive cultivation worsened the spread of the pathogen and the associated disease [35]. The bacterium invades the xylem of a wide range of hosts, it has wreaked havoc on vineyards in California and citrus trees in Brazil. Affected areas have been reported in other European Countries: Corsica (2015), France (2015), Balearic Islands (2016), Spain (2017), Portugal (2019) [36]. The regeneration strategies concern the replanting of *X. fastidiosa*-resistant olive tree cultivars [37,38], through the adoption of intensive and superintensive olive-growing models, since they increase yield and reduce the operating costs [33] with an enhancement of level of income. In alternative, a substitution of olive orchard with other crops, similar in soil, climate and technical requirements, have been taken in consideration in developing plans [39]

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 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 productions in the second half of the last century, the Mediterranean Basin is revaluing this crop, which provides significant results if it 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 cultivated with superintensive management has been considered, because it is a highly efficient system in terms of productivity and management [17,28].

Pomegranate (Punica granatum L.) is a temperate species that requires high summer temperatures to ripen properly. For this reason, its cultivation is relegated to the Mediterranean basin, southern Asia, and several countries of North and South America [2]. The cultivation is increasing commercial interest thanks to the recognized health properties that include it among the functional fruits [3]. Processing of fruit, destined to the "ready to use" product, has contributed to the increase of crop areas in the world reaching a cultivation area wider than 300,000 ha and a world production 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 [40]. Particularly:

- In pomegranate orchards: mild water deficit during flowering-fruit set period, considered as a non-critical period, allow water saving up to 30%, without affecting marketable yield [41,42]; drip irrigation system, in an arid region, saved about 32% of the water compared to surface irrigation practices [43] and reduced energy consumption and greenhouse gas emissions by approximately 15.6% [44].

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- In almond orchards, regulated deficit irrigation strategies and subsurface drip irrigation have allowed a 45% water saving while production was reduced by 17% [45]; deficit irrigation has improved almond quality and water saving, without significant yield loss [46].

A crucial requirement to perform LCA and LCC is the availability of complete and accurate technical and economic data-set regarding the whole cultural cycle. This need was provided for by performing a focus-group among key informants (practitioners, representatives of farmers' associations and technical assistants) with a deep knowledge of Mediterranean agriculture systems. Their suggestion allowed to select and contact a convenience sample of 20 farms 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 sample resulted from six farms for pomegranate, six for almond and eight for olive cultivation; the farms of the sample were directly interviewed, reported about their own structural features and cultivation practices (Table 1) and filled in a structured questionnaire including all cultivation inputs and outputs data, related to the study period. The farms analysed declared to adhere to the Integrated Production (IP) principles [47], as confirmed by data collected during the interviews.

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

Characteristics	**Cultivation system**		
	Pomegranate	**Almond**	**Olive**
Reference area	1 ha	1 ha	1 ha
Planting density (orchard layout)	800 trees ha^{-1} (5m x 2,5 m)	2083 trees ha^{-1} (4 m x 1,2 m)	1000 trees ha^{-1} (4,0 m x 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 (tractor and atomizer)	Conventional (tractor and atomizer)	Conventional (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 [48–50]; the analysis allows to detect the stages of the crop cycle and the inputs that most influence the total impact, with a systematic approach; results allow to compare alternative production methods and processes in order to suggest improvements increasing sustainability [51–54].

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

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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, equal to the average economic life for the analysed 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 full production phase. As 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 SimaPro 7.3 software based on Ecoinvent database 3.0. The environmental impact indicators considered in the study were selected according to ISO 14040; system boundaries were defined from production of the inputs to harvested products at the farm gate. The Environmental Product Declaration 2008 (EPD 2008) method was selected to investigate the main environmental impact categories [55], 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 (NRF) in MJ. This method was preferred because it allows to evaluate the main impact category involved in fruit growing sector [56]. EPD method is based on principles inherent in the ISO standard for Type III environmental declarations (ISO 14025) giving them a wide-spread international acceptance [57].

2.2.2. Life cycle inventory

The data were collected in integrated orchards; the International Organization for Biological and Integrated Control of Organic (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 with polluting inputs as little as possible.

For life cycle inventory, primary data were collected through interviews with the farmers using a questionnaire and used for both environmental and economic analysis. Data associated to the studied systems concerned: orchard characteristics; cultivation techniques; types and amount 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, labour and services, quotas, and other duties); crops production.

The selected farms have declared to adhere to the regional integrated production specification; therefore, the management systems for each of the three scenarios did not differ significantly. Almond and olive groves involved in the study were all mechanically pruned, so the same average consumption of diesel fuel was declared by the farmers. Pomegranate orchards were manually pruned with similar labour needs. Taking into account the high homogeneity of soil and climatic conditions on farms in the same area, the supply of fertilisers, pesticides and water resulted very similar and always within the range reported on the regional production specification. Therefore, in the life cycle inventory, average data were used. In particular, as farmers declared, had been considered: three fungicidal treatments and two insecticides, with the same active substances for each crop; two tillage and one weed mowing; the average irrigation water volume.

The average inputs used by the sample of farms are reported in Table 2, 3 and 4.

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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
	sulphur	kg	145.60
Insecticides (as active principle)	pyrethrin	kg	1.46
	spinosad	kg	0.02
Fertilizers	ammonium sulphate	kg	3,900.00
	phosphoric acid	kg	1,203.70
	potassic nitrate	kg	3,673.91
Water	water for irrigation	m^3	55,000.00
	water for phytosanitary	m^3	130.00
Fuel	fuel	kg	4,630.74
	lube 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
	miclobutanil	kg	1.56
Insecticides (as active principle)	deltametrina	kg	0.53
	spinosad	kg	7.49
Fertilizers	ammonium sulphate	kg	3,714.29
	phosphoric acid	kg	1,444.44
	potassic nitrate	kg	1,978.26
Water	water for irrigation	m^3	42,000.00
	water for phytosanitary	m^3	117.00
Fuel	fuel	kg	5,608.21
	lube 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
	copper sulphate	kg	39.00

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Fungicides (as active principle)	copper ion (Cu++)	kg	39.00
Insecticides (as active principle)	phosmet	kg	22.88
	dimethoate	kg	22.23
Fertilizers	ammonium sulphate	kg	5,330.00
	phosphoric acid	kg	650.00
	potassic nitrate	kg	3,380.00
Water	water for irrigation	m^3	29,000.00
	water for phytosanitary	m^3	65.00
Fuel	fuel	kg	4,537.39
	lube 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) is an economic evaluation technique that takes into consideration all cash flows that appear during the life cycle of a product, project or service **[58]**. The principal application is to quantify the cost-effectiveness for ranking different alternative investments inside a decision-making or evaluation process **[59,60]**. 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 tariff of the Apulian consortia was considered for irrigation cost;
4. The revenues were calculated considering the average producer prices for olives, pomegranates and almonds, detected through 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%, which is realistic for Mediterranean tree crops **[61,62]** and recommended by the European Commission **[63]**, was assumed.

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

Internal Rate of Return (IRR) is the discount rate at which discounted cash inflows is equal to discounted cash outflows, meaning the discount rate at which Net Present Value (NPV[1]) of the investment equals zero. [63,64] .

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

[1] The NPV indicator 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 NPV is positive. Among two or more alternative investments, the higher NPV value identifies the more profitable option [38].

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

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Discounted Payback Time (DPBT) measures the period at the end of which the cumulative discounted cash flows equal the investment costs [65,66]. Therefore, one investment becomes more viable than another with the decreasing of the necessary period.

3. Results and discussion

3.1. LCA results

Table 5 show the results for the characterization of impact of the three orchards per functional unit. Impact categories linked to the energy supply and use (GWP, ODP, NRF) were mostly affected by fuel consumption. These results are in line with other LCA insights [67–69]. Pomegranate showed the worst environmental performance: the steel support structure and the energy requirement for the higher irrigation needs (4,000 m^3 vs 3,000 m^3 and 2,000 m^3 for almond an olive in a year, respectively) mainly contributed to the impact. GWP, AP and NRF resulted almost double respect to the other two crops. The elevated needs for ammonium and phosphorous based fertilizers for pomegranate also affected the EP, resulted triple then the other crops; fuel requirements resulted lower than others crops due to the hand-harvesting and manual pruning.

Olive showed the best environmental performance due to lowest water and energy requirements. Pruning and harvesting mechanization in almond and olive had the greatest impact affecting mainly AP and GWP.

Fertilizers impacted particularly on AP and EP impact categories, due to their high emissions of nitrogen compounds in air, phosphates in water pollution and copper releases to soil. Basically, life cycle impact assessment (LCIA) showed that the greatest environmental loads come from fuel consumption for mechanical practices and the use of electricity for irrigation.

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

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	5.20 x 10^4	3.90 x 10^4	2.60 x 10^4
Global warming Potential (GWP)	kg CO_2 eq	12.7 x 10^3	6.15 x 10^3	5.28 x 10^3
Ozone depletion potential (ODP)	kg CFC-11 eq	3.17 x 10^{-3}	4.46 x 10^{-3}	3.76 x 10^{-3}
Acidification Potential (AP)	kg SO_2 eq	4.66 x 10^1	2.47 x 10^1	2.08 x 10^1
Eutrophication Potential (EP)	kg PO_4 eq	21.9	6.08	5.66
Non-renewable, fossil (NRF)	MJ	2.09 x 10^5	1.24 x 10^5	1.12 x 10^5

3.2. LCC results

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 full production phase yearly gross revenue, operating costs and gross margin were calculated. Pomegranate was the most expensive cultivation, averaging 13,267.80 € ha−1, manual operations such as harvesting and pruning had the greatest impact, approximately 82.3% of total cost, while irrigation accounted for 9.7%. Regarding almond and olive orchards, obtained results showed that the cost for 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, around 26% of total cost. In addition, integrated production technique optimizes the use of resources, especially energy and chemicals, allowing to reduce the costs and to obtain more sustainable production [66,67]. In fact, production cost of integrated farms related to utilized products (fertilizers, pesticides, herbicides, fuel) have 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 (€ ha^{-1})	Operating costs (€ ha^{-1})	Gross margin (€ ha^{-1})
Pomegranate	25.00	20,000.00	13,267.80	6,732.20
Almond	2.00	10,000.00	3,806.45	6,193.55
Olive	12.00	6,000.00	2,635.45	3,364.55

The financial performance of the three cultivation systems was evaluated through the 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.

Results show the economic feasibility for all three alternatives, recording an IRR higher than the discount rate 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 800 €/t has been considered, yield of shelled almonds was 2,0 t/ha and the market price 5,000 €/t, whilst for olive crop a yield of 12,0 t/ha and a market price of 500 €/ t has been assumed. Indeed, even if almond yield is lower (2.0 t ha-1) than olive (12.0 t ha-1), its higher market price of

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production generates a significant financial performance. Pomegranate cultivation showed an economic performance better than other crops with a GM of 6,732.20 € almost double if compared to olive crop and greater than 9% respect to almond. The IRR values demonstrate the best efficiency of almond cultivation in terms of return of capital (IRR=22.7%), while the other two cultures show significantly lower IRRs, respectively 11.2% and 9.4% for olive and pomegranate. The DPBP indexes show that discounted cash flows equal the expenses in just 5.1 years in 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 demonstrate the superiority of the almond crop in ensuring profitability and return of investments but are less consistent regarding to olive and pomegranate. Olive crop with respect to pomegranate has higher IRR (11.2% vs. 9.4%) but the GM value is half the GM of pomegranate (3,364.55€ vs. 6,732.20€) in the face of very similar return times. The differences are not surprising, as underlined by other authors [70,71]: it is due to the different distribution of costs during the crop's life cycle. In pomegranate crop the plant costs are higher than in olive due to the higher price of trees needing support structures, the higher incidence of costs in the first years affects the value of indicators. In the later cultivation stages the higher GM are mainly due to the more profitable market price and the earlier entry into production.

The superior result despite of very similar DPBPs, demonstrates to what extent the pomegranate crops 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 one, followed by pomegranate and olive.

Table 7. Life cycle costing (LCC) results

Crop	Gross margin (€ ha^{-1})	IRR (%)	DPBP (y)
Pomegranate	6,732.20	9.4	9.1
Almond	6,193.55	22.7	5.1
Olive	3,364.55	11.2	8.7

Despite the results in terms of profitability could represent a good guidance in crop diversification strategy, it is to be considered that the tree crops present different technical and financial risk profiles. Olive and almond superintensive cultivation can not overlook the availability of machinery for mechanized pruning and harvesting. The farmers have to carefully evaluate the convenience to purchase 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, especially for almond and pomegranate, could suggest market opportunities and profitable prices to entrepreneurs.

3.3. Irrigation performance indicators

Agriculture is acknowledged worldwide as a major contributor to global emissions of greenhouse gases (GHGs) [72]. Agriculture is also the largest freshwater consumer, accounting for almost 70% of the world's water withdrawals [73]. Water is an essential environmental factor increasing crop yield [74] contributing to economic growth but its scarcity, especially in particular areas, recall to recalls the need to optimize this resource with a 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 impacts of interventions, to better understand determinants of performance, and to compare the performance of a system with others or with the same irrigation system over time [75]. The type of

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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 analysed crops. The two indicators relate Global Warming Potential (GWP) and profitability (gross margin) to irrigation water supplied (Table 9). They can provide a contribution to environmental and economic sustainability assessment.

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 value of the product using local market prices.

The GWP index provides useful information on environmental sustainability of production methods and on agricultural systems. It is used to evaluate the environmental impact of production system [76]: the lower the value of this index the more environmentally sustainable a system is.

As shown in Table 9, pomegranate 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 need 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 generated 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 through profitability per cubic meter of water applied: the higher the value of this indicator, the more 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, so a better water economic efficiency. Table 9 shows that a cubic meter of water is able to generate a profit of 2.16 € if used for almond irrigation, and a profit of 1.59 € and 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 the pomegranate showed a gross margin lower by 35% and a GWP higher by 53% compared to almond. Finally, olive gross margin was the lowest, 5% lower than pomegranate and 43% lower than almond; regarding GWP the LCA for olive resulted in an intermediate value between the other two crops.

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

Table 9. Global warming potential (GWP) and profitability related to the irrigation supply

Crops	GWP/unit irrigation supply (kg CO_2/m3)	Gross margin/unit irrigation supply (€/m3)
Pomegranate	0.23	1.59
Almond	0.15	2.16
Olive	0.18	1.51

4. Conclusions

Farms specialized in monoculture are more vulnerable than those where more species are cultivated particularly with the intensification of competitive pressure. The emerging scenario is increasingly dominated by specialised and mechanized farms with an average farm size of more than 5 hectares, while Mediterranean tree farming sector is mainly composed of small farms. The productivity of these systems is relatively low and,

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as a result, the production costs are significantly higher than other Countries with better structural conditions (e.g., for the olive sector, Spain, the biggest producer of olive oil in the world).

Moreover, climate change adaptation, spread of new pathogens, loss of resilience and water restrictions [77] 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 [78,79]. 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.

The results of environmental analysis highlighted that olive cultivation generated the lowest total environmental load, followed by almond and pomegranate. 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 fertilisers should be favoured instead of synthetic products [80–82], and it would be necessary to implement the practice of grassing [83] to reduce mechanical interventions.

From the financial analysis, on the other hand, it emerged that almond is the most profitable, followed by pomegranate and olive. Economic analysis shows that pomegranate and almond cultivation would allow profitability. Several studies demonstrated the health properties of these fruits [16,84], which is reflected in the increase in demand and the average market price.

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

To maintain adequate levels of production, the results of the literature lead 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 a 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, in which agricultural landscapes should be redesigned on the base 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 insights may represent a framework useful to support policy makers [85] in defining strategies for the development of Mediterranean rural areas and models for the best management of scarce resource, in particular the irrigation water.

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