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ABSTRACT

Olive farming represents an important source of income and employment in the rural areas of Andalusia (Spain), which is the most important olive oil-producing region in the world. Unfortunately, it also exerts important environmental pressures with regard to soil erosion, use of polluting inputs, excessive water consumption and biodiversity reduction. This paper uses Data Envelopment Analysis (DEA) techniques and pressure distance functions to contribute an assessment at the farm level of the eco-efficiency of a sample of 292 Andalusian olive farmers. We distinguish between managerial eco-efficiency and program eco-efficiency; the latter being associated with the different natural conditions prevailing in the three main olive cultivation systems in the region, namely, traditional rain-fed mountain groves, traditional rain-fed plain groves and irrigated intensive groves. Our findings show that eco-inefficient management is a widespread practice across olive farmers, mainly explained by a generalised technical inefficiency. Furthermore, the most eco-efficient production system is the traditional plain growing system. Finally, we find that land productivity strongly influences managerial eco-efficiency in all three aforementioned cultivation systems.

Keywords. Olive grove; Economic-ecological efficiency; Environmental pressures; Data Envelopment Analysis.

1. Introduction

Given its biophysical nature, farming is part of ecosystems, rather than being external to them. The farming industry is, in the vast majority of countries, the main user of land and water and exerts positive and negative pressures on the environment. Nowadays, the impact of agriculture on the environment is a matter of public concern, particularly with regard to the achievement of sustainable agriculture (Brouwer, 2004, Pretty, 2008). Concerning this matter, our contribution is twofold, namely, policy-oriented and methodological. On the one hand, we shed some light into the economic and environmental performance of olive farming in the Southern Spanish region of Andalusia - a sector of paramount social, economic and environmental importance - aiming at pointing out some policy consequences. On the other hand, we expound on how a farm-level indicator of eco-efficiency can be constructed in order to assess individual farms' balance between the creation of economic value and the restriction of negative environmental impacts. Accordingly, we propose a Data Envelopment Analysis (DEA) methodological approach to build up a composite indicator of eco-efficiency, taking into account the main environmental impacts of olive farming.

Andalusia is by far the largest olive growing region worldwide. It comprises an area of 1.5 million hectares, representing 59% of the total Spanish area of olive groves, 30% of the European Union area and 19% of the world area. Olive groves generate 26% of agricultural production in the region, and provide employment for about 32% of the agricultural workforce, being the main income source in more than 300 municipalities, where growing olive trees has become an economic monoculture (CAP, 2008). Olive groves have currently reached record levels in terms of area and production, by taking advantage of the favourable policy context granted by the European Common Agricultural Policy (CAP). This rapid development, while increasing socio-economic well-being in Andalusian rural areas, has also endangered environmental sustainability. Some negative impacts of olive growing are briefly summarized below (Beaufoy and Pienkowski, 2000, Gómez-Calero, 2009, EC, 2010, CHG, 2010):

a. *Soil erosion*. This problem has been accentuated by the expansion of olive cultivation into soils with unfavourable conditions for agricultural production, and aggravated by inadequate management, particularly with regard to the systematic removal of the natural vegetation land cover. Official data (CAP, 2008) show that 52.7% of the Andalusian olive surface has an erosion rate of over 12 t/ha per year.

b. *Loss of biodiversity*. One of the peculiarities of traditional olive cultivation systems was the rich biodiversity associated with cultivation. The presence of trees and underbrush in the form of mosaics provided a diversified habitat where large numbers of insects, birds, reptiles and small mammals found shelter. However, olive production intensification (change in cultural practices and increased use of agrochemicals) and specialisation (large monoculture areas) has contributed to a decline in the number and diversity of species.

c. *Overexploitation of water resources*. Thirty years ago olive farming was almost exclusively rain fed, but the trend towards intensification has meant that today there are 546,425 hectares of irrigated olive trees, representing 35.3% of the Andalusian olive groves surface. Although olive trees are a crop with low water needs and highly efficient drip irrigation systems are currently widespread, the total pressure exerted on water resources has been significant, as this single crop is currently consuming about 22% of overall water consumption in the Guadalquivir Basin, the main catchment area of the region. As a result, the satisfaction of the demand for water in Andalusia has been put at risk and a wide range of aquifers and surface water bodies are now overexploited.

d. *Diffuse water pollution*. The quality of water flowing through the olive agro-ecosystems has suffered as a result of the systematic use of chemicals, including herbicides and fertilizers. Problems of diffuse pollution of rivers, reservoirs and aquifers have arisen, generating several health scares that have resulted in the occasional prohibition of consuming water from reservoirs whose feeding basin is covered by olive groves.

Some recent trends point towards the development of more eco-friendly models of production in Andalusia, with the growth of organic farming and integrated production. The European CAP's recent reforms are also exerting a positive influence along three basic lines of action: the decoupling of subsidies (which discourages intensive production), the application of conditionality and the development of agro-environmental programs. Also on the positive side, olive trees make a major contribution towards CO_2 fixation, which has been estimated at more than 900 thousand tons per year over the period 1990-2004, thus mitigating climate change (CAP, 2008).

Analysing and quantifying the environmental impacts of agriculture is a demanding task, requiring the use of multiple individual indicators and sometimes aggregating them to build up composite indicators (see Rao and Rogers, 2006 for a short introduction to the topic). Different groups of academic researchers have seen their proposals concerning environmental or *sustainability* indicators reflected in a growing literature (Brouwer and Crabtree, 1999; van der Werf and Petit, 2002; Niemeijer, 2002; Payraudeau and van der Werf, 2005; Bell and Morse, 2008). In addition, several international institutions have developed different frameworks of analysis (OECD, 2001, EEA, 2006).

Our preferred approach differs from some of the more commonly used frames of reference for agro-environmental indicators in two important aspects: the micro-scale of the analysis and the willingness to consider simultaneously the economic and the environmental dimensions of farmers' performance. We believe that a site-specific approach is necessary to depict the state of the environment accurately. In our case it has led us to distinguish between a variety of olive cultivation systems, responding to different endowments of natural resources and degree of production intensification. Furthermore, the environmental relevance of specific managerial practices and differences in the grasp of environmental-friendly farming techniques by individual farmers all point to the advantages of adopting a farm-level scale of analysis. Therefore, this paper belongs in the particular stream of literature that has stressed the need to collect and use farm or local farming system-specific agro-environmental data (Andreoli and Tellarini, 2000, Rigby *et al.*, 2001, van der Werf and Petit, 2002, Pacini *et al.*, 2003). Concerning the other basic tenet of this paper - the joint assessment of the economic and environmental performance of individual farms - we have deemed convenient the use of the *eco-efficiency* concept.

The economic-and-environmental efficiency or *eco-efficiency* has been coined in the literature as an operational concept well suited to a practical approach to the notion of *sustainability* (Schaltegger, 1996). The topic was also addressed by the OECD (1998), which defined eco-efficiency as '*the efficiency with which ecological resources are used to meet human needs*', and has been adopted and popularised by the World Business Council for Sustainable Development (WBCSD, 2000, Verfaillie and Bidwell, 2000) as a way of encouraging companies to achieve higher levels of competitiveness and environmental responsibility simultaneously. From a practical point of view, eco-efficiency represents the ability to achieve economic results by making a minimum use of natural resources and with the least possible environmental degradation. Accordingly, eco-efficiency can be calculated using ratios which relate the economic value of goods and services produced by any single entity –farm, company, industry, region or country– with environmental pressures and impacts arising from production processes. Eco-efficiency improves when negative environmental impacts decrease while the value of production is maintained or raised. In scoring eco-efficiency we use DEA, a non-parametric technique of efficiency analysis employed in several papers to assess eco-efficiency (Korhonen and Luptacik, 2004, Kuosmanen and Kortelainen, 2005, Zhang *et al.*, 2008), even if relatively few of them have approached the analysis of farming eco-efficiency (De Koeijer *et al.*, 2002, Ribal *et al.*, 2009, Picazo-Tadeo *et al.*, 2011).

Eco-efficiency indicators are related to sustainability because improvements in eco-efficiency may be considered as an intermediate step in the quest for sustainability of production processes. But achieving higher efficiency at the micro level do not guarantee the achievement of environmental objectives defined in absolute terms at the macro level (Huppes and Ishikawa, 2005). Sustainability, as opposed to eco-efficiency, is concerned with the absolute pressure that economic activities exert on the absorptive capacity of ecosystems. That is, even if the relative level of environmental pressure generated by a particular economic activity is low, the absolute level of environmental pressure may still exceed the threshold of compatibility with the performance of vital functions of natural ecosystems. Also, the existence of a *rebound effect* can neutralise or overcompensate for the efficiency gains harvested in the first place (Holm and Englund, 2009), further differentiating eco-efficiency and sustainability.

Despite these and other shortcomings, the concept of eco-efficiency remains useful, with at least two basic reasons supporting its widespread use (Kuosmanen and Kortelainen, 2005). On the one hand, eco-efficiency improvements may represent the most cost-effective way to achieve a reduction in environmental pressures, and, on the other, policy-makers may find it easier to adopt policies aimed at achieving improvements in eco-efficiency than other more radical policies that directly restrict the level of economic activity.

A win-win outcome from policies promoting eco-efficiency can be frequently expected. This is because companies often are not operating at the frontier of economic efficiency, which creates a chance of making net cost savings in addition to reducing their environmental impacts (Ekins, 2005). Proponents of this line of reasoning have argued that pollution is a form of economic inefficiency and that reducing pollution may increase efficiency and cut costs (Porter and van der Linde, 1995; Picazo-Tadeo and Prior, 2009). According to this view, efforts to reduce pollution and to maximise profits go hand in hand, because both include the efficient use of inputs, innovation, and increased product value to the consumer. This represents a substantial departure from the more traditional paradigm, wherein environmentally-friendly performance is always costly and requires the enforcement of policy regulations to bring about any environmental improvements.

Within the aforementioned context, the objective of this paper is to analyse the eco-efficiency of olive farms in the Southern Spanish region of Andalusia. In particular, we assess eco-efficiency at farm level distinguishing between managerial eco-efficiency and program eco-efficiency, the latter representing the eco-efficiency due to the characteristics –endowment of natural resources– of the particular olive farming system farms belong to. Our results will allow us to perform several specific tests, designed to address, *inter alia*, the following questions:

In which proportion does the eco-efficiency of olive farms depend on the endowment of natural resources and/or their management by farmers?

What structural and socio-demographic variables influence the eco-efficiency of these farms?

Are those holdings receiving institutional financial support more efficient?

The insight gained by answering these questions may contribute to improve the design and implementation of public policies aimed at improving *governance* of the olive farming sector.

Following this Introduction, Section 2 expounds the main insights of the methodology. Section 3 describes the agricultural systems being analysed and comments on the data. Section 4 discusses the main findings and their policy implications, and, finally, Section 5 arrives at some policy conclusions.

2. Methodology

2.1. Computing eco-efficiency

As we have defined in the introduction the concept of eco-efficiency utilised in this paper, let us assume that we observe the net income *i* variable as representing economic results, and the $n = 1,\ldots,N$ damaging environmental pressures, denoted by the vector $p = (p_1,\ldots,p_n)$, generated in their production processes by a set of $k = 1,\ldots,K$ farms. Following Picazo-Tadeo *et al.* (2011), the *pressure generating technol-*

ogy (*PGT*) that represents all feasible combinations of income *i* and environmental pressures *p* is defined as:

$$PGT = \left[(i,p) \in R_{+}^{1+N} \mid \text{income } i \text{ can be generated with pressures } p\right] \qquad (1)$$

Furthermore, in order to formalise the concept of eco-efficiency, we follow Kuosmanen and Kortelainen (2005) and formulate it as a ratio between net income and a measure of environmental (ecological) performance. For farm *k*, eco-efficiency is then defined as:

$$\textit{Eco-efficiency}_k = \frac{i_k}{P(p_k)} \qquad (2)$$

where *P* is a function which aggregates the *n* environmental pressures into a single environmental pressure score.

A sensible approach to computing a single environmental pressure score is to take as an aggregating function a weighted average of the particular environmental pressures generated by each farm. For farm *k*, this can be formally expressed as:

$$P(p_k) = \sum_{n=1}^{N} w_n p_{nk} \qquad (3)$$

w_n being the weight awarded to pressure *n* in the computation of the aggregate environmental pressure score.

Furthermore, as already noted, in assessing farms' eco-efficiency we make use of DEA techniques and what we have called *pressure distance functions*, which are just an adaptation to our framework of analysis of the well-known input distance functions. The pressure distance function is defined as:

$$\text{Pressure distance function}(i,p) = Max\, \vartheta \mid (i, \vartheta^{-1} p) \in PGT \qquad (4)$$

Expression (4) measures the maximal attainable proportional contraction of all environmental pressures, so that the resulting combination of net income and environmental pressures still belongs to the *pressure generating technology set*, i.e. pressures are reduced without decreasing the level of income. Drawing a parallel with conventional DEA literature, the pressure distance function for farm *k'* can be computed from the following mathematical program:

$$\textit{Maximize}_{\vartheta_{k'}, z_k} \ \vartheta_{k'}$$

subject to:

$$\begin{aligned} & i_{k'} \le \sum_{k=1}^{K} z_k i_k & & (5i) \\ & \vartheta_{k'}^{-1} p_{nk'} \ge \sum_{k=1}^{K} z_k p_{nk} \qquad n = 1,\dots,N & & (5ii) \\ & z_k \ge 0 \qquad k = 1,\dots,K & & (5iii) \end{aligned} \qquad (5)$$

z_k being a set of variables that represent the intensity with which each observed farm *k* enters into the composition of the eco-efficient frontier. In other words, this set of weights allows us to compute a *virtual* eco-efficient point of reference located on the technological frontier against which farm *k'* is compared.

In program (5) we have also assumed that the pressure generating technology exhibits constant returns to scale (*CRS*).[1] In addition, this is a non-linear program and its computation involves some difficulties, which can be overcome by solving the following linear program:

$$
\begin{aligned}
&\textit{Minimize}_{\varphi_{k'}, z_k} \ \varphi_{k'} = \vartheta_{k'}^{-1} \\
&\textit{subject to:} \\
&\qquad i_{k'} \le \sum_{k=1}^{K} z_k i_k && && (6i) \\
&\qquad \varphi_{k'} p_{nk'} \ge \sum_{k=1}^{K} z_k p_{nk} && n = 1,\ldots,N && (6ii) \\
&\qquad z_k \ge 0 && k = 1,\ldots,K && (6iii)
\end{aligned}
\qquad (6)
$$

The pressure distance function is always lower-bounded to one, the score that represents best performance. Moreover, the greater the score computed the lower the eco-efficiency; for instance, a value of 1.5 for a particular farm k' would mean that its level of observed environmental pressures is 50% above the eco-efficient level.

2.2. Decomposing eco-efficiency: program and managerial eco-efficiencies

In one of the first empirical applications of DEA, Charnes *et al.* (1981) suggested that groups of decision-making units belonging to different groups or programs might have different technological frontiers due to program differences. In this paper, the authors propose an empirical approach to distinguishing between *managerial efficiency* and *program efficiency*. While the former assesses the performance of decision-making units when they are compared to best managerial practices observed in the group or program they belong to, program efficiency identifies differences in performance between programs.

Here, we have adapted this methodology to the evaluation of *program eco-efficiency* (*PEE* hereafter). In order to do so, the following four steps need to be performed: First, the sample has to be divided into as many groups as different programs

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[1] Economies of scale are relevant in agricultural production, so that from an economic view farming is a variable returns to scale (*VRS*) activity. Nonetheless, agriculture might be considered as a *CRS* activity from an environmental perspective, because the effect of farming on ecosystems is directly related to agricultural practices and not to the allocation of land into individual farms. As assessing eco-efficiency involves analysing the economic and ecological performance of farming simultaneously, both of the aforementioned considerations could be taken into account. However, we have opted for *CRS*, as in Picazo-Tadeo *et al.* (2011), because in our research we are interested in assessing eco-inefficiency of farms, regardless of whether it comes from either inappropriate management, given the size of the farm, or inadequate farm size. Kuosmanen and Kortelainen (2005) also assume *CRS*.

we wish to consider. Second, eco-efficiency is separately assessed in each group, i.e., considering only farms belonging to that group. This allows scores of *intra-program* or *managerial eco-efficiency* (*MEE* henceforth) to be computed. Then, observed data on the environmental pressures of eco-inefficient farms in each group need to be projected onto the eco-efficient frontier of their own group in order to clear up managerial eco-inefficiency. For pressure *n* and farm *k'*, this can be formally done by using the following expression:

$$p_{nk'}^{projected} = \vartheta_{k'}^{-1} p_{nk'} \quad (7)$$

The third step consists of assessing eco-efficiency once again, but now using all farms in the sample regardless of the group they belong to, and the projected data on environmental pressures obtained in the previous step. In this way, once *MEE* has been cleared up, *PEE* is assessed. Finally, and in the fourth place, the significance of the average differences in *PEE* between programs or groups needs to be evaluated using different statistical tests.

Figure 1 provides a graphic intuition of both *MEE* and *PEE*. Let us assume that we observe farms A to G, of which farms A, B and C (represented by dots) operate under program 1, while D, E, F and G (marked with crosses) operate under program 2. Furthermore, all farms produce a given level of net income *i* generating environmental pressures p_1 and p_2. While eco-efficient farms A, B and C and their convex linear combinations give shape to the frontier of farms operating under program 1, the segment DEF shapes the eco-efficient frontier of farms within program 2. In addition, the joint frontier, i.e., the eco-efficient frontier when all farms in the sample are jointly considered, is shaped by the segment ABC, thus coinciding in this example with the frontier of program 1.

Insert Figure 1 around here

Let us now focus on farm G which, as noted, belongs to program 2. Comparing farm G with best observed practices within its own program yields point G', showing that pressures p_1 and p_2 could be proportionally contracted while maintaining net income at level *i*. Verbalizing, the managers of farm G are not using best practices thus incurring managerial eco-inefficiency, which is measured by the ratio OG/OG'. Furthermore, once figures on environmental pressures have been transformed according to expression (7), projecting point G' onto the joint frontier yields point G'', showing that after the best economic-ecologic performance that program 2 allows has been achieved, additional radial reductions in environmental pressures could still be possible by moving to the best performing program. In other words, this farm is also affected by program eco-inefficiency, which is assessed by the ratio OG'/OG''.

As a result, the aggregate eco-efficiency (*AEE*) of farm G, which is measured by the ratio OG/OG'', can be decomposed into the result of *MEE* and *PEE*. In formal terms, the following relationship holds:

$$\frac{OG}{OG''} = \frac{OG}{OG'} \times \frac{OG'}{OG''} \quad (8),$$

or, alternatively:

$$\begin{aligned} &\textit{Aggregate eco-efficiency (AEE)} = \\ &\textit{Managerial eco-efficiency (EE)} \times \textit{Program eco-efficiency (PEE)} \end{aligned} \quad (9)$$

3. Data and sample

3.1. Case study: olive groves in Andalusia (Spain)

Olive farming is the most widespread agricultural use in Andalusia, covering 30% of the region's Utilized Agricultural Area (1.5 million hectares). This large extension of olive groves explains how Andalusian olive production is far from homogeneous. In this sense it is worth mentioning that regional olive-growing systems can be characterized based on three dichotomous variables (CAP, 2003): a) the slope of the land ('moderate slope' or 'plain' *vs.* 'high slope' or 'mountain'), b) the availability of irrigation water ('rain-fed' *vs.* 'irrigated'), and c) the density of olive trees ('less than 140 trees per hectare' or 'traditional' *vs.* 'more than 140 trees per hectare' or 'intensive'). The two first variables specify the availability of the two main natural resources for agricultural production (soil and water), and the third identifies the productive strategy followed by olive growers, also based on the endowment of soil and water resources. Considering these variables, eight different olive farming types can be defined. Within this typology, three types are the most important because of their larger land cover:

a. *Traditional mountain groves*. Olive farming developed in high slope land and rain-fed conditions, where a low density of trees per hectare has been implemented. This olive system covers 444,465 hectares in Andalusia (32.7% of the region's surface devoted to olive orchards).

b. *Traditional plain groves*. Olive system based on moderate slope land and rain-fed conditions, with a low density of trees per hectare. This kind of olive farms occupies 436,942 hectares (32.1% of Andalusian olive surface).

c. *Irrigated intensive groves*. Olive farms type featuring moderately sloped land where irrigation water is available. Due to these favourable conditions, a high density of trees per hectare can be achieved. This system accounts for 226,184 hectares in the region, representing 16.6% of the region's olive orchards.

All together, these three olive growing systems represent 81% of Andalusian olive farming, being the particular production *programs* considered for this study. Thus, our empirical application has been implemented on a representative sample of Andalusian olive farms, divided into three subsamples, one for each of the productive systems mentioned above.

3.2. Variables used in the analysis

3.2.1. Value added variable

The variable representing economic results is, as already noted, net income per hectare at farm level (i_k). For each farm k in the sample, this variable is computed as:

$$i_k = Net\_income_k = \frac{Sales_k - Direct\_costs_k}{Land_k} \tag{10}$$

where $Sales_k$ comprises incomes obtained from the sale of olives and $Direct\_costs_k$ are the costs due to the following inputs: labour (both own and hired)[2], fertilisers, pesticides, energy, contracted services and fixed costs directly related with olive production (machinery depreciation and maintenance). All these variables are measured in € at 2010 prices. The resulting net income is expressed per hectare being divided by the surface devoted to olive groves measured in hectares, variable $Land_k$.[3]

3.2.2. Environmental pressure variables

Taking into account the ecological features and problems of olive production in Andalusia already pointed out in the introduction, six indicators have been deemed relevant to measure environmental pressures from this farming activity:

a. *Erosion*. The amount of soil eroded at farm level has been estimated using the *Revised Universal Soil Loss Equation* (Renard *et al.*, 1997):

$$p_{1k} = Erosion_k = R_k \times K_k \times LS_k \times C_k \times P_k \tag{11}$$

where $Erosion_k$ is the average annual soil loss measured in tons of soil per hectare, R_k is a rainfall erosive factor, K_k is soil erodibility, LS_k is the slope length and slope gradient factor, C_k is a cover management factor[4] and P_k is a support practice factor[5], all of them quantified for the farm k. For further details about all these technical factors see Gómez *et al.* (2003).

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[2] Own labour provided by the farmer and his/her family has been priced according to its market value, as an opportunity cost, as has been the hired labour.

[3] As can be observed, net income has been calculated without considering agricultural subsidies because the income support currently received by olive growers, based on the *Farm Single Payment* scheme, is based on subsidies completely decoupled from production.

[4] The C-factor reflects the effect of cropping and management practices on erosion rates. This effect is mainly due to variations on soil cover, as elements able to intercept raindrops and slow surface runoff. In the case of olive farming, this factor can be particularly affected by tilling and weed management practices followed by growers.

[5] The P-factor reflects the impact of farming routine on erosion. Thus, this factor takes into account practices such as strip-cropping, contouring or terracing *vis-à-vis* straight row farming up-and-down slope.

b. *Biodiversity*. Biodiversity is a complex ecological concept dealing with species richness and variety, difficult to be accounted within a single figure (OECD, 2003). In this research we have designed an *ad hoc* indicator in order to obtain a *proxy* variable of biodiversity. For this purpose, we have considered the agricultural practices that better enhance biodiversity in olive farming (Duarte *et al.*, 2009): a) maintaining vegetal covers on soil[6], b) controlling vegetal covers by sheep/horse grazing[7], c) piling up pruning residues[8], d) allowing some olives to remain on trees after the harvest[9], and e) irrigating olive trees with buried drips[10]. Related to each of these practices, a binary variable has been built (*Vegetal_cover*, *Grazing*, *Piling_residues*, *Remaining_olives* and *Buried_drips*, respectively), taking the value zero if they are actually implemented, and one if they are not[11]. Then, the *Biodiversity* indicator has been calculated as a weighted sum of these variables as follows:

$$\begin{aligned} p_{2k} = Biodiversity_k = w_1 Vegetal\_cover_k + w_2 Grazing_k + \\ + w_3 Piling\_residues_k + w_4 Remaing\_olives_k + w_5 Buried\_drips_k \end{aligned} \quad (12)$$

where w_i are the weights given to each variable by a panel of ten biologists with expertise in this field: w_1=56.6%, w_2=9.6%, w_3=13.0%, w_4=9.8% and w_5=11.0%.

c. *Pesticide risk*. This indicator provides information about the overall toxicity annually released into the environment by the pesticides used for olive production. This toxicity has been estimated by means of the potential lethality to live organisms by the active matters included in these agrochemicals, measured in kg of rat per hectare. The formula used with this purpose is:

$$p_{3k} = Pesticide\_risk_k = \sum_{m=1}^{M} 1{,}000 \frac{Quantity\_commercial\_product_{mk}}{Lethal\_dose\_50_m} \quad (13)$$

where $Quantity\_commercial\_product_{mk}$ is the quantity of the product m used annually in farm k (in kg of m per hectare) and $Lethal\_dose\_50_m$ is the lethal dose 50% of the commercial product m (in g of m per kg of rat).

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6 Increasing the level of organic matter in soils, improving in this way the first trophic level for all food-chains.

7 This practice is the most environmental-friendly option of weed control.

8 Building up of refuge zones for certain animal species.

9 Maintaining a food reservation for wild fauna during the winter.

10 Minimizing animal poisoning.

11 According to this coding, the greater the value of *Biodiversity* indicator, the gretater the negative impact on the environment.

d. *Water use*. This indicator quantifies the amount of water extracted annually from the ecosystems to irrigate olive orchards, and is measured in cubic metres per hectare:

$$p_{4k} = Water\_use_k = \frac{Irrigation\_water_k}{Land_k} \tag{14}$$

where $Irrigation\_water_k$ is the total amount of water used to irrigate olive trees in farm *k*.[12]

e. *Nitrogen ratio*. This indicator is quantified using the following formula:

$$p_{5k} = Nitrogen\_ratio_k = \frac{Nitrogen\_input_k}{Nitrogen\_output_k} \tag{15}$$

where $Nitrogen\_input_k$ is the quantity of nitrogen used to fertilize the olive orchard and $Nitrogen\_output_k$ is the quantity of nitrogen extracted by the olives harvested in farm *k*, both measured in kg of nitrogen per hectare. This ratio provides information about the efficiency of the farm *k* regarding nitrogen use; the higher the value of this indicator, the less efficient it is from this point of view.

f. *Energy ratio*. Energy use, as a *proxy* of greenhouse gases (GHG) emissions, has also been considered by employing an input/output focus. Thus, this indicator is measured as the ratio between the energy consumed to generate the agricultural inputs and the energy fixed by olive groves and exported by the output harvested (olives):

$$p_{6k} = Energy\_ratio_k = \frac{\sum_{c=1}^{C} Energy\_inputs_{ck}}{Energy\_output_k} \tag{16}$$

where $Energy\_inputs_{ck}$ is the amount of energy virtually included in the inputs used in every farming activity *c* implemented in farm *k*, and $Energy\_output_k$ is the energy included in the production of olives in the same farm, both being variables calculated in kcal per hectare. Thus, the higher the value of this indicator, the less efficient farm *k* is from an energy perspective.

3.2.3. Socio-economic variables

With the purpose of characterizing the eco-efficiency of our olive farms, we have also considered some socio-economic variables regarding farmers' features and some structural variables about farms' characteristics. All these potential explanatory variables of eco-efficiency have been selected taking into account previous litera-

[12] The value of this indicator is obviously zero for rain-fed olive groves, pointing out the inexistence of any environmental pressure from this perspective.

ture (Basset-Mens *et al.*, 2007; Meul *et al.*, 2007; van Passel *et al.*, 2007 and 2009; Pelletier *et al.*, 2008; Ribal *et al.*, 2009; Picazo-Tadeo *et al.*, 2011) and own rational hypotheses to be tested. These second-stage variables are:

a. *Farmers' features*: age, time experience as olive growers, percentage of working time devoted to farming activities, membership of agricultural cooperatives, level of education (level of studies reached) and specific professional training (type of agricultural instruction).

b. *Farms' features*: farm surface area, number of contracted-out farming activities, age of orchard, location inside a denomination of origin, average yield, total labour and percentage of total labour provided by the farmers and their families.

The hypotheses to be tested with these variables are, on the one hand, that farms' eco-efficiency increases as farmers are younger (age), with more time acting as olive growers, more involved in farming activities (percentage of time devoted to farming and member of cooperatives) or their managerial skills are higher (level of education and specific professional training). On the other hand, we also want to test the hypothesis that farms' eco-efficiency increases as farms' size is larger, more activities are contracted out, the farm is located inside a denomination of origin and the olive orchard is not aged, the yield, the total labour and the percentage of family labour are higher.

3.3. Data gathering

We have relied on the data provided by an *ad hoc* survey as the main source of primary information for the calculation of the abovementioned variables. With this purpose, a specific questionnaire was designed, with a universe made up of the 176,468 olive farms operating in Andalusia, according to last official data. Two-stage sampling was followed to obtain a representative sample of olive farms. First, five agricultural districts were randomly chosen comprising 429,156 hectares of olive groves (29.3% of Andalusian land devoted to olive production). In each of these districts, 80 olive growers were randomly selected to be interviewed. Therefore, 400 questionnaires were obtained. The survey was completed by personal interviews implemented from May to September 2010.

Because some of the olive farms sampled were included in olive farm systems different than the ones analysed in this research and, also, some olive growers were seen to provide unreliable data (farms considered as *outliers*), 108 questionnaires were ignored. Thus, a sample of 292 farms was finally considered for eco-efficiency assessment, including the following three subsamples: traditional mountain groves (96 farms), traditional plain groves (108 farms), and irrigated intensive groves (88 farms).

In order to calculate net income and environmental pressures, the primary information supplied by the survey has been complemented with secondary additional information, which is valid for all farms in the sample. This information has been collected from two main sources: a) scientific literature for technical coefficients valid worldwide required to compute environmental pressures (e.g., the amount of nitrogen or energy contained per unit of input used or output produced in the farms, the amount of the active matters included in the agrochemicals used or the lethal dose 50% of these active matters), and b) official statistics for input and output prices valid at regional level required to calculate sales and direct costs.

Table 1 depicts a summary descriptive analysis of all variables used in our analysis, both for the whole sample (Table 1a) and for the three olive systems considered (Table 1b). As can be checked by the analysis of variance (ANOVA tests) carried out, net income and environmental pressures show significant differences across olive systems. Furthermore, Table 2 shows a summary description of farmers and farm features. However, few differences between olive systems are now observed. Only the average yield (land productivity), age of orchards and the percentage of family labour are statistically different among olive systems.

Insert Tables 1a and 1b around here

Insert Tables 2a and 2b around here

4. Results and discussion

4.1. Eco-efficiency assessment

In the first place, we have computed scores of aggregate eco-efficiency (*AEE*) directly from program (6) using all 292 farms in the sample, regardless of the farming system they belong to. The results are in Table 3, which displays the main descriptive statistics of *AEE*, both for all farms sampled and for each olive system considered. At a glance, these results point to a high degree of eco-inefficiency in all cases. Just as an example, the average *AEE* score for all farms in the sample is 3.622, which means that the average olive farm is actually producing environmental pressures 262% higher than a virtual eco-efficient farm with the same level of net income. Relatively similar results are found for the three olive systems examined. In fact, the difference observed in the means of *AEE* among olive growing systems is not statistically significant according to the results of an ANOVA test.[13]

Insert Table 3 around here

Results regarding a widespread eco-inefficient farming have also been recently found by Picazo-Tadeo *et al.* (2011). These authors provide three main reasons to ex-

[13] The F-statistic for the ANOVA test is 0.79, with a *p*-value of 0.456. A similar result has been obtained by implementing the Kruskal-Wallis' test.

plain eco-inefficiency: a) a generalised technical inefficiency, b) the consideration of environmental pressures as *externalities* that do not influence farmers' personal utility function (no civic-minded behaviour should be expected from farmers in order to minimise these environmental pressures), and c) farmers' decision-making based on a multi-criteria framework (farmers' behaviour cannot be explained only on the basis of profit maximisation, as considered in the eco-efficiency analysis).

Although the last two aforementioned reasons could also play a relevant role in our case study, the data gathered and the analysis implemented do not give any further insight in this sense. However, we are able to assess how relevant technical inefficiency is in explaining eco-inefficiency. With this purpose, a standard DEA-based analysis of technical efficiency has been performed using input distance functions. The objective is to maximize the ratio between farms' production (kg) and a weighted sum of inputs, both variable –fertilizers (€), pesticides (€), labour (working days) and energy (€)– and fixed –land (ha). Furthermore, variable returns to scale (*VRS*) are assumed.

The average input distance function for the whole sample is 1.405, showing that farms are overusing inputs by 40.5%. Furthermore, technical efficiency has turned out to be highly correlated with *AEE*, showing a Pearson's correlation coefficient ranging from 0.47 to 0.67. Results are similar for every olive growing system considered.[14] Thus, we may confirm that in this case study, technical inefficiency is also a major source of eco-inefficiency. A positive relationship between efficiency improvements and environmental improvements in farming has also been found by other recent works. Among them, Mouron *et al.* (2006) for integrated fruit production in Swiss farms, Piot-Lepetit and Le Moing (2007) in the case of the French pig sector, Solís *et al.* (2009) for hillside farmers in El Salvador and Honduras, and Hoang and Rao (2010) for agricultural production in OECD countries.

Once *AEE* has been analysed, it is worth studying its decomposition into both program and managerial eco-efficiencies. Only in this way will it be possible to assess which share of eco-inefficiency is due to farms belonging to one particular system of olive farming (*PEE*), i.e. different endowments of natural resources, and which share is due to farmers' management (*MEE*). These results are summarized in Table 4, which displays both arithmetic and geometric means as central tendency statistics.

Insert Table 4 around here

Averages for *MEE* and *PEE* suggest, at first glance, that farmers' management is a more important source of eco-inefficiency in the three olive systems than differences in the availability of natural resources (means of *MEE* are larger than means of *PEE*).

[14] Results using technical efficiency scores computed under the assumption of constant returns to scale (*CRS*) are similar, with Pearson's correlation coefficient ranging in this case from 0.68 to 0.78.

However, it is difficult to compare both determinants of eco-efficiency in relative terms because of their multiplicative linkage. In order to facilitate comparability, expression (9) has been linearised by taking logarithms:

$$log\left(AEE\right) = log\left(MEE\right) + log\left(PEE\right) \quad (17)$$

The results are in Table 5 and show wide differences between olive systems. For traditional plain groves, managerial performance –*log(MEE)*– explains up to 99.5% of aggregate performance –*log*(*AEE*)–, while the availability of natural resources or program performance –*log(PEE)*– is an insignificant determinant of eco-inefficiency. Conversely, in traditional mountain groves the availability of natural resources is much more relevant, explaining 42.8% of aggregated eco-efficiency. Decomposition for irrigated intensive groves shows intermediate values.

Insert Table 5 around here

Let us now move to the assessment of program eco-efficiency by comparing the means of *PEE* scores among olive growing systems.[15] This comparison will allow us to assess which cultivation system frontier is closer, on average, to the joint or overall eco-efficient frontier, i.e. closer to the origin in terms of Figure 1. The averages of *PPE* for our three olive growing systems have been compared using an ANOVA test, results confirming that significant differences in *PEE* among them exist[16], i.e. the *average distances* between olive system frontiers and the joint frontier are statistically different. Results from the implementation of the Ryan-Einot-Gabriel-Welsch's F test demonstrate that traditional mountain groves have the highest significant mean value of *PEE* (1.398), followed by the irrigated intensive system (1.146) and, finally by traditional plain groves (1.003). In other words, the most eco-efficient frontier, i.e. closer to the joint frontier, is that of traditional plain olive farms; the frontier of irrigated intensive olive farms follows, while the least eco-efficient frontier belongs to that of traditional mountain groves.

These results could be seen as counterintuitive if they were to be analysed jointly with the figures in Table 1b, which show how traditional mountain groves have a relatively good environmental performance, presenting the best records for four out of our six pressure indicators. However, eco-efficiency is a relative measure of economic performance per unit of aggregate environmental pressure, and the traditional mountain olive system shows by far the lowest economic performance. It is

[15] It is worthwhile to highlight here that comparison of managerial eco-efficiency among growing olive systems is meaningless. The reason is that efficiency is a relative concept assessed with respect to a given sample of observations and a characterisation of the technology, and our DEA programs have been run separately for each olive growing system.

[16] The F-statistic for the ANOVA test is 130.54, with *p*-value of 0.000. Results from implementing the Kruskal-Wallis' test are similar.

easy, then, to understand the poorer economic-ecological performance of this olive growing system.

According to these findings, the traditional plain groves deserve a special and more favourable treatment in terms of support by policy-makers, as they score better in terms of eco-efficiency. Nevertheless, our eco-efficiency indicator only accounts for the relationship between economic and environmental performance, other social and territorial policy targets being ignored. Doubtless, if avoiding depopulation of the hilly areas of Andalusia, and the consequent further worsening of territorial imbalances within this region is also a matter of concern for public policy, supporting traditional mountain olive groves should be of higher priority.

4.2. Determinants of managerial eco-efficiency in olive farms

In this section we test some hypotheses about the factors affecting managerial eco-efficiency. In doing so, censored Tobit regression is used, considering *MEE* computed at the farm level as a dependant variable, and the variables regarding farmers' features and structural variables about farms' characteristics already mentioned as explanatory variables. As *MEE* has been separately computed for each olive farming system, the analysis of its determinants is also performed separately. The results are displayed in Table 6 and are in line with Picazo-Tadeo *et al.* (2011), which already pointed out that eco-efficiency can hardly be explained through traditional socio-structural features.

Insert Table 6 around here

Only land productivity (average yield) is a significant variable for the three systems analysed, showing that managerial eco-efficiency increases as the land productivity of the groves also rises. However, and given the positive sign of the coefficient for the square of average yield and its statistical significance, improvements of eco-efficiency are achieved at decreasing rates. This finding means that the intensification of olive farming can improve eco-efficiency because gains in economic performance (net income in our case) are relatively higher than increases in environmental pressures. However, this relationship only holds up to a certain level of intensification. Taking into account the coefficients estimated in our regressions, production levels that minimise *MEE* are 7,316 kg/ha in the case of traditional mountain groves, 9,490 kg/ha in traditional plain groves and 8,380 kg/ha in irrigated intensive groves.[17] Further intensification beyond this level would lead to a drop in eco-efficiency due to increased environmental pressures - overcoming gains in economic performance.

[17] Comparing these values with average yields shown in Table 2a, it can be observed that *MEE* optimising productivity levels are much higher. In fact, it can be pointed out that z-values (standardization) of these optimum values are 2.06, 2.28 and 1.56, respectively.

Other variables have proved to be statistically significant, but only for some olive growing systems. Farmers' age is significant for traditional mountain groves, confirming the hypothesis that eco-efficiency increases when farmers are younger. Variables regarding educational level also present some significant coefficients. However, in this case our initial hypothesis has been partially refuted. For the cases of traditional mountain and irrigated intensive groves, results obtained show that farmers with secondary studies (even primary studies in the case of irrigated intensive groves) are more eco-efficient than farmers with university studies (which is the category omitted in the regression). A similar conclusion was reached by Picazo-Tadeo *et al.* (2011) which explains this counterintuitive result by the fact that in their study most of the farmers holding university degrees had a degree not related with agricultural activities. Thus, higher education does not provide them with any special knowledge or training about farming. Moreover, for most of them, farming was just a secondary source of income, carried out in non-professional way. This explanation also fits for olive growing in Andalusia. Variables measuring farmers' professional training are only significant in the case of traditional mountain groves, where it is confirmed that olive growers with an official degree are more eco-efficient than those with specific knowledge obtained in agricultural extension courses.

Aside from the aforementioned relationships, none of the remaining variables seem to affect the eco-efficiency of olive farmers. These relatively poor results show that more research is needed in order to find out the determinants of eco-efficiency. In this sense, the consideration of farmers' psychological features (environmental concerns, agricultural vocation, etc.) could lead to more fertile outcomes.

Finally, we have analysed the influence of agricultural subsidies on *MEE*. For this purpose, we have just carried out a correlation analysis, as shown in Table 7. Results confirm that in the three olive systems, considered eco-efficiency and CAP's subsidies (farm single payments) are positive and significantly correlated. In fact, as demonstrated by Pearson's correlations, subsidies can explain between 54% to 70% of farms' eco-efficiency variability. In any case, affirming that subsidies are currently benefiting the more eco-efficient farms does not preclude the idea that other alternative criteria to assign subsidies to individual farmers could enhance farms' eco-efficiency in a more effective way.

Insert Table 7 around here

5. Conclusions and policy recommendations

In this paper, we assess the eco-efficiency of olive farming in the Southern Spanish region of Andalusia, the primary olive oil-producing region in the world. In doing so, we compute eco-efficiency scores at the farm level using Data Envelopment Analysis techniques and what we call pressure distance functions. Furthermore, a basic distinction has been made between managerial eco-efficiency and program eco-efficiency, the latter being due to the different natural conditions prevailing in the three main olive cultivation systems in the region, namely, traditional rain-fed mountain groves, traditional rain-fed plain groves and irrigated intensive groves.

Our main findings concerning the assessment of eco-efficiency are summarised as follows. First, eco-inefficient management is a widespread practice among Andalusian olive farmers. On average, the pressure on the environment exerted by the farms in our sample is 262% above the pressure that would correspond to a virtual eco-efficient farm enjoying the same level of net income. In addition, eco-inefficiency is highly correlated with lack of technical efficiency, which points to the existence of substantial room for improvement in the management of inputs as a way to attain both better economic returns and fewer environmental impacts. In other words, a win-win outcome can be expected from more efficient olive-growing management. Second, and concerning the distinction between managerial and program eco-efficiency, we find that managerial eco-inefficiency explains nearly one hundred per cent of the eco-inefficiency of olive farmers in traditional plain groves, while the availability of natural resources, or program eco-inefficiency, is much more relevant in explaining eco-inefficiency in traditional mountain groves. Specific handicaps of farms operating in hilly areas result in more costly mechanisation and lower yields.

In the third place, and where program eco-efficiency is concerned, traditional plain olive groves represent the most eco-efficient cultivation system, followed by the irrigated system, with the traditional rain fed mountain system in the last position. These results shed light on the important distinction between sustainability and eco-efficiency. Ecologically-minded experts have always pondered the advantages in terms of biodiversity protection of the traditional extensive olive cultivation system in the hilly areas of Andalusia. But eco-efficiency is meant to strike a balance between economic returns and environmental pressures and, accordingly, the inferior economic returns of mountain groves also enter the equation. Traditional plain groves simply offer a better trade-off between both types of concerns, economic and environmental, which is important from the point of view of agricultural policy, lessening the opportunity cost of promoting more environmentally-friendly olive production systems.

In the second part of our research, we have carried out an investigation into the determinants of eco-efficiency, finding that the only statistically significant variable for all three olive cultivation systems is land productivity. Other variables were found to be relevant only for some specific systems, such as age and farmers' professional training for mountain groves. In line with previous literature, our results here do not seem to shed much light on the determinants of eco-efficiency either. In consequence, it is difficult to design structural policy measures aiming at promoting more eco-efficient farms based on classical targeting criteria such as surface, dedication to farming activities or age. Alternatively, policy instruments focused on the promotion of concrete practices or technologies that could enhance eco-efficiency at farm level are recommended.

Finally, this research has shown how current CAP subsidies are positively correlated with managerial eco-efficiency. However, it is possible to imagine a better distribution of CAP payments beyond the farm single payment scheme based on the historical criteria implemented nowadays. One conservative alternative to achieve a more eco-efficient performance could be the maintenance of this scheme with a stricter implementation of conditionality. In this case, the payments should be *conditioned* to the implementation of more ecologically-friendly practices or technologies, e.g. the maintenance of vegetal cover to protect soil, the implementation of adequate farming routine (contouring or terracing), piling up pruning residues, amongst others. Another more ambitious possibility would be a new reassignment of agricultural subsidies among farmers directly dependent on the provision of environmental public goods, as is currently being debated for the next CAP reform to be implemented in 2013 (Cooper *et al.*, 2009). This means that CAP subsidies should be granted in exchange for concrete environmental externalities provided by farmers as a result of a more ecologically-concerned management.

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FIGURES AND TABLES

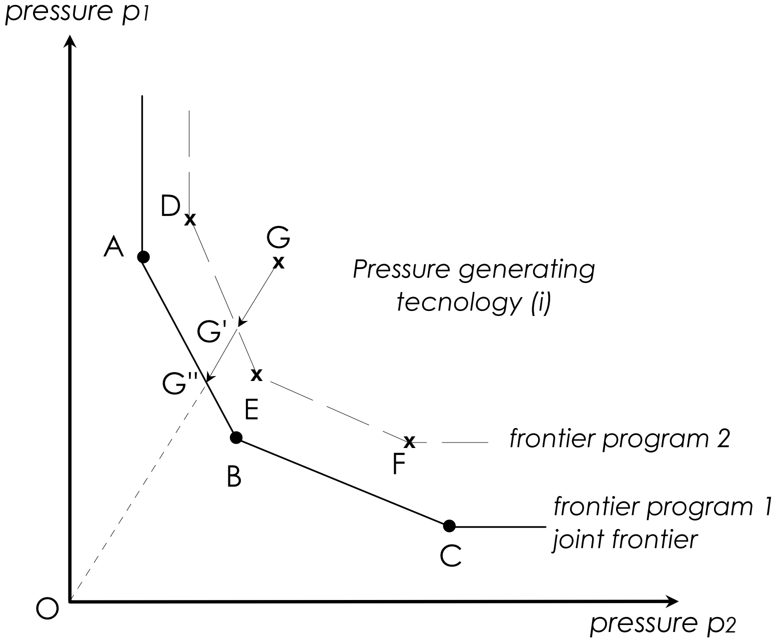

Fig. 1. Managerial and program eco-efficiency.

Table 1a

Variables for eco-efficiency assessment. Sample description for all farms.

	Mean	Standard deviation	Maximum	Minimum
NET INCOME (euros/ha)	841	537	3,013	100
ENVIRONMENTAL PRESSURES				
Erosion (tons/ha)	15.0	13.1	94.1	0.6
Biodiversity (adimensional)	0.434	0.215	1.000	0.194
Pesticides risk (kg rat/ha)	4,402	3,513	36,643	636
Water use (m^3/ha)	226	389	2,000	0
Nitrogen ratio (adimensional)	1.054	0.794	4.777	0.000
Energy ratio (adimensional)	0.265	0.133	0.818	0.021
NUMBER OF FARMS				292

Table 1b

Variables for eco-efficiency assessment. Sample description for the different production systems.

	Traditional mountain groves		Traditional plain groves		Irrigated intensive groves		ANOVA test [1]	
	Mean	SD	Mean	SD	Mean	SD	F-stat	*p*-value
NET INCOME (euros/ha)	701	440	891	634	933	476	5.16	0.006***
ENVIRONMENTAL PRESSURES								
Erosion (tons/ha)	27.1	15.0	8.9	6.5	9.2	6.1	104.23	0.000***
Biodiversity (adim.)	0.372	0.120	0.510	0.279	0.410	0.177	73.84	0.000***
Pesticides risk (kg rat/ha)	3,592	2,452	5,584	4,656	3,836	2,294	10.44	0.000***
Water use (m^3/ha)	0	0	0	0	750	329	528.74	0.000***
Nitrogen ratio (adim.)	1.260	0.679	0.987	0.894	0.912	0.741	5.16	0.006***
Energy ratio (adim.)	0.227	0.091	0.242	0.139	0.335	0.137	20.50	0.000***
NUMBER OF FARMS		96		108		88		

[1] The null hypothesis is that the three samples are drawn from the same population.

(*) Significance level $p<0.10$, (**) Significance level $p<0.05$, (***) Significance level $p<0.01$.

Table 2a

Farmers and farms features. Sample description for the different production systems (metric variables).

	All farms		Traditional mountain groves		Traditional plain groves		Irrigated intensive groves		ANOVA test [1]	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F-stat	*p*-value
FARMERS FEATURES										
Age (years)	50.5	11.2	49.0	11.2	52.3	11.9	49.9	10.1	2.3506	0.097*
Experience as olive growers (years)	24.8	14.2	24.3	14.8	25.3	15.1	24.8	12.3	0.1415	0.868
% time devoted to agric.	50.8	40.5	57.1	42.1	48.3	40.8	46.9	38.1	1.7838	0.170
FARMS FEATURES										
Farm surface (ha)	17.5	28.6	12.9	17.9	18.7	25.1	21.0	39.7	1.9888	0.139
Num. activities contracted-out	0.37	0.76	0.25	0.60	0.46	0.81	0.38	0.83	2.0209	0.134
Age of orchard (years)	115	110	140	107	108	116	96	101	4.1376	0.017**
Average yield (kg/ha)	5,245	1,752	4,419	1,406	5,151	1,903	6,263	1,358	30.9429	0.000***
Total labour (day/ha·year)	9.47	8.16	9.00	8.70	9.37	8.66	10.11	6.87	0.4335	0.649
% family labour	0.44	0.43	0.38	0.41	0.42	0.43	0.54	0.44	3.4984	0.032**
NUMBER OF FARMS		292		96		108		88		

[1] The null hypothesis is that the three samples are drawn from the same population.

(*) Significance level p<0.10, (**) Significance level p<0.05, (***) Significance level p<0.01.

Table 2b

Farmers and farms features. Sample description for the different production systems (categorical variables).

		All farms		Traditional mountain groves		Traditional plain groves		Irrigated intensive groves		Cross table test [1]	
		Absolute. Freq.	Relative Freq.	Absolute. Freq.	Relative Freq.	Absolute. Freq.	Relative Freq.	Absolute. Freq.	Relative Freq.	X^2-stat	*p*-value
FARMERS FEATURES											
Member cooperative	No	21	7.2	5	5.2	12	11.1	4	4.5	3.975	0.137
	Yes	271	92.8	91	94.8	96	88.9	84	95.5		
Educational level	School-leaving	76	26.0	27	28.1	28	25.9	21	23.9	12.232	0.057*
	Primary	134	45.9	44	45.8	45	41.7	45	51.1		
	Secondary	53	18.2	19	19.8	26	24.1	8	9.1		
	University	29	9.9	6	6.3	9	8.3	14	15.9		
Agricultural training	Family	184	63.0	62	64.6	65	60.2	57	64.8	2.042	0.728
	Agr. extension	100	34.2	30	31.3	41	38.0	29	33.0		
	Official degree	8	2.7	4	4.2	2	1.9	2	2.3		
FARMS FEATURES											
Located inside Denom. Origin	No	239	81.8	78	81.3	87	80.6	74	84.1	0.443	0.802
	Yes	53	18.2	18	18.8	21	19.4	14	15.9		
NUMBER OF FARMS			292		96		108		88		

[1] The null hypothesis is that the different farmers or farms features are associated with the olive systems of the farm.

(*) Significance level $p<0.10$, (**) Significance level $p<0.05$, (***) Significance level $p<0.01$.

Table 3

Estimates of aggregated eco-efficiency (AEE).

	Mean	Standard deviation	Maximum	Minimum
All farms	3.622	3.088	18.336	1.000
Traditional mountain groves	3.696	2.664	16.369	1.000
Traditional plain groves	3.829	3.562	18.336	1.000
Irrigated intensive groves	3.287	2.946	16.664	1.000

Table 4

Decomposition of aggregate eco-efficiency.

Olive system	Statistic	Aggregated eco-efficiency	Program eco-efficiency	Managerial eco-efficiency
Traditional mountain groves	Arithmetic mean	3.696	1.398	2.708
	Geometric mean	2.980	1.377	2.164
	Standard deviation	2.664	0.256	2.031
Traditional plain groves	Arithmetic mean	3.829	1.003	3.811
	Geometric mean	2.835	1.003	2.826
	Standard deviation	3.562	0.007	3.494
Irrigated intensive groves	Arithmetic mean	3.287	1.146	2.870
	Geometric mean	2.474	1.135	2.180
	Standard deviation	2.946	0.174	2.656

Table 5

Logarithmic decomposition of aggregate eco-efficiency.

	Traditional mountain groves	Traditional plain groves	Irrigated intensive groves
Mean log(*AEE*)	0.4743	0.4526	0.3934
% / log(*AEE*)	100.0%	100.0%	100.0%
Mean log(*MEE*)	0.3354	0.4512	0.3385
% / log(*AEE*)	57.2%	99.5%	76.9%
Mean log(*PEE*)	0.1389	0.0013	0.0549
% / log(AEE)	42.8%	0.5%	23.1%

Table 6

Results of Tobit regressions for second-stage analysis.

Independent variables	Traditional mountain groves			Traditional plain groves			Irrigated intensive groves		
	Coeff.	t	*p*-value	Coeff.	t	*p*-value	Coeff.	t	*p*-value
Constant	12.5229	5.61	0.000***	16.7778	4.82	0.000***	29.48116	7.15	0.000***
FARMERS FEATURES									
Age (years)	0.04307	1.78	0.080*	-0.02478	-0.78	0.439	-0.02222	-0.89	0.376
Experience as olive growers (years)	-0.03021	-1.65	0.102	0.01212	0.51	0.611	0.01876	0.96	0.341
% time devoted to agric	-0.00433	-1.12	0.265	-0.00607	-0.79	0.434	0.00629	1.22	0.228
Member cooperative (yes)	0.41176	0.61	0.546	1.55185	1.57	0.120	0.81587	0.92	0.361
Educ. Level: School-leaving	-0.31856	-0.46	0.647	-0.73941	-0.63	0.529	-0.70235	-1.02	0.313
Educ. Level: Primary	-0.51627	-0.78	0.438	0.40848	0.37	0.710	-1.27374	-2.15	0.035**
Educ. Level: Secondary	-1.36442	-1.93	0.057*	-0.61812	-0.54	0.591	-1.67430	-1.88	0.064*
Agricul. Training: Family	1.12791	1.30	0.197	0.38185	0.18	0.861	-1.83214	-1.44	0.154
Agricul. Training: Agr. extension	1.78680	1.98	0.052*	1.18003	0.55	0.582	-1.84971	-1.45	0.151
FARMS FEATURES									
Farm surface (ha)	-0.00441	-0.50	0.618	-0.00302	-0.26	0.799	0.00647	1.42	0.159
Num. activities contracted-out	-0.10659	-0.40	0.689	-0.50948	-1.35	0.179	-0.12328	-0.48	0.630
Age of orchard (years)	-0.00220	-1.51	0.135	-0.00163	-0.63	0.530	0.00105	0.54	0.590
Located inside Den. Origin (yes)	-0.10682	-0.26	0.795	-0.54412	-0.73	0.469	0.20506	0.38	0.702
Average yield (kg/ha)	-0.00394	-6.37	0.000***	-0.00366	-4.69	0.000***	-0.00652	-5.67	0.000***
(Average yield)^2 (kg^2/ha^2)	2.69e-07	4.57	0.000***	1.93e-07	3.08	0.003***	3.89e-07	4.21	0.000***
Total labour (day/ha·year)	-0.04286	-2.34	0.022**	-0.02821	-0.84	0.400	-0.01495	-0.55	0.586
% family labour	0.54075	1.34	0.186	0.09095	0.13	0.897	0.52118	1.09	0.280
NUMBER OF OBSERVATIONS			96			108			88
LR X^2 (p-value)			91.22 (0.000***)			68.02 (0.000***)			106.16 (0.000***)
PSEUDO R^2			0.2294			0.1229			0.2658

Dependent variable = *MEE*, the managerial eco-efficiency. Categories omitted, Educational Level: University; Agricultural training: Official degree.

(*) Significance level $p<0.10$, (**) Significance level $p<0.05$, (***) Significance level $p<0.01$.

Table 7

Correlation between Farms Single Payment and eco-efficiency.

	Traditional mountain groves	Traditional plain groves	Irrigated intensive groves
Pearson's correlation	-0.590	-0.545	-0.702
p-value	0.000***	0.000***	0.000***
Spearman's Rho	-0.787	-0.791	-0.815
p-value	0.000***	0.000***	0.000***
NUMBER OF FARMS	96	108	88

(*) Significance level $p<0.10$, (**) Significance level $p<0.05$, (***) Significance level $p<0.01$.