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Profitability, Productivity, and Technical Efficiency of Cretan Olive Groves across Alternative Ecological Farm Types

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Abstract: Olive groves are an important element of the Mediterranean landscape and heritage and contribute significantly to the area's rural economies. The primary interest of researchers and policy-makers lies in the economic performance of this activity, especially in light of the resource limitations imposed by climate change. Profitability and productivity analyses, as well as technical efficiency methodologies, have been applied to evaluate the economic sustainability of olive cultivation and have often identified shortcomings in farms' management and structure. In our study, we use profitability and productivity indicators, as well as data envelopment analysis, to estimate the economic performance of Cretan olive groves and a second-stage regression analysis to determine factors that affect efficiency scores. One novelty of this study is that the results are presented across alternative ecological approaches, i.e., organic, conservation, low-input, and standard farms. Our findings indicate that organic farms perform better in the examined economic indicators. On the other hand, standard farms demonstrate a low labour productivity, while conservation and low-input farms exhibit an inefficient use of capital. Scale inefficiencies indicate that certain farm types should also increase in size to be more competitive. Finally, our analysis suggests that training, market orientation, and a commitment to farming positively affect the efficiency of olive groves.

Keywords: olive groves; technical efficiency; productivity; profitability; Greece; ecological farm types; organic

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1. Introduction

Olive cultivation is inextricably linked to the Mediterranean identity and culture and, throughout the years, has remained of great socio-economic importance for rural populations in the Mediterranean region [1–3]. Olive is a crop very well-adapted to the Mediterranean climate [4] and is characterized by its drought tolerance [5] and ability to grow on sloping lands with shallow soil depth, which makes olive farming ideal for lands where the cultivation of most crops is not viable [6]. All the above characteristics of olive farming are even more pronounced in light of ongoing climate change, which poses additional constraints to agricultural production.

Furthermore, the consumption of olive oil, particularly virgin and extra-virgin oil, has been acknowledged for its benefits for health in several studies worldwide [7–9]. Its demand is expected to grow even more in the years to come, especially in non-traditional markets, along with the emergence of new countries in olive oil production [10].

The significance of the sector for rural economies and landscapes [11] and the increasing demand for olive oil [10] have turned researchers' interest to the production perspective and, specifically, towards identifying the factors that shape the economic performance and the competitiveness of this activity in the international market. Within this context, several studies have focused on the economic profitability and productivity of olive groves, especially in the Mediterranean region [12–15].

Estimations of the economic performance of primary sector activities have often employed the concept of technical efficiency (TE) [16–22]. Technical efficiency is the ability of a production unit to yield the maximum output given the level of inputs or the ability to produce a given level of output with the minimum amount of inputs [23,24]. According to this definition, TE is an appropriate measure of the economic performance of agricultural activities as it reflects both the need of producers to manage their resources cost-effectively, as well as the objective of policymakers to ensure an output for consumers and protect scarce resources.

Efficiency analysis is central to many studies that aim to evaluate the economic performance of olive farms [25–31] and the olive sector [32,33]. A common methodological approach to estimate the TE of olive groves is data envelopment analysis (DEA), initially developed by Charnes et al. [34]. Beltrán-Esteve [28] and Bernal Jurado et al. [35] used this methodological approach to estimate the efficiency of olive-producing farms in Andalusia. Accordingly, Stillitano et al. [30] applied DEA approaches to investigate the TE of Southern Italy's traditional and intensive olive farms. Similarly, Artukoglu et al. [36] employed DEA to estimate the TE of Turkish olive groves. In Greece, Niavis et al. [29] used a DEA model to assess the efficiency of the extensive olive oil farms on Pelion mountain.

The economic performance and TE estimates of olive groves are often examined across different management systems, providing evidence not only from conventional olive groves but also from organic ones [31,37,38]. Other studies distinguish economic performance among traditional (rainfed) mountain and plain olive groves [28] or among extensive and more intensive olive production systems [30]. However, there is a limited literature on the economic performance of olive groves across various ecological farm types, besides the organic type, like conservation and low-input farms.

This study aims to evaluate the farm-level economic performance of Greek olive production using various indicators of profitability and productivity. The technical efficiency of olive groves is estimated using the DEA methodology, while, in addition, a second-stage regression analysis is applied to identify factors which affect the TE scores.

Our case study focuses on Greece and, specifically, on the island of Crete. Greece has a long history of olive farming, with the activity being widespread throughout the nation and remaining traditional in many rural areas. In 2021, the total area occupied by olive trees exceeded 753,000 ha, with an average density of 196 trees per hectare and the Region of Crete comprising 26% of this area, followed by the Region of Peloponnese with 25% [39]. Olive oil production is the main orientation of olive cultivation in Greece, with the production for the year 2021 amounting to 255,705 tons [39].

More specifically, this study investigates olive farms in East Crete, i.e., in the regional units of Heraklion and Lasithi. Olive farming is one of the main cultivations in Crete due to, among other reasons, the olive tree's adaptivity to the environmental conditions of the island, such as the Mediterranean climate, soil salinity, and drought (see for example [40]). In 2021, the regional units of Heraklion and Lasithi had 103,970 and 27,132 hectares of olive cultivation, respectively, representing 17% of Greece's total number of olive trees [39]. The amount of olive oil produced in the study area during the same year reached a total of 56,979 tons, corresponding to over 20% of Greece's total olive oil production in that year [39].

Although the density of olive groves in Eastern Crete is slightly lower than the country's average density, their yield is 12% higher than the country's average yield, indicating that they are characterized by a higher productivity. According to the latest available data from EUROSTAT [41], the study area held 52,707 olive farms in 2016, representing 12% of the country's total number of olive farms.

The most commonly encountered quality certifications in the Greek olive oil sector with an environmentally friendly orientation are the organic certification according to the EU legislation and the AGRO 2, a national integrated management systems certification. In 2017, there were 736 and 290 certified organic farms in the regional units of Heraklion and Lasithi, respectively, which represented 4% of the total area occupied by olive trees

in Eastern Crete [42]. In the same year, there were, in total, 5166 farms under AGRO2 certification, accounting for 12,045 hectares in the study area [43].

Since quality certifications in Cretan olive production are relatively common, the case study area is ideal for exploring economic performance across alternative ecological approaches. The analysis utilizes a dataset and a farm typology obtained within the framework of the LIFT (Low-Input Farming and Territories—Integrating knowledge for improving ecosystem-based farming) H2020 project to identify differences in the profitability, productivity, and TE of olive farms belonging to alternative ecological farm types. The examination of the economic performance across ecological approaches can have practical implications as it can help identify shortcomings and necessary management adjustments for enhancing the economic performance of these environmentally friendly farming practices.

2. Materials and Methods

As already mentioned, the assessment of the economic performance of Cretan olive groves has been conducted utilizing an available dataset originally obtained through a large-scale farmer survey carried out during the implementation of the LIFT project (https://www.lift-h2020.eu/, accessed on 8 September 2023). The LIFT survey database contains detailed socio-economic information on farms across Europe (the reference year is 2018) that can be used to derive valuable economic sustainability indicators. The data obtained through the LIFT include the costs and revenues at the farm level, the farm management practices, and the demographic and social characteristics of the farmers surveyed.

The Greek case study, within the LIFT survey, encompasses information on farms with permanent crops, i.e., olives and vines. However, the focal point of this analysis centers on olive groves, for which a rigorous evaluation of profitability, productivity, and technical efficiency analysis is performed. In the context of this specific case study, it is assumed that a farm is categorized as an olive farm when at least two-thirds of its total revenue emanate from olive-related activities, primarily centered on olive oil production.

It should be emphasized that, for the selection of olive farms included in the LIFT database, a form of snowball sampling approach was employed, as suggested by the project's guidelines regarding the sampling procedure. According to these guidelines, the main recommended sampling requirement was to include farms that employ different ecological farming practices, since one of the main objectives of LIFT was to derive a farm typology based on these practices and map alternative ecological farm types in the case study area. Additionally, the other recommended characteristics of the sample were to include women farm managers and farms with various sizes, including small holdings.

To this end, in the case of Greece, local experts, primarily from cooperatives, agricultural cooperative unions, and private companies engaged in the production, standardization, and trade of olive oil, were initially approached and asked to assist in identifying farms with the desired characteristics. Organic and integrated (certified AGRO2) farms, farms in the process of converting to organic farming, and conventional farms that were scattered to cover the whole case study area were included in the sample, so as to ensure that the latter would capture the diversity of practices and agricultural farmlands present in the region. The original farmers that were interviewed pointed out peers with diverse characteristics, which could also be included in the sample. It should be emphasized that this sampling method satisfied the LIFT requirements but did not lead to a representative sample of Cretan olive groves, since it is a non-probability sampling method.

For the purpose of this study, a thorough examination of the original LIFT Greek subset was conducted to identify and exclude outliers or incomplete registrations of technico-economic elements. A total of 59 olive groves were retained for inclusion in the final set of sample farms analyzed in this study.

These 59 olive groves (30 situated in Heraklion and 29 in Lasithi) occupy plain or hilly land with altitude of less than 600 m above the sea level, while 28 of the farms are located

in areas with altitudes of less than 300 m. Irrigation is a common practice among Cretan olive groves. In our sample, 53 out of 59 farms utilize irrigated farmland. The structure and the main economic characteristics of the sample farms are thoroughly presented in the Results section.

Regarding the sampled farmers' characteristics, the majority of farm owners are male, with an average age of over 50 years. These farmers possess significant experience in the field of agriculture, averaging over 30 years. Almost all the farmers have completed at least middle school, while a significant proportion (38%) have a degree in higher education. Additionally, 12 of the farmers in our sample have had agricultural training or education. In terms of management, it is pertinent to highlight that, despite their specialization in olive production, many of the sample's farmers are pluri-active and derive income from other sources outside of agriculture. It is estimated that, on average, only one-third of the family income is generated from the farm. Lastly, it should be noted that olive production is distributed primarily through producer organizations and that the average selling price for olive oil is estimated at 3.13 EUR per kilogram.

The sampled farms included in the LIFT database were, during the project's implementation, classified into various ecological farming approaches, i.e., organic, conservation, low-input, and standard farms. This classification was performed according to a protocol, i.e., a set of rules based on farming practices and management, developed within the LIFT project. This protocol was, in fact, one of the main outputs of the project, and it is available and described in detail in the corresponding documentation [44].

In short, the LIFT protocol suggests the categorization of the sampled farms according to over 50 crop farming practices that involve dimensions like soil conservation and biodiversity (including tillage, crop rotation, crop diversification, and soil cover practices) and input use (including practices on the application of various fertilizers, weed, pest, and plant diseases management, the application of soil amendments, water consumption, and fuel use). Each practice is assigned a basic score that represents the merit of the practice relative to the above ecological dimensions. These scores were derived from a group of experts involved in the LIFT project for this purpose.

Additionally, farm-specific data regarding the share of farmland on which the practice is applied are then used as a weighting factor for the basic score to produce a weighted score of the practice in that specific farm. For example, the basic score is multiplied by a 0.5 factor if the practice is applied in 25–50% of the farmland and a 0.75 factor if the practice is applied in 50–75% of the farmland. Finally, partial scores are estimated using the weighted scores of the practices referring to the same farming aspects, e.g., tillage, and all the partial scores are added to calculate a final score that represents the performance of each individual farm. The final score of each farm has to be equal to or higher than a predefined threshold for each ecological farm type in order for the farm to be included in that specific farm type.

A detailed description of the meticulous methodology followed in the LIFT protocol for the classification of farms is beyond the scope of this study, but readers may refer to the documentation for the basic score attached to each ecological practice by the LIFT experts, as well as the weighting process based on individual farm-level data.

According to the LIFT protocol [44], conservation farms are defined as farms that utilize practices that enhance the soil's structure. Similarly, low-input farms use lower agricultural inputs (fertilizers and pesticides) and resources like water and fuel. Additionally, organic farms have the organic certification, and standard farms are farms that do not belong to any of the other ecological farm types. The latter farm type resembles in many ways the conventional farms established in the literature. The structure of the LIFT protocol allows for overlaps between the farm types. A farm may belong to more than one type if the criteria for more than one type are met. According to the classification performed within the LIFT project and following the developed protocol, in the Cretan farm sample used in this study, 11 olive groves were characterized as organic, 38 were characterized as low-input, 15 employed conservation farming, and 19 were characterized as standard farms. It should

be clarified that, though these are ecological farming approaches found among Cretan olive groves, the distribution of farms among these approaches is not representative of the population since the sampling methodology was non-probabilistic. Because the main objective of the sampling methodology was to capture the diversity of ecological approaches in the area, it is rather realistic to assume that standard farms are underrepresented in the sample and that other ecological approaches are overrepresented.

The initial phase of our analysis entails the estimation of the profitability and productivity indicators defined in Table 1. To estimate these indicators all the cost and revenue elements of the sampled farms have been assessed, as will be discussed in more detail in the Results section. To discern and evaluate potential statistically significant differences in these economic indicators, among the alternative farm types, we executed a non-parametric Mann–Whitney test [45]. The statistically significant differences are marked with asterisks. In regard to profitability, the main indicator used in our analysis is a farm's net income, which is more appropriate in the case of family-owned farms, like the majority of Cretan olive groves.

Table 1. Explanation of the profitability and productivity indicators.

Indicator	Definition
Revenues	Value of agricultural production.
Farm net income	Revenues including subsidies minus depreciation costs, variable costs, contract, and hired labour costs (see also definitions provided in the Farm Accountancy Data Network (FADN)) [46]. An economic indicator that presents the income available to farmers.
Land productivity	Expressed as the ratio of revenues to utilized land.
Labour productivity	Expressed as the ratio of revenues to hours worked.
Fixed capital productivity	Expressed as the ratio of revenues to value of fixed capital.
Variable capital productivity	Expressed as the ratio of revenues to value of variable capital.
Revenues to revenues plus subsidies ratio	The ratio of revenues to revenues plus subsidies. As an indicator, it provides insight into the dependency of olive groves on subsidies.

The subsequent phase of our economic analysis of olive groves is centered on the estimation of their technical efficiency. As already mentioned, TE can be defined as the ability of a production unit, in our case an olive grove, to yield the maximum output given the level of inputs (output-oriented analysis) or the ability to produce a given level of output with the minimum amount of inputs (input-oriented analysis) [24,47].

Every farm in our sample combines inputs, including capital, labour, and land, to generate an output (mainly olive oil). However, certain farms exhibit a superior degree of efficiency regarding their input use compared to others. Specifically, they can achieve the same output while utilizing fewer inputs or, alternatively, maximize their output with the same input quantities. The main purpose of the methodology employed in our study is to generate an efficiency score for each farm within the sample, thereby quantifying the extent to which each farm can potentially reduce its inputs while maintaining consistent output levels.

To estimate the TE of the olive groves in our study, the DEA methodology has been used. As already mentioned, DEA was developed by Charnes et al. [34], and it comprises a non-parametric approach to efficiency estimation, i.e., it does not assume a specific form of the production function, as opposed to alternative methodologies such as stochastic frontier analysis. The model we employ in the current study is input-oriented since it attempts to minimize inputs given the level of output. We have chosen the input-oriented specification since it is more appropriate and consistent with the objectives of farmers and decision-makers, who feel less comfortable compromising the output but wish to reduce their input use and costs.

The DEA methodology revolves around the construction of a production frontier that encompasses all decision-making units (DMUs), in our case olive groves. DMUs that deploy a minimum level of inputs to produce a specific output are positioned onto this

deterministic frontier. Any deviation from this frontier is indicative of inefficiency. In our analysis, we have employed the following model specification solved for all n DNUs [24,48]:

$$\begin{array}{c} min\theta, \\ \text{subject to} \\ -y_i + Y\lambda \geq 0 \\ \theta x_i - X\lambda \geq 0 \\ \lambda \geq 0 \end{array} \quad (1)$$

where the value of θ is the technical efficiency score of the DMU; λ is a vector of constants; y_i, and x_i, represent the output and input vectors of the i-th DMU, respectively; Y is the matrix of outputs and X is the matrix of inputs that contain data for all DMUs; $Y\lambda$ and $X\lambda$ are the projections onto the constructed frontier. When θ = 1, the DMU is technically efficient, while θ< 1 denotes that the DMU is inefficient and can equiproportionaly reduce its inputs by $1 - \theta$, keeping the output constant.

Expression (1) assumes that the DMUs operate under constant returns to scale (CRS) and, thus, that all DMUs are operating at an optimal scale. But, this assumption rarely holds for several reasons, including market conditions and access to funding [24]. Thus, in the case of the CRS model, the TE measurements may also reflect scale inefficiency. To determine technical and scale inefficiencies the variable returns to scale (VRS) model can be used, as follows:

$$\begin{array}{c} min\theta, \\ \text{subject to} \\ -y_i + Y\lambda \geq 0 \\ \theta x_i - X\lambda \geq 0 \\ N1'\lambda = 1 \\ \lambda \geq 0. \end{array} \quad (2)$$

The constraint $N1'\lambda$ is introduced in model (1), which is a $n \times 1$ vector of ones and allows for the comparison of DMUs of a similar size. By employing both the CRS and a VRS models, scale efficiency (SE) can be derived as the ratio of the CRS TE score to the VRS TE score.

The input and output variables used in the TE analysis are presented in Table 2. The input variables involve the variable capital input, which includes all the expenditures directly linked to the level of production, i.e., fertilizers, pesticides, water, fuel, contract, labour, and other direct costs. The labour input (family and hired) is also included in the model and is expressed in hours. Additionally, the land input, in hectares, is considered, as well as the fixed capital input. The inclusion of the latter suggests a long-term TE estimation that would also allow the adjustment of the fixed capital, since, in the short-run, fixed capital is considered constant. The output variable is specified as "Revenues". This variable does not consider the subsidies received, since they do not affect the TE of the groves. The revenues plus subsidies are only presented in the profitability analysis of the groves. The input and output variables used in this analysis reflect the main technical characteristics of olive groves in terms of size, available resources, and production capabilities and are commonly used in efficiency studies (see for example [30]).

As common in the TE literature [49], our methodology also includes a second-stage regression analysis, which seeks to investigate the connection between the TE scores yielded using the DEA model and the specific attributes of the sampled farms and farmers. To this end, a truncated regression analysis has been conducted, employing the set of explanatory variables outlined in Table 3. The selection of the truncated regression analysis instead of ordinary least squares (OLS) regression is motivated by the fact that the dependent variable, constituting the TE scores, is truncated and, in such cases, truncated regression models are considered more suitable [50].

Table 2. Input and output variables used in the DEA model.

	Definition
DEA inputs	
Variable capital	Value of variable capital input including fertilizers, pesticides, energy, water, and contract labour (in euros)
Capital	Value of capital assets excluding land (in euros)
Labour	Labour inputs (in hours)
Land	Agricultural land utilized (in ha)
DEA output	
Revenues	Value of agricultural production (excluding subsidies) (in euros)

Table 3. Variables used in the truncated regression analysis.

Variable	**Definition**
Experience	Farmer's experience in agriculture (in years)
Training	Binary variable that indicates whether the farmer has received education or training in agriculture (value 1 = received training and 0 = no training)
Contribution of family labour	Family labour inputs to total labour inputs ratio
Contribution of market value	Revenues to revenues plus subsidies ratio
Contribution of olive farming	Revenues from olive cultivation to total farm revenues ratio
Contribution of farm income	Revenues from farming to total household income
Organic farms	Binary variable to denote if the farm is characterized as organic (1 = farm is organic, 0 = farm is not organic)
Conservation farms	Binary variable to denote if the farm is characterized as conservation (1 = farm is conservation, 0 = farm is not conservation)
Low-input farms	Binary variable to denote if the farm is characterized as low-input (1 = farm is low-input, 0 = farm is not low-input)

The variables featured in the truncated regression analysis encompass the characteristics of the farmers (experience and training in agriculture), the management aspects of the farm (contribution of family labour to the total labour inputs, contribution of market value to the total revenues including subsidies, contribution of olive farming to the total farm revenues, contribution of farm income to the total family income), and the ecological farm type, specifically organic, conservation, and low-input farms. Other variables, such as a farmer's age, were excluded due to strong correlations with other variables. The inclusion of the farmer's age in the regression analysis was preempted by a strong correlation with the experience variable. Consequently, it was deemed prudent to exclude a farmer's age from the regression analysis to prevent multicollinearity and ensure the robustness of the model. Both the statistical and DEA analyses were executed using the STATA/SE 13.0 software.

3. Results

The first step in determining the profitability of olive groves is the estimation of the primary cost elements of the cultivation. In our case study, the average costs per hectare for the olive groves in our sample are presented in Table 4. The table also presents the average of these cost elements per ecological farm type. The average costs per hectare are also graphically presented in Figure 1. As can be seen in the Table, conservation farms have a statistically significant difference in farm structure compared to the rest of the farms as they present a larger size in hectares. The smallest average farm size is encountered in standard farming, though this difference is not statistically significant.

Table 4. Annual costs, revenues, and profitability indicators per hectare of olive groves, average for all the farms sampled and per ecological farm type (EUR).

	Mean /St.Dev									
	All Farms		**Organic Farms**		**Conservation Farms**		**Low-Input Farms**		**Standard Farms**	
Size in hectares	5.03	/3.75	5.29	/2.80	6.68 *	/4.87	5.42	/4.04	4.40	/3.25
Fixed costs										
Rents	455	/111	468	/147	462	/104	472	/121	426	/84
Depreciation	758	/493	589	/519	960 **	/436	748	/464	794	/579
Interests	188	/193	175	/174	197	/150	193	/161	193	/254
Labour costs										
Family labour	1458	/1170	1523	/1301	957 **	/709	1170 *	/708	1839 *	/1532
Hired labour	482	/707	613	/842	561	/876	591 **	/780	308 *	/532
Variable costs										
Contract labour	234	/665	33	/63	0 ***	/0	252	/646	221	/748
Fertilization	240	/292	168	/258	266	/265	229	/318	249	/252
Pest control	64	/101	90	/94	98 ***	/83	78	/119	34	/44
Other costs	624	/610	920	/864	701	/570	620	/595	563	/621
Total costs	4503	-	4578	-	4204	-	4353	-	4628	-
Revenues	2570	/1854	3398	/2149	2592	/2256	2727	/2083	2306	/1409
Revenues with subsidies	3208	/1838	4079	/2214	3283	/2278	3317	/2228	2977	/1746
Revenues/revenues plus subsidies	0.77	/0.18	0.78	/0.23	0.74	/0.22	0.78	/0.21	0.77	/0.14
Farm net income	806	/492	1667 *	/1862	696	/1634	798	/1899	808	/1858

Significance level: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

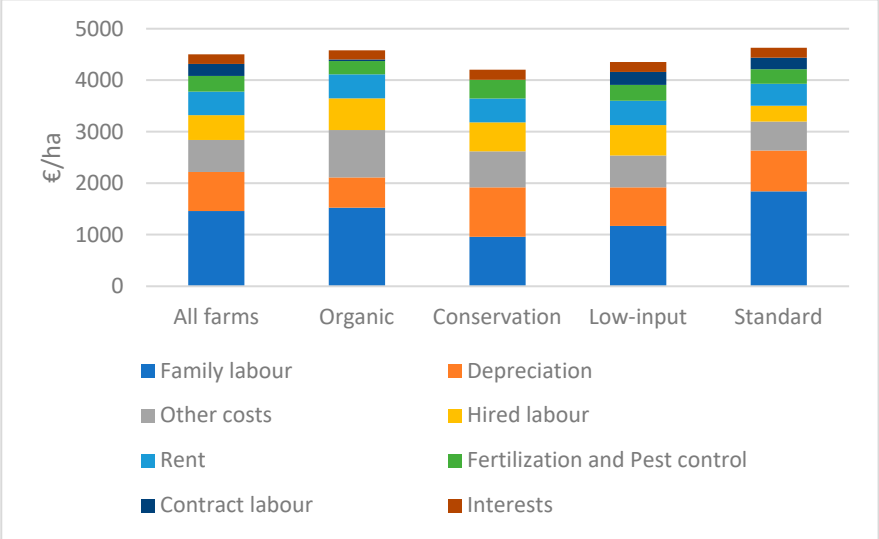


Figure 1. Annual costs of the olive groves per hectare, average for all the farms sampled and per ecological farm type (EUR).

Notably, labour emerges as a substantial element within the annual cost budget, accounting for over 40% of the total costs of the examined olive groves. Family members are the main contributors of labour in the examined olive groves, where additional hired and contract labour are also employed for specific tasks like harvesting and pruning (hired labour) or tillage (contract labour). Concerning labour, conservation farms seem

to utilize less family labour than the other farm types and no contract labour as well. One reason for this may be the fact that these farms, by definition, avoid tasks like tillage that are primarily assigned to other professionals through contract labour. In general, no statistically significant differences are identified in the utilization of total labour (family and hired), though it appears to be higher in the organic and standard farms (2136 EUR and 2148 EUR, respectively).

Depreciation costs are also important, accounting on average for 16% of the total costs, and are higher in the conservation farms sampled. Though the explanation for this is not evident and further investigation is required, one reason could be that the conservation farmers in our sample have made higher investments in the last few years. Indeed, the conservation farmers are younger and with less experience compared to the other farmers in the sample (statistically significant difference, $p = 0.02$); thus, they have entered this activity more recently. Subsequently, their capital investments are more recent. The cost of fertilizers and pesticides is estimated, on average, at 8% of the total costs, and it is again higher in the conservation farms, particularly the cost of pesticides. Other costs, including fuel and irrigation expenses, contribute by 13%, on average, to the total costs and seem to be higher in the organic farms, though this difference is not statistically significant.

As far as revenues are concerned, no statistically significant difference is found among ecological farm types, though the organic farms seem to have a higher value of production compared to the other farm types. This difference is due to the price premium received for organic products. Indeed, the average selling price for olive oil is 3.13 EUR/kg, but the price for organic olive oil is, on average, 3.43 EUR/kg, while standard farms receive 2.78 EUR/kg for olive oil. No statistically significant difference is detected regarding the revenues with subsidies, even though the subsidies are higher in the organic farms compared to the whole sample of olive groves (682 EUR/hectare and 637 EUR /hectare, respectively).

Farm net income is also higher in the organic olive groves, with a statistically significant difference. This profitability indicator reveals that the olive farms featured in our case study are capable of covering their variable costs, depreciation costs, as well as hired labour costs; thus, the farmers can meet their liabilities. It should be noted that rents are not subtracted from the farm net income as the majority of olive groves are owned by the farmers (over 75% of the utilized land within the sample olive groves). However, the farm net income would be positive even after subtracting the rents. It is evident from the data in Table 4 that the olive groves yield a negative net profit (defined as revenues plus subsidies minus total costs), which means that the olive groves are not able to cover the family labour costs and interests of their owned capital. It is important, though, to underscore that the data refer to the year 2018, which was marked by reduced yields in olive groves, primarily attributable to adverse weather conditions and infestations of the olive fly. Finally, the data in Table 4 show that one third of the farms' income is attributed to subsidies, across all alternative farm types. In the case of olive groves, subsidies seem to significantly contribute to the profitability of the activity.

The performance of the alternative ecological farm types regarding farm net income and the "revenues to revenues plus subsidies ratio" are depicted in Figure 2, together with their average performance on the productivity indicators (Figure 2 presents normalized data). The productivity indicators are also presented in Table 5. The partial productivity of the land is notably high, surpassing the rental cost per hectare, which is approximately 500 EUR, by a substantial margin. Furthermore, the productivity of the labour, though it is generally considered low for agricultural activities, surpasses the average wage per hour, which is estimated at 4.4 EUR per hour.

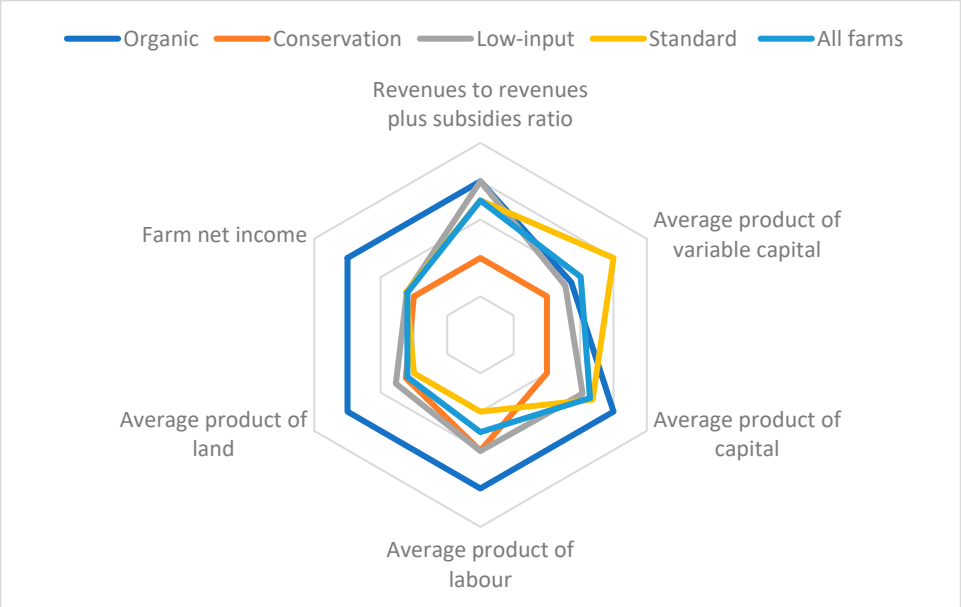


Figure 2. Profitability and productivity indicators of the olive groves across the alternative farm types (normalized data).

Table 5. Summary statistics of the main productivity indicators for the olive groves, estimated for all the sample farms and per ecological farm type.

	All Farms	Organic Farms	Conservation Farms	Low-Input Farms	Standard Farms
Indicator			**Mean/Standard Deviation**		
Land productivity	2570/1854	3398/2149	2592/2257	2727/2083	2306/1410
Labour productivity	5.89/3.93	7.62 */4.76	6.46/4.14	6.47 */3.95	5.04/3.90
Fixed capital productivity	2.01/2.41	2.36/3.22	1.37/1.13	1.90/2.61	2.11/2.04
Variable capital productivity	3.69/6.05	3.35/2.29	2.48/1.31	3.14/2.32	5.03/11.04

Significance level: * $p < 0.1$.

The partial productivities of inputs across the ecological farm types indicate statistically significant differences only in the case of labour productivity (note that land productivity is, in fact, revenues per hectare). Land and labour productivities appear higher in the case of the organic farms, while labour productivity is also higher in the low-input farms (significance level $p < 0.1$), as well as in the conservation farms, though the latter has no statistically significant difference. On the other hand, the standard farms appear to have lower land and labour productivity but seem to manage their variable capital more productively.

Table 6 presents the summary statistics of the variable capital, the fixed capital, labour, land, and revenues, which are used as the input and output variables in the DEA model. The average revenues per farm (excluding subsidies) are estimated at 14539 EUR, and the invested capital is, on average, 11537 EUR. The average size of the sampled olive groves is about 5 hectares, as already presented in Table 4.

Though, as already explained, the sample of olive groves used in this analysis is not representative of the olive groves in Crete, it is worth mentioning that the means of the main input and output variables used in the DEA model are comparable to the FADN estimations of the region with area code 480, which includes Crete (Sterea Ellas-Nissi Egaeou-Kriti) [51]. Specifically, according to the FADN estimations for specialist olive farms in the aforementioned region for the year 2018, with economic sizes of 2000–8000 EUR and 8000–25,000 EUR, the mean labour inputs in hours were 1795 and 2285, respectively. The mean total utilized agricultural area in hectares is 3.8 and 6.1 for the two economic

size categories, respectively. Additionally, the intermediate expenses, which correspond to the variable capital in our case, were 3540 EUR and 7476 EUR for the two economic size categories, respectively. The estimated mean capital (excluding the value of land) in the FADN data is somewhat higher than in the case of the sample farms (13531 EUR and 17,323 EUR for the two economic size categories, respectively). Finally, the values of the output estimations of the FADN were a little lower than those in our sample (8969 EUR and 14,419 EUR for the two economic size categories, respectively).

Table 6. Summary statistics of the input and output DEA variables.

	Mean Value	**St. Deviation**
DEA inputs		
Variable capital (EUR)	4708	5450
Capital (EUR)	11537	13983
Labour (hours)	2167	2454
Land (ha)	5.03	3.75
DEA output		
Revenue (EUR)	14539	25267

The results of the DEA methodology are presented in Table 7 and also depicted in Figures 3 and 4. Particularly, Table 7 presents the summary statistics of the CRS and VRS TE scores, as well as the scale efficiency scores The means and standard deviations of these estimates are also presented per ecological farm type. The average TE CRS of the olive farms was estimated to be 0.46, which indicates very low efficiency levels. Part of this inefficiency is due to the fact that the olive groves are not operating at their optimal scale, as described in the Materials and Methods section. The "pure" TE is estimated with the VRS model at 0.58, and the SE is subsequently estimated at 0.79. According to the DEA methodology, the average TE VRS score denotes that the olive groves can reduce their inputs by 42% (estimated as 1-TE score) and still achieve the same level of output [24]. Concerning scale efficiency (SE), it was observed that the size of the majority of the olive farms is suboptimal. Specifically, 50 farms operate at increasing returns to scale (IRS), indicating the need to increase their size (production level). In contrast, three farms operate at decreasing returns to scale (DRS), suggesting the necessity for these farms to reduce their optimal size. Finally, only six farms in our sample have a SE of one, which indicates that they operate at their optimal size.

Table 7. Summary statistics of the technical efficiency of the CRS specification (TE CRS), the technical efficiency of the VRS specification (TE VRS), and the scale efficiency (SE) of the sampled farms.

	Sampled Farms					**Organic**	**Conservation**	**Low-Input**	**Standard**
Variable	**Mean**	**St. Dev**	**CV**	**Min**	**Max**	**Mean/St. Dev**			
TE CRS	0.46	0.29	63%	0.04	1	0.70/0.31	0.39/0.28	0.49/0.31	0.42/0.25
TE VRS	0.58	0.27	47%	0.13	1	0.74/0.30	0.47/0.27	0.59/0.29	0.57/0.25
SE	0.79	0.24	30%	0.13	1	0.93/0.16	0.82/0.18	0.82/0.23	0.74/0.26

Scale of operation	Number of olive groves	Share (%) of olive groves farms
Increasing Returns to Scale (IRS)	50	85%
Constant Returns to Scale (CRS)	6	10%
Decreasing Returns to Scale (DRS)	3	5%

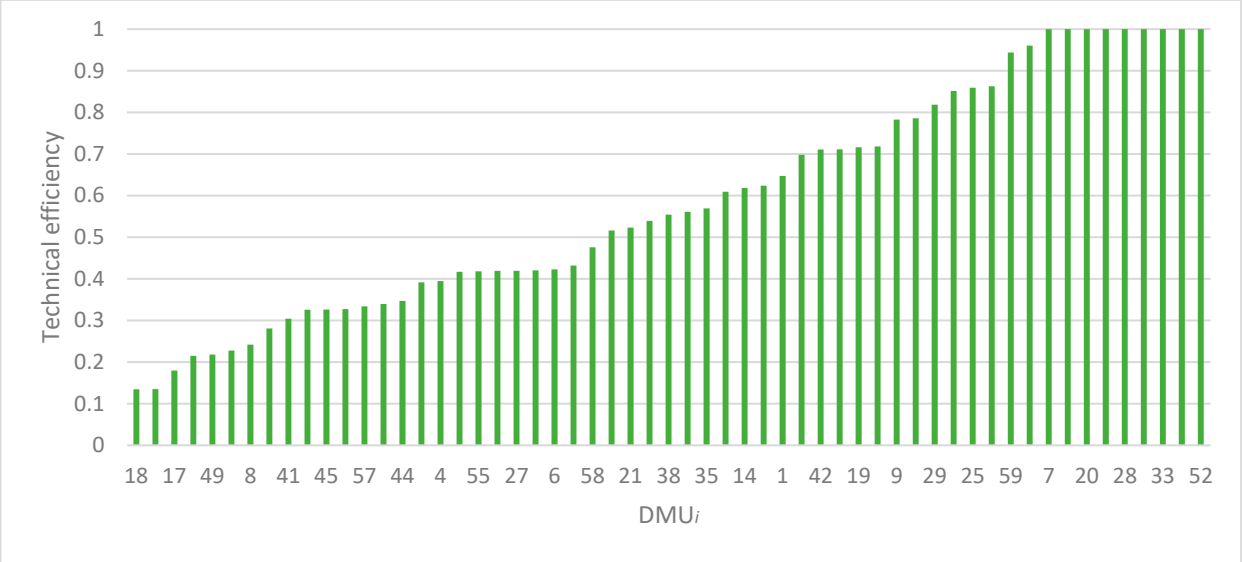


Figure 3. Technical efficiency of the VRS specification (TE VRS) of the olive groves of the sample.

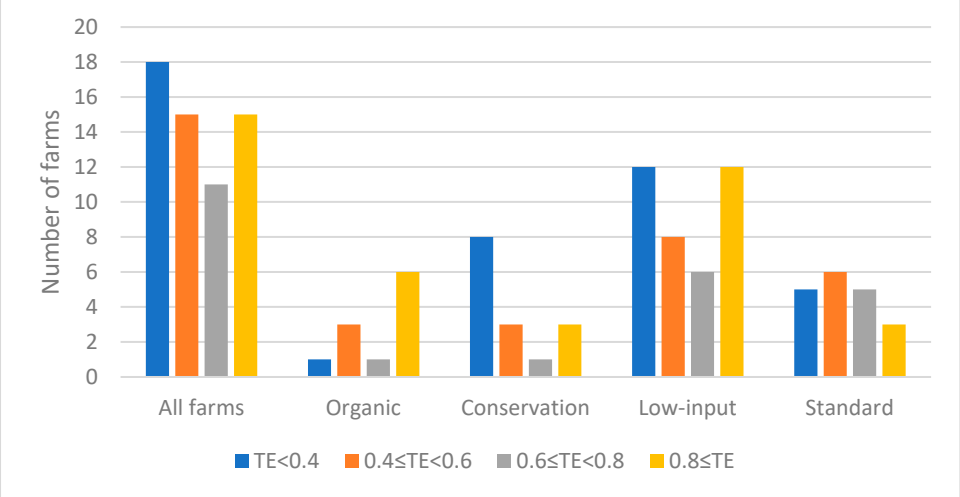


Figure 4. Number of farms per various levels of technical efficiency of the VRS specification (TE VRS) across the ecological farm types.

Furthermore, the organic farms appear to be more technically efficient than the alternative ecological farm types since their TE VRS is estimated at 0.74. The smallest technical efficiency is observed in the conservation farms, followed by standard farming. The SE scores are also very high in organic production compared to the other ecological farm types. In Figure 3, the olive groves in our sample are presented in ascending order, according to their efficiency score. As the figure indicates, nine farms are forming the efficient frontier (TE VRS scores = 1).

The distribution of the olive groves according to their technical efficiency scores is also presented in Figure 4. As the figure indicates, 18 farms have a TE score lower than 0.4. The majority of these farms are low-input and/or conservation farms (note that there are overlaps between the farm types). On the other hand, 15 farms have TE VRS scores over 0.8; these farms are mainly organic and low-input farms. Indeed, the organic farms have a completely different distribution of TE scores, skewed to the left. Six of the farms characterized as organic have an efficiency score higher than 0.8. On the other hand, eight of the farms that are characterized as conservation farms, twelve low-input farms, and five standard farms have efficiency scores lower than 0.4.

The examination of the underlying reasons for technical inefficiency was further scrutinized through a truncated regression analysis. The results, presented in Table 8, indicate the main factors that explain the TE VRS scores. As far as the characteristics of the farmer are concerned, it appears that agricultural training has a positive effect on the TE of the farms.

Table 8. Results of the truncated regression analysis.

Variables	Coefficient	Std. Err.	z	$p > z$	[95% Conf. Interval]	
Training	0.281049	0.158296	1.78	0.076	−0.02921	0.591304
Contribution of family labour	0.00056	0.002417	0.23	0.817	−0.00418	0.005298
Experience	−0.00051	0.004217	−0.12	0.904	−0.00877	0.007756
Contribution of olive farming	0.009706	0.006876	1.41	0.158	−0.00377	0.023184
Contribution of farm income	0.003973	0.002005	1.98	0.047	4.38×10^{-5}	0.007902
Low-input farms	0.163878	0.138117	1.19	0.235	−0.10683	0.434581
Organic farms	0.398628	0.190377	2.09	0.036	0.025496	0.771759
Conservation farms	−0.37392	0.176477	−2.12	0.034	−0.71981	−0.02803
Contribution of market value	0.561126	0.318781	1.76	0.078	−0.06367	1.185926
_cons	−1.04578	0.869166	−1.2	0.229	−2.74931	0.657756
/sigma	0.290622	0.058886	4.94	0	0.175209	0.406036

Experience appears to have no significant effect on the TE of the olive groves. Accordingly, the contribution of family to the total labour seems to have no impact on TE, in contrast to previous studies about olive groves [52]. The contribution of farm income to the total income of a household also affects TE positively. In other words, farmers who are more involved in farming activities manage their resources more efficiently. Part-time farmers have fewer working hours to spend on the farm, and this may result in the practice of less efficient management.

As expected from the profitability and productivity results, practicing organic agriculture has a positive impact on the TE of the olive groves. On the other hand, employing conservation practices may harm the TE of the olive groves. This indicates that, in conservation farms that employ practices which enhance soil fertility, emphasis on the management of other resources is complementary to achieve TE.

4. Discussion

Productivity and efficiency have been a focal point of agricultural research and policy-making for many decades. Efficiency in terms of maintaining output with minimum resources has received re-emerging attention, as it compromises producers' need for cost minimization and society's need for adequate and resource-friendly food, especially within the context of ongoing climate change. Notably, essential agricultural resources like land and water are progressively diminishing, while the pressure to augment farm productivity intensifies to meet the increasing global food requirements. The literature on efficient resource use has often demonstrated suboptimal performance in conventional farming practices. The latter, together with the increasing consumer demands for high-quality and environmentally sustainable agricultural products have intensified research on the economic performance of alternative ecological farming practices in many activities, including olive production.

Within this context, many studies focusing on olive groves have demonstrated the superiority in terms of economic profitability and efficiency in resource use of organic olive groves [14]. However, there is limited research regarding other ecological approaches like conservation and low-input farms. This study concentrates on the assessment of the economic performance of Cretan olive groves in terms of profitability, productivity, and efficiency in input use. The study manages to provide insight into the economic performance of olive groves across ecological farm types, i.e., standard, organic, conservation, and low-input farms, by utilizing the available dataset and farm typology of the LIFT Project.

The findings of this analysis demonstrate the ability of olive groves to produce adequate farm net income, which covers variable inputs, hired labour costs, and asset depreciation. However, adjustments in production are necessary for the farms in the sample to yield a positive net profit. It should be emphasized that, during the reference year, the olive groves faced several environmental challenges and damages from olive fly infestations, which impacted the output. Nonetheless, the incorporation of imputed costs into the analysis, especially family labour costs, exposes negative profitability indicators, raising concerns about the long-term viability of these farms, without the appropriate adjustments in their production.

As Stilitano et al. [14] emphasize, high production costs and low productivities cause unstable economic results and restrict the competitiveness of Italian olive farms in the global market. Indeed, in our study, the partial productivity indicators also support these results. The productivity of the land is quite high and significantly higher than the average rent per hectare. It is also estimated at the same level as the average land productivity for Greek agriculture, according to the output value and land use provided by the EUROSTAT [41,53]. On the other hand, the productivity of labour is lower than the average productivity identified for Greek agriculture, according to the output value and labour input data of the EUROSTAT [53,54]. The labour productivity indicator, according to the latter source and assuming an annual work unit equal to 1750 h of labour, is 16 EUR /h for Greece, which is significantly higher than what our study estimates. This indicates the need for the sampled olive groves to manage their labour input more productively.

The technical efficiency scores among the olive groves underscore the necessity for enhanced input management. Specifically, the mean technical efficiency of the farms in our sample is estimated at 0.58, which indicates that the olive groves studied can reduce their input by 42% and still achieve the same level of output. This observation aligns with other studies employing a similar analytical approach and concentrating on the technical efficiency of olive farms in the Mediterranean region [25–27,29,30]. Our study indicates that only nine farms in our sample are technically efficient. Accordingly, Fernández-Uclés et al. [55] identified only a small number of Tunisian olive farms that achieved efficiency. Tzouvelekas et al. [56] conducted an assessment of the technical efficiency of conventional olive groves in Greece, revealing a TE score of 0.54. These findings indicate that there is a substantial potential for enhancing the overall efficiency of resource allocation and output generation in Greek olive groves. Conversely, Niavis et al. [29] undertook an analysis of the extensive olive farms situated in the Pelion region of Greece, which yielded a notably higher TE score of 0.86. A higher mean technical efficiency score of 0.78 is also estimated for the Spanish olive farms in the study of Lambarraa et al. [57]. In our case, the technical efficiency scores are higher only in specific ecological approaches.

Turning to the results per ecological farm type, our analysis indicates that the standard farms (which, as stated in the Materials and Methods section, resemble conventional farms) exhibit a smaller size, higher costs, and lower revenues compared to the rest of the olive groves in our sample. They also exhibit a low productivity of labour and low technical efficiency scores. The technical efficiency analysis also indicates that the scale efficiency is smaller in the standard farms. This analysis, thus, suggests that a managerial option that would enhance the economic outcome of standard farms would be to expand in size, so that the available family labour and invested capital would be used more efficiently. Similar findings are identified in the study of Colombo et al. [58], who emphasize that larger olive farms in Andalusia achieve economies of scale that allow them to reduce the production cost and efficiently use inputs like fixed capital. They also note that small farms (5 ha) are more likely to be less competitive due to their inability to achieve economies of scale. Colombo et al. [59] also emphasize, in their findings, that increasing the efficiency of agricultural labour in olive farms would encourage their professionalization and generate quality employment

Standard farms also present lower prices for olive oil, which considerably affects their revenues. Looking into alternative marketing channels or enhancing product quality could

also improve the economic performance of standard olive groves. This is also emphasized in Stilitano et al. [15], who underline the benefits of producing high-quality, extra virgin oil in the profitability of olive groves in southern Italy when coupled with a better management of the inputs, as well as Dios-Palomares et al. [32], who emphasize that the olive sector can increase its competitiveness through quality and added value to consumers.

On the other hand, organic farms perform better in economic terms when compared to the rest of the farms in our study. One reason for this is the price premium of organic products, as well as the higher subsidies received by organic farms. The effect of the better prices and subsidies on the economic performance of organic farms is also emphasized in the study of Stillitano et al. [14], as well as in the study of Sgroi et al. [38]. In our study, the organic farms yield higher revenues and farm net income, perform better in terms of partial productivity of land and labour, and achieve higher technical efficiency scores. The results regarding organic farming are in accordance with similar studies that also indicate the higher TE of organic compared to conventional olive farms [31,36]. Additionally, the results of the efficiency analysis indicate that the organic farms achieve higher scale efficiency, compared to the rest of the sampled farms, which means that they operate close to their optimal scale.

It should be emphasized, however, that organic farms seem to have higher variable costs attributed mainly to their excessive use of water to maintain productivity (see also [60]) and fuel to perform mechanical tasks. Adjusting the use of these inputs through, for example, more appropriate irrigation techniques would further promote the productivity and efficiency of organic olive groves, especially considering future restriction that climate change will pose [61].

As far as conservation farms are concerned, the economic analysis performed in this study indicates that further managerial adjustments are needed so that these farms can improve their profitability, productivity, and efficiency performance. Conservation olive groves are larger and have smaller costs per hectare compared to the other farm types, with the exception of pesticides. Pesticides have been acknowledged as the least productive input used in olive groves also in the work of Beltrán-Esteve [28] and as a reason behind a lower profitability. With regard to farm size, Rodríguez-Entrena and Arriaza [62], who focused on olive farms in Southern Spain, also found that medium to large farms are more likely to adopt conservation practices.

In our study, the conservation farms appear to also have smaller technical efficiency scores and perform poorly in most productivity indicators, except for labour. The results of our analysis also denote that these farms have higher fixed capital costs per hectare, which indicate a higher, rather underutilized, invested capital. The underutilization of invested capital in olive farms and its consequences on economic performance has also been identified in the study of Karafillis and Papanagiotou [37]. As also indicated in the scale efficiency results, though conservation farms are more extensive, further increasing in size may help them achieve better economic results by utilizing the invested capital more efficiently (see also [58]).

The results for the low-input farms resemble those of the conservation farms, though the profitability, productivity, and efficiency indicators are better in the former case. Specifically, the low-input farms appear to have the second highest average revenue per hectare, after the organic farms, as well as the second-best average productivity of labour. Again, the productivity of the fixed capital is lower, indicating that a significant amount of invested capital is tied in low-input farms. A size increase can, in this case, also be a way to improve efficiency and productivity.

The truncated regression analysis, performed to explain the efficiency scores, reveals that, as expected, training helps farmers achieve a higher technical efficiency, as they manage their resources in a way that causes less overuse and waste. Additionally, training increases environmental awareness and familiarizes farmers with more cost-effective and ecological practices. Fernández-Uclés et al. [55] and Bernal Jurado et al. [35] also emphasize the positive effect of managers' training on the efficiency of olive groves. Similar findings

are emphasized in Dios-Palomares et al. (2011) [32], in their study on the technical efficiency of the olive oil industry in Spain, which appears to be higher in firms with higher training levels. The results also indicate that the percent of income derived from farming also has a positive effect on efficiency, indicating that full-time farmers or farmers who are more involved with this activity are also more efficient compared to farmers who have other main occupations. Finally, the regression analysis highlights the fact that farms managed under the organic scheme have higher efficiency scores.

On the other hand, practicing conservation farming without additional management practices has a negative impact on technical efficiency. A notable association between efficiency and subsidies also derives from our research. This is indicated by the fact that the contribution of the market value of production to the total revenues of the grove including subsidies enhances efficiency. Subsidies, while assisting in the profitability of olive groves [14], especially during low-yield years, may be affecting farm management in such a way that productivity and efficiency are compromised. This finding is consistent with the conclusions of other studies focused on the technical efficiency of olive farms in Greece and in the Mediterranean region [63,64]. Policymakers should consider these results critically, as subsidies seemingly fulfill one of their principal objectives, maintaining farm income, while falling short in another, namely, improving farm management and the use of resources. The mixture of subsidies provided to farmers may require adjustments to encourage managerial restructuring and enhance technical efficiency and economic sustainability.

5. Conclusions

The current study provided significant insights into the economic performance of the olive groves that operate in Crete, Greece. The analysis included the evaluation of profitability and partial productivity indicators, together with a technical efficiency estimation, using the DEA methodology. A significant contribution of the research is that it explores the economic performance of olive groves belonging to alternative ecological approaches, which include organic, conservation, low-input, and standard farming. Consequently, differences in the profitability, productivity, and efficiency indicators among the alternative farm types are reported.

The results of the analysis indicate that groves managed under the organic scheme, exhibit higher profitability, productivity, and efficiency indicators. On the contrary, the performance of standard farms is inferior, especially in terms of profitability and labour productivity. Conservation farms also exhibit low efficiency scores, mainly due to a high invested capital and relatively low revenues. It is also important to highlight the significance of appropriate training for farmers to achieve a higher efficiency, as well as the negative impact that subsidies can have on the appropriate management of inputs and resources.

Additional research is warranted to explore factors that may not have exhibited statistically significant impacts on the TE, including the experience of farmers. Furthermore, extending the sample of farms or using additional reference years may be necessary to verify the influence of area-specific or time-specific variables on the efficiency scores and produce more robust results. Finally, even though the efficiency analysis performed takes into consideration farm-specific characteristics like inputs and outputs and differentiates among scale and pure technical inefficiency, further investigation may be required to understand the limitations for achieving efficiency. For example, the analysis may suggest scale inefficiency, but farms may not be able to expand in size due to market or credit limitations.

In essence, the efficient use of farm inputs carries significance for olive producers, as it enhances their economic outcome, but also for society and policymakers. Achieving efficiency can alleviate the environmental impacts of food production, conserve valuable and limited resources, and offer sufficient and affordable goods to consumers.

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curation, A.S. and V.K.; writing—original draft preparation, A.S., V.K. and P.G.; writing—review and editing, I.T.; visualization, A.S.; supervision, A.S. and I.T.; project administration, I.T.; and funding acquisition, I.T. All authors have read and agreed to the published version of the manuscript.

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