The inefficiency and production costs due to parcel fragmentation in olive orchards

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Jel classification: Q12, O13

Abstract

Olive trees in the Mediterranean countries comprise the most widespread fruit-tree crop. Spain, Italy and Greece, the three main producer countries in Europe, account for 65% of the total world production. The production structure of olive farms in these countries is mainly characterized by traditional small-scale management. In addition to a small size, these farms also have a highly fragmented structure, typically made of several scattered parcels. The fragmented structure hampers farm competitiveness by raising production costs. This leads to a progressive exclusion of these farms from international markets and eventually to land abandonment. Here, we quantify the inefficiency due to parcel fragmentation, in particular losses due to the border effect, and we propose farmers' cooperation as a measure to reduce such losses. The results indicate significantly lower efficiency due to parcel fragmentation. Currently, farmers are managing around 14.4% of olive orchards inefficiently relative to a comparable situation without fragmentation. The results call for specific agricultural policies that foster cooperation among farmers in order to reduce parcel fragmentation and production costs.

Keywords: *fragmentation, olive orchard, production costs.*

Résumé

Les Oliviers sont la culture fruitière la plus répandue dans les pays méditerranéens. L'Espagne, l'Italie et la Grèce, les trois principaux pays producteurs en Europe, représentent 65% de la production mondiale totale. Dans ces pays, la structure de production des oliveraies se caractérise principalement par les petites exploitations traditionnelles. Ces oliveraies ont également une structure très fragmentée, généralement composée de plusieurs parcelles dispersées. Cette fragmentation complique la compétitivité agricole tout en augmentant les coûts de production. Cela conduit à une exclusion progressive de ces exploitations sur les marchés internationaux et, finalement, à l'abandon des terres. Cet article met en évidence la baisse de rendement due à la fragmentation des parcelles, en particulier les pertes causées par "l'effet de bord"; on propose aussi la coopération entre les agriculteurs en tant que mesure visant à réduire ces pertes. Les résultats indiquent que l'efficacité est significativement plus faible en raison de la fragmentation parcellaire. Actuellement, environ 14,4% des oliveraires sont gerées par les agriculteurs et elles seraient plus rentables si les parecelles n'étaient pas fragmentées. Il serait donc nécessaire d'établir des politiques agricoles spécifiques qui favorisent la coopération entre les agriculteurs afin de réduire la fragmentation des parcelles et des coûts de production.

Mots-clés: fragmentation, oliveraie, coûts de production.

1. Introduction

Land fragmentation can be defined as a number of spatially separated parcels of land which are farmed as a single unit (King and Burton, 1982). This results from institutional, political, historical, and sociological factors over the time, which provoke the geographical scattering of the agricultural parcels. Land fragmentation is generally considered an impediment to efficient crop production, because it hampers agricultural mechanization, generates more intensive management with the corresponding costs for the extra time and fuel necessary to travel between parcels, and it reduces economic profits (Akkaya *et al.*, 2007, Chukwukere Austin *et al.*, 2012). On the other hand, studies also point to beneficial effects due to land fragmentation such as risk reduction through spatial dispersion (Blarel *et al.*, 1992) or improvements in landscape quality and farm biodiversity (Di Falco *et al.*, 2010).

The impact of land fragmentation on farms' performance has been studied under different approaches, among which the use of production function has been the most widely used (Blarel *et al.*; 1992; Hang *et al.*, 2007; Kawasaki, 2010). In these studies, land fragmentation is assumed to affect either production costs or production efficiency. Results indicate that fragmentation impedes efficient production, even when the benefits are explicitly taken into account (Kawasaki, 2010). Other studies have analysed the impact of land fragmentation on a set of farm-performance indicators related to production costs, yields, revenues, and efficiency scores. Latruffe and Piet (2014) regressed a set of 10 land-fragmentation descriptors referring to the number, size, shape, and distance between parcels, with the farm-performance indicators and found that land fragmentation raises production costs and lowers yields, revenue, profitability, and efficiency.

In the case of olive orchards, the information available on land fragmentation is scarce. Although it is well recognized that the production structure is typically very fragmented (European Commission, 2012a), no studies available have characterized the fragmentation within the olive-orchard sector and estimate the impact of fragmentation on production costs. For example, Eurostat (2015) reveals that the average farm size in the three main European olive-oil pro-

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ducers, Spain, Italy and Greece, is just 5.8, 1.8 and 1.5 ha, but does not provide any information concerning the production structure within the farms, such as the parcel numbers, size, shape, or their geographical distribution. In a similar vein, previous studies on crop-production costs do not take fragmentation into account, typically assuming labour times for homogeneous fields, normally of large dimensions, and without any impediment to machinery performance. The production-cost study by AEMO (Cubero and Penco, 2012) assumed a field type of 30 ha in pricing the mechanized labour by the companies providing services. Arbonés *et al.* (2014), in their study based on the technical-economic analysis of different olive-tree planting systems in semi-arid areas, assumed that there were no limitations to machinery use. Therefore, the results of these studies may diverge significantly from reality, since they are not based on the real conditions of olive-orchard fragmentation and territorial scatter of fields that make up the farms.

The economic situation of olive farms has significantly worsened over the last decade (European Commission, 2012a), leaving the traditional olive farms barely profitable and at abandonment risk without the subsidy of the Common Agricultural Policy (CAP). The last CAP reform, made within a context of budget reductions and redistribution, has reduced the support for olive farming, a typical highly-subsidized sector, making the continuity of traditional olive orchards even more precarious. In this context, improving farming performance is essential for the survival of traditional olive farms, and saving on production costs via the reduction of inefficiency due to parcel fragmentation may be a valuable option especially in areas where, for topographical and climatic limitations, no other alternatives are feasible in order to boost profitability, as for example irrigation or intensive cultivation (Sánchez Martínez and Gallego Simón, 2011).

In this study, we analyse the parcel fragmentation of the traditional olive orchards in the province of Jaen (Andalusia, Spain), in order to assess its impact on production costs. The analysis was made considering the production inefficiency resulting from land fragmentation in the management of the borders of the parcels. We did not consider the distances between parcels or between the plots and the farmsteads[1]. We defined this inefficiency as the "border-effect area". This concept quantifies the impact of mechanization on the borders of the parcel, where efficiency is lost because only the outer side of olive row is treated, while between rows the treatment can be applied to two rows of olive trees at once. Consequently, the efficiency of a management task at the border of an olive parcel is reduced by 50% relative to the efficiency of the same task in the centre of olive orchards. For a given size, farms with more parcels, i.e. more fragmented, have proportionally more borders than farms with fewer parcels and, as a consequence, greater inefficiency. By relating the inefficiency to the time farmers need to apply the field treatments, it is possible to translate the inefficiency into production costs. No available studies have made this analysis and thus the present paper aims to fill this gap.

This paper also analyses farmer cooperation as a means of reducing the impact of parcel fragmentation on farm profitability. Typically, to reduce parcel fragmentation, land-consolidation programs have been implemented, especially (but not exclusively) in less developed countries (Blarel *et al.*, 1992; Niroula and Thapa, 2005; Van Hung *et al.*, 2007; Kawasaki, 2010). The main aim of these programs was to enable farmers to amalgamate their fragmented parcels to introduce ostensibly better farming techniques and improve the competitiveness of their farms. Land-consolidation programmes require the re-allocation of parcels with substantial changes in land tenure according to the basic principle that all farmers must not be worse off after consolidation than before it. However, this is quite difficult to implement in practice, given that the assessment of property values is generally based on the natural productive capacity, while other issues concern the farmers' subjective value of their lands, such as the position relative to other parcels, available infrastructures, roads, farm buildings, and facilities. Intangible values may even be involved, such as the participation in the existing social network, inheritance details, and environmental issues. In the case of olive orchards, a perennial crop that would be costly to change and where the production varies greatly according to the alternating biological cycle of the olive tree (alternating seasons of heavy and light yield), olive variety, soil, and local climatic conditions, land consolidation is even harder to accomplish. Therefore, farmer cooperation, where no land tenure is changed and farmers enter in management arrangements only of their lands, offers an option to reduce land fragmentation.

The paper is organized as follows. Firstly, we describe the study area in terms of the economic, social, and environmental importance of the olive orchard and several aspects relative to the existing production structure. Next, we outline the methodology used for data analysis. Then we report the results and discuss implications for decision-making. We end the article with a set of conclusions.

2. Study Case

Andalusia (Spain) is the world leading olive-oil production region, with 75% of national olive-oil production and 62% of growing area (Mili *et al.*, 2013). With an area of more than 1.5 million ha, olive orchard is the characteristic agricultural crop of Andalusia per excellence. The study case focuses on the traditional olive orchards of the

[1] There is no source of information on rural paths at the province scale that enables a map to be drawn of isochrones between plots of a farm. The sources of information available lack exactitude (work scale), are partial (do not cover the entire study area), or do not separate the ownership of the lanes (public/private) and therefore the distance between plots cannot be modelled using existing roads.

province of Jaen, in Andalusia. In this province, the olive grove is by far the most important agricultural activity. Orchards cover 83.3% of the agricultural surface area, constituting approximately 26% of the total surface area of olive orchards in Spain (CES, 2011).

It is noteworthy that the olive-oil production in this province alone is larger than the olive-oil production in the other two most important production countries in the world, Italy and Greece. As such, the olive industry in this province has overwhelming economic, social, and environmental importance (Gomez Limón and Riesgo, 2012). In economic terms, olive orchard is the leading agricultural sector, representing 74% of the total agricultural production value. In addition, olive groves have been identified as "the social crop" for the significant impact it has on employment, generating the most jobs in the province (36,360 direct jobs, [CAPDR, 2015]). Traditional olive orchards have also been associated with high natural value agricultural systems, despite that the ecological value has diminished in recent decades due to the modernization of olive farming, resulting in olive monoculture systems in large areas of the province (Areal and Riesgo, 2014).

Semi-intensive and extensive olive-growing systems prevail in the province and are characterized by highly fragmented structure. The traditional olive orchard would be barely profitable if not for the common agricultural policy (CAP) subsidy from the European Union (Colombo *et al.*, 2015). Thus, improved performance by reducing production costs is essential for the survival of olive farms.

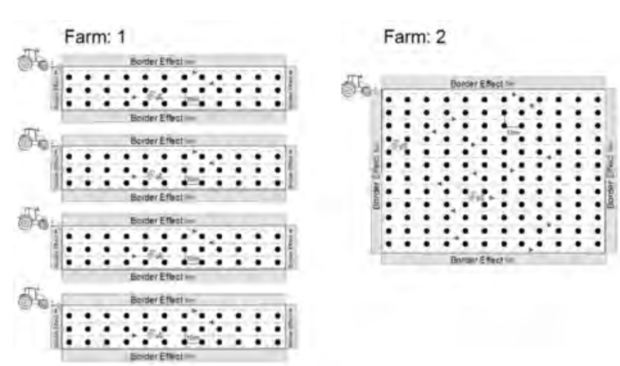
3. Methodology

Information about the olive-orchard parcels was taken from the shapefile of SIGPAC 2013. SIGPAC is the official government geographic information system which delineates the spatial configuration of the agricultural parcels in Spain. It provides the spatial details of all'"reference parcels", defining the minimum unit of cultivation, characterized by being a continuous land surface delimited geographically within a parcel having a single use. It was enforced by Council Regulation (EC) No 1593/2000 for the identification of agricultural parcels when carrying out administrative checks on areas declared by farmers. SIGPAC does not represent the real fragmentation structure of the agricultural parcels because it does not consider whether the reference parcels are adjacent or not, causing that a single large olive parcel is split into several reference parcels. Thus, starting from the reference parcels included in SIGPAC 2013, we joined all the olive parcels that belong to the same owner. These parcels, thus defined, constitute the true work units of labour and machinery on each farm, and therefore should be used to calculate the impact of land fragmentation. Additionally, given that we are interested only in the traditional olive orchards that can enter into farmers' cooperation arrangements, i.e. those that can be managed by means of a tractor and that share the same management, we included in the analyses only the parcels for which slope was lower than 25% and tree density was less than 200 trees per ha. Considering slope restriction, we filtered out the non-mechanizable olive orchards where no tractor could be used. For density restrictions, we removed the intensive orchards that had different management requirements. Thus, the traditional olive orchard considered in this study covers 78.5% of the olive-orchard area and is the most representative crop of the province.

Parcel fragmentation causes inefficiency due to the border effect because treatments using tractor-pulled equipment can be applied only to one side of the edge row of olive trees instead of two rows at once as inside the orchard. All parcels have borders, and therefore an intrinsic degree of inefficiency. Therefore, parcel fragmentation increases the inefficiency because farms with separated parcels have proportionally more borders than the same-sized farm having one or fewer separated parcels. As such, the border effect is directly related to land fragmentation. As an example, for demonstrative purposes, Figure 1 delineates the border effect for two identical-sized farms with different degrees of fragmentation. Of course, this effect only occurs in treatments that, within the olive orchard field, reach two rows of olive trees simultaneously, such as spraying for weed control, fertilizers, manure applications, and plant cover control. Although these are not all of the tasks, they represent the majority of the work undertaken by most farmers[2].

Figure 1 - *Examples of the border effect area for two identical sized farms with different parcel fragmentation.*

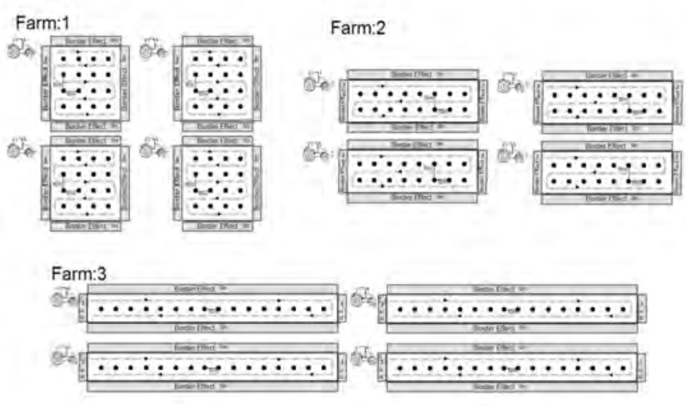
Graphs and Drawings:



The border effect also depends on the shape of the parcels. Squared parcels have a lower border effect than rectangular parcels, as the more elongated the shape, the higher the border effect (Figure 2). Thus, both parcel number and shape need to be considered when calculating the border effect.

[2] On average, a farmer carries out a total of 8-10 field tasks each year. Clearly, the number of tasks finally undertaken depends on the management system of each farm. In Andalusia, the most common management system is reduced tillage, followed by the use of plant covers and traditional management (ESYRCE, 2012).

Figure 2 - *Examples of the border effect area for two identical sized farms with the same number of parcels but different shapes.*



The inefficiency due to the border effect can be expressed quantitatively in terms of agricultural area managed inefficiently, by considering the area that is "lost" due to the impossibility of treating two olive rows at once along the perimeter of the parcels. Assuming a typical planting frame of 10 * 10[3], in the inner lines of the olive trees, a farmer treats 10 square meters of the olive orchard per meter travelled with the tractor, while in the outer line just 5 square meters are treated. As such, for each agricultural parcel, the area lost due to the border effect can be calculated as follows:

$$BEA_j = \left(\frac{M}{2}\right) * P_j \qquad [1]$$

where BEA_j is the border effect area of parcel *j*, M is the planting scheme, and P is the perimeter of the parcel.

Given the specific parcel-fragmentation structure of each farm, the BEA of farm *i* can be calculated by adding together the BEA_j of the J parcels making up the farm:

$$BEA_i = \sum_j^J BEA_{ji} \qquad [2]$$

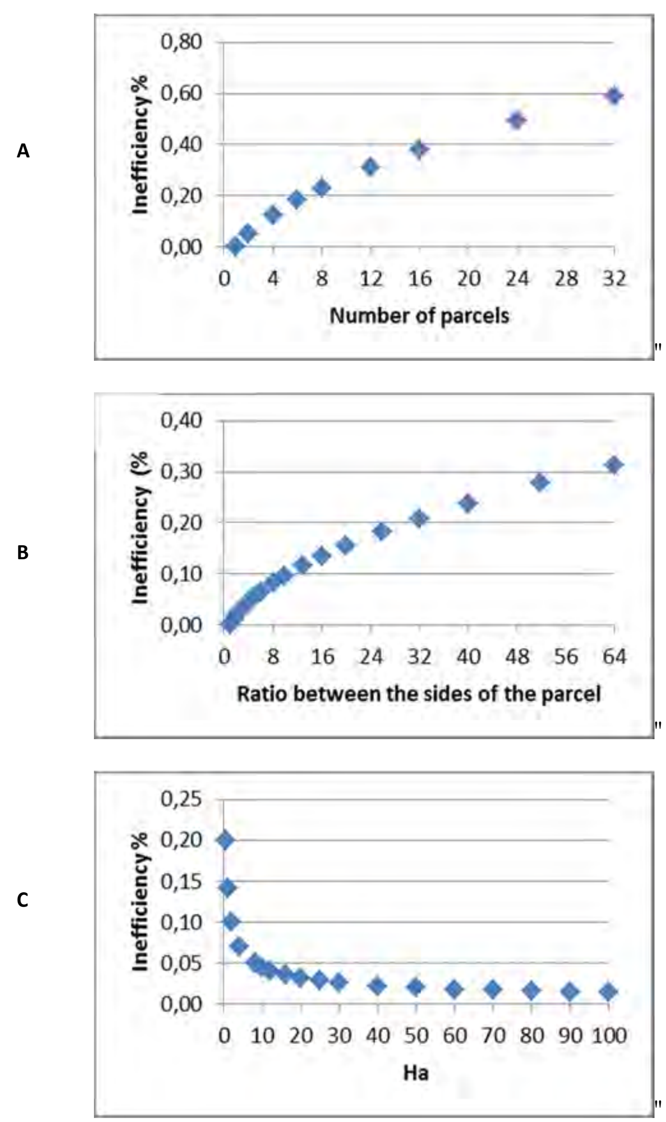
The BEA calculated following Eq. 2 describes the area that a farmer manages inefficiently due to the borders of his parcels. This is an absolute value for each farm which is not comparable among farms because it does consider neither the farm area nor the fact that all farms, even non-fragmented ones, have borders and thus an intrinsic BEA that should not be taken into account when calculating the BEA due to fragmentation. To estimate the loss of efficiency due to parcel fragmentation in a comparable way among farms, we need to calculate the BEA that is managed inefficiently relative to total area of the farm, considering at the same time that non-fragmented square farms have not any BEA managed inefficiently. This is done by subtracting from the BEA of farm *i* (Eq. 2) the BEA of a hypothetical "optimal farm" of the same size and dividing the results by the farm area. For optimal farm, we consider a farm that is no fragmented and is composed by a single square parcel. For each farm, an estimate of the area lost (inefficiency) due to land fragmentation (Eq. 3) is represented by the expression

$$I_i = \frac{BEA_i - BEA_{NFi}}{A_i} * 100 \qquad [3]$$

where BEA_{NFi} is the border effect area of farm *i* in the ideal non-fragmented case, BEA_i is the border effect area for the same farm in the real situation, and A_i is the total area of the farm. As can be seen, when farm *i* is made up of just a single square parcel, the inefficiency is equal to 0.

The inefficiency from the border effect depends on the

Figure 3 - *Inefficiency due to the border effect as a function of number of parcel (Fig. A), ratio between sides (Fig. B), and farm size (Fig. C).*



[3] In the province of Jaén the typical tree density per ha is 100, which corresponds to a planting scheme of 10 x 10.

area, shape, and number of parcels making up a farm. Figure 3 shows the inefficiency resulting from three hypothetical cases where we vary these structural farm characteristics. In particular, Figure 3.a, with constant farm size (5 ha) and the shape (rectangular with border 1 = 2* border 2), shows the inefficiency on varying the number of parcels. Figure 3.b, with constant parcel size (5 ha) and number (1), indicates the inefficiency by varying the parcel shape, assuming a rectangular form. Finally, Figure 3.c presents the inefficiency on varying the farm size but keeping constant the number of parcels (1) and the shape (rectangular with border 1 = 2* border 2).

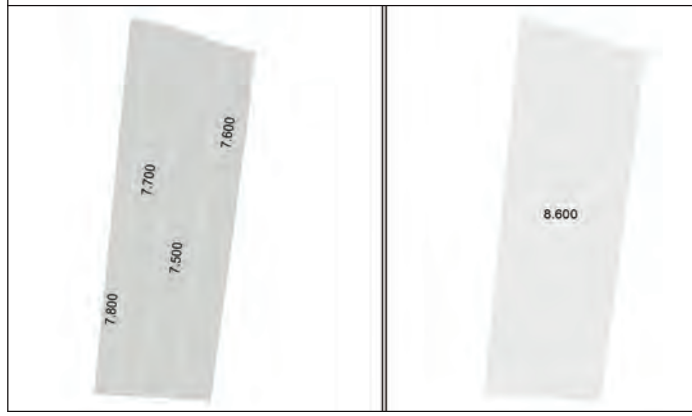
As can be seen, the inefficiency rises rapidly when the number of the parcels increases, reaching very high values when the number of parcels is higher than six. Under these conditions, the higher proportion of the border relative to the total area causes farmers an efficiency loss of more than 20% of the land in their management operations. The same happens, although to a lesser extent, when the parcels are more elongated. Rectangular parcels in which the longest side is more than 10 times the shortest cause an inefficiency of 10%. All else being equal, the larger the farm the lower the inefficiency, given the lower weight of the borders relative to the total area of the parcel.

The value of inefficiency estimated in Eq. 3 corresponds to the "overall" effect of land fragmentation and is relative to the ideal case in which all agricultural parcels belonging to a farm can be joined to form a large square parcel. Clearly, this is not possible in practice where only the adjacent parcels can be joined to reduce the inefficiency due to the border effect, and the shape of the resulting agglomerate of parcels may differ from a square. Assuming that all farmers that share a common border cooperate such that the adjacent parcels form an aggregate of parcels[4], we can calculate the increase of the efficiency due to the reduction of the border effect via farmers' cooperation by comparing the BEA of the *k* parcels which belong to the agglomerate *K*, with the BEA of the agglomerate *K*. The resulting efficiency gain (EG) is given by the following formula,

$$EG_k = \frac{\sum_{J=1}^{J} BEA_J - BEA_K}{A_k} * 100 \quad [4]$$

where A_k is the area of the agglomerate K and the other terms have been defined previously. Figure 4 shows an example of the aggregation process taken from the study area, where we form an aggregate from four parcels that belong to four different farmers. As can be seen, the efficiency gain

Figure 4 - *BEA (in square metres) of single and agglomerate of parcels resulting from joining the adjacent borders. Area of the agglomerate: 7.6 ha. Efficiency gain: 29%.*



is highly significant (29%) given that the agglomerate reduces the number of parcels and increases the area (rendering it more squarish) in relation to the perimeter.

To translate the inefficiency value into production costs requires calculating the time farmers loose in their treatments for the inefficiency due to the border effect and quantifying it in monetary terms. According to data of the Spanish Ministry of Agricultural Food and Environment (MARM, 2008), the time needed to manage one ha of traditional olive orchard is 206.5 hours per year. Out of this time, the field operations affected by the border effects require an average of 33 hours $ha^{-1}y^{-1}$ (MARM, 2008)[5]. Thus, a 1% of inefficiency due to the border effect causes the farmer to employ almost 0.33 hours more per ha y^{-1} in field operations. This time can be converted into production costs considering an average wage of 9.85 €/hour for the tractor driver and 10.91 €/hour for tractor utilization (Márquez, 2007). Using these values, it results that each 1% of inefficiency due to the border effect costs around 6.85 € ha^{-1} y^{-1} to farmers.

4. Results

The province of Jaén has a total of 460,614 "reference" parcels of traditional olive orchards which occupy an area of 448,831 ha. The joining of the adjacent parcels which belong to the same owner provides a total of 261,450 parcels of traditional olive orchards. The area of the smallest parcel is only 0.04 ha while the largest is 350 ha. Table 1 shows that the distribution of the olive parcels is positively skewed, with the mass of the distribution concentrated on the left. That is, 63% of the parcels have less than 1 ha, with an average of 0.5 ha in this group. About 94% of the parcels have less than 5 ha and extend over more than half of the total olive-orchard area of the province. On the other hand, there are less than 400 parcels larger than 50 ha.

In total, there are 84,788 farms, of which 36% show no fragmentation, being composed of only one parcel. The rest has different degrees of fragmentation with the majority made up of 2 to 4 parcels for an average of 4.3 parcels. The most fragmented farm had 101 parcels, though farms with

[4] The resulting aggregates represent spaces of olive orchards internally homogeneous with the same management operations. They are separated from other aggregates by roads, rivers or other physical boundaries.

[5] We include the time needed for 3 treatments for pest control, 1 fertilizer application, 1 treatment for weed control using herbicides, and 2 treatments by cultivation methods such as hoeing, cultivating, or using weeding tools.

Table 1 - *Structure of olive-orchard parcels in Jaén province (Spain).*

Size (ha)	Parcels N.	%	Average surface area (ha)	Accumulated surface area (ha)	%
0 – 1	164,526	62.93	0.48	79,896	17.80
1.01 – 5	81,576	31.21	2.02	164,975	36.76
5.01 – 10	9,103	3.49	6.87	62,564	13.94
10.01 – 15	2,764	1.05	12.12	33,515	7.47
15.01 – 20	1,253	0.47	17.16	21,506	4.79
20.01 – 50	1,832	0.70	29.52	54,081	12.05
50.01 – 100	314	0.12	66.15	20,772	4.63
>100	82	0.03	140.84	11,519	2.56
Total	**261,450**	**100**		**448,831**	**100**

more than 10 parcels made up just 3.4% of the total. Table 2 summarizes the distribution of these parcels according to the number of parcels comprising a farm.

The inefficiency due to the border effect in a specific farm of the province of Jaen would be the result of the inefficiency values of its parcels' composition and characteristics, namely number, shape, and size. Overall, the fact that the olive farms of Jaen province are characteristically small, fragmented, and irregularly shaped implies significant inefficiency due to parcel fragmentation. Specifically, the 84,788 farms contain 261,450 parcels, and of these, only 6% (5256) show no marginal inefficiency due to border effect, being an ideal square parcel. The rest of the farms show different degrees of inefficiency, which average 14.4%. According to an average cost 6.85 € ha^{-1} y^{-1} for each 1% of inefficiency, the average impact of land fragmentation on production costs is 98.6 € ha^{-1} y^{-1}. Considering that the mean production costs of the traditional rainfed olive orchard is 1513 €/ha and 2262 €/ha for the irrigated one (Cubero and Penco, 2012), we find that land fragmentation causes a significant rise in production costs, i.e. a 6.5% and 4.4% higher costs for the rainfed and irrigated olive orchards, respectively. Table 3 shows the distribution of inefficiency due to the border effect for all the farms of the study area and the associated production costs.

Table 2 - *Number of olive-orchard parcels in the farms of the study area.*

N. Parcels	N Farms (abs.)	N Farms (%)	Area (ha)	Area (%)
1	30816	36	53932	12
2-4	38010	45	156158	35
5-7	10004	12	95913	21
8-10	3257	4	52457	12
11-15	1790	2	45386	10
16-20	544	1	22167	5
>21	367	0.4	22819	5
Total	**84788**	**100**	**448831**	**100**

Table 3 - *Inefficiency due to the border effect and its production cost.*

Inefficiency (%)	Number of farms	Cost (€ ha^{-1} y^{-1})
I=0	5256	0
I <5	7935	0.1 – 34.2
5 ≥ I < 10	20755	34.3 - 68.4
10 ≥ I < 15	21333	68.5 – 102.7
15 ≥ I < 20	14044	102.8 – 136.9
I >20	15465	> 137.0

From Table 3 it is worth noting that a significant proportion of farms (18%) have more than 20% inefficiency. This means that the impact of the inefficiency due to the border effect raises the production costs of these farms by more than 9% in the case of rainfed olive orchards and 6% for the irrigated ones. In practice, these values are even greater due to the time that farmers need to move around their parcels. This time can become highly significant when the number of parcels is high and the distance between them large.

The inefficiency calculated above gives the economic cost that farmers currently bear due to their specific farm fragmentation. It represents the results of an ideal consolidation programme that agglomerates all the agricultural parcels of each farm into a square. As pointed out, it is a theoretical value which summarizes the impact of land fragmentation on production costs. However, in practical terms, under the assumption of no changes in land tenure, the maximum reduction in inefficiency due to the border effect can be achieved if all the farmers cooperate in the management of their adjacent parcels. The analysis of the resulting aggregates reveals that out of 261,450 parcels only 16,260 (6% of the total area) have no neighbouring parcels, and thus cannot benefit from a reduction of the border effect by cooperation. The rest of parcels form a total of 15,689 aggregates, with an average size of 26.8 ha, where cooperation can reduce the inefficiency due to parcel fragmentation (Figure 4).

Table 4 shows the frequencies of the agglomerates of parcels according to the number of farmers and parcels that make up the agglomeration. As can be seen, the majority of the aggregates are composed of a reduced number of farmers and parcels. In fact, more than half of the aggregates are made up of less than four parcels and farmers. In this situation, farmer cooperation should be relatively easy to implement. On the other hand, around a quarter of the aggregate is formed by more than 10 parcels or farmers. Here, farmer cooperation would be more difficult to implement and would involve larger transaction costs. The last column of Table 4 lists the average efficiency gain resulting from joining the adjacent olive groves parcels into the K aggregates as in Eq. 4. As expected, the efficiency gain is larger when more parcels are joined in the aggregate. It bears mentioning that the joining

Table 4 - *Frequency of the aggregate according to the number of parcels and number of farmers that belong to the aggregate.*

N	Number of agglomerates with N farmers	Cumulative frequency	Number of agglomerates with N parcels	Cumulative frequency	Average Efficiency Gain (EG_k %)
2	4333	27,6	4186	26,7	7.1
3	2335	42,5	2264	41,1	9.3
4	1470	51,9	1485	50,6	10.5
5	1023	58,4	981	56,8	11.2
6	772	63,3	780	61,8	11.9
7	536	66,7	540	65,2	11.9
8	451	69,6	439	68,0	12.7
9	419	72,3	375	70,4	12.4
10	344	74,5	370	72,8	13.6
>10	4006	100	4269	100	15.0

of just 4 (small) parcels represents an efficiency gain of more than 10%, for an average saving of 72 € ha^{-1} y^1.

Table 4 also indicates a strong similarity between the number of parcels and the number of farmers in the aggregates (columns 2 and 4). This means that a large majority of farmers has just one parcel in each aggregate. As the average number of parcel is 4.3, the olive groves parcels belonging to a farm are highly scattered throughout the territory. Thus, a farmer wishing to reduce the fragmentation of all parcels owned would need to cooperate with different groups of farmers in the common management, and this could hinder the practical implementation of the cooperation, which would require specific incentive policies.

5. Discussion

At the European scale, the size of the basic unit of farm production is small or very small. In 51% of the countries of the European Union, farms covering less than 2 ha exceed 25% of agricultural land. In Europe, 69% of the farms have a surface smaller than 5 ha and only 2.7% exceed 100 ha (European Commission, 2013). Olive cultivation is no exception to this rule and shows a production structure typically formed by small agricultural holdings. In addition to the small size, these holdings typically have a large degree of spatial fragmentation into scattered parcels. In Spain, this structure of land ownership is due partly to a process of splitting up farm property, which began in the 16th century and reached its height in the 19th century with the civil and ecclesiastical disentailment, on the one hand, and the breaking of the majorat system by the Liberal Reform, on the other (Alía and Del Valle, 2004).

[6] FADN (Farm Accountancy Data Network) is a European system of sample surveys that take place each year and collect structural and accountancy data relating to farms. The aim is to monitor the income and business activities of agricultural holdings and to provide representative data in three dimensions: by region, economic size, and type of farming.

Land fragmentation may have significant impact on production costs because farmers have to move from one agricultural parcel to another and because the efficiency of some management tasks decreases along the border of the parcels. In this study, we analyse the impact of the latter cause, leaving the quantification of the former to future research. We found significant production inefficiency due to land fragmentation, which caused inefficient management of around 14.4% of land relative to the ideal case of no fragmentation. This inefficiency translates as a significant increase in production costs, reducing the competitiveness of fragmented farms.

The study focuses on the province of Jaén, the world-leading province in olive-oil production. However, the proposed methodology is fully transferable to other sites and crop systems. In the case of olive orchards, we expect that in the other main producer countries, Italy and Greece, the inefficiency due to land fragmentation may be even more severe, because amongst the three main world olive-oil producers, Spain is the country where farms are on average larger and possibly less fragmented than elsewhere (European Commission, 2012b). In the case of other perennial crops, as for instance pistachios and almond, we expect comparable results given the similar production structure. However, future research should be undertaken to determine the final impact of the border effect on production costs in these crops.

The inefficiency due to parcel fragmentation is proportional to the shape, number and size of the parcels that belong to a farm. Thus, to reduce inefficiency, either the area of the farm must increase (reducing the number of parcels), or the shape needs to be squared as much as possible. Land-consolidation programmes have been used for these purposes in several countries, but they require modifications of the production structure such as land reparcelling and tenure changes, which are difficult to implement in the case of olive orchards. Farmer cooperation may be a viable alternative to reduce the inefficiency due fragmentation while maintaining the current production structure and land tenancy.

Farmer cooperation can take two main forms, namely shared cultivation and assisted cultivation. Shared cultivation should be defined as the activity of a group of farmers who cooperate in the care of their orchards using means in common. In assisted cultivation, owners turn over the management of their olive orchards to an entity with the necessary human, technological, and mechanical resources for professional farming. Both approaches increase the homogeneity in the cultivated surface area and reduce land fragmentation. In the study area, the cooperation between a small number of farmers who share any border of their parcels would significantly lower production costs. In the clusters formed by 4 parcels the average gain is 72 € ha^{-1} y^{-1}, corresponding to a 4.7% saving on production costs in the case of rainfed olive orchards.

Farmer cooperation, by increasing the average size of the agricultural parcels, also creates economies of scale that have proved significant in reducing production costs. According to the EU report on olive-oil farms based on FADN data[6], high income can be related to large olive orchards. This is particularly true in Spain, where farms with higher income are on average three-fold larger than the national average (European Commission, 2012b). The main reason is the greater labour productivity due to the mechanization of the harvest of olives. In the study area, the aggregates that result from the joining of the adjacent parcels have an average size of 26.7 ha, which is significantly greater than 1.7 ha of average size of the parcels which form the aggregates. Thus, the effect of economies of scale is also expected to be significant and should be investigated in future research.

Additionally, farmer cooperation has the potential to improve other matters related to production, such as input supply, marketing, and credit provision. Although parts of these matters are already covered by well-designed marketing and credit cooperatives, farmer cooperation has the potential to offer improvements. This is because such cooperation implicitly creates social capital[7] that would help improve coordination and the transmission of information and knowledge, contributing to reduced operational costs and also to uphold farmers' involvement in the cooperation (Jones *et al.*, 2009). Along the same line, farmer cooperation can improve rental market systems for specialized services, possibly organized by farmers themselves.

Farmer cooperation also has the potential to improve the environmental performance of farming, a cornerstone of the current and future CAP. Fragmented parcels and properties are obstacles to undertake territorial planning, as well as to improve environmental management. This is because the ecological processes take place at landscape-scale and, consequently, the policies aimed at avoiding ecological damage or biodiversity conservation cannot be designed at the individual level, but rather need joint effort among farmers. Making agriculture more economically viable for the future whilst at the same time restoring and maintaining natural capital should be core functions of agriculture beyond 2020 and reflected in the objectives of the forthcoming CAP (IEEP, 2014).

On the other hand, cooperation involves additional transaction costs which should be adequately compensated. This compensation should cover not only the costs borne by farmers in drawing up a cooperation plan and the associated operational costs, but also should reward farmers for the time and effort necessary to organize the networking and other activities related to improving the social capital. In this context, policies that aim to foster cooperation should include measures for training, testing activities, and disseminating results through demonstrative actions. The presence of a technical adviser who serves as a reference for all members to address the farmer's potential doubts should also be promoted. Rocamora *et al.*, (2014) found the latter a principal condition to improve the likelihood of olive farmers to cooperate.

The current rural development policy framework explicitly favours collective actions to enhance the economic, social and environmental performance of agricultural activity. Article 35 of the European Rural Development Regulation (European Parliament and the Council of the EU, 2013) specifically includes measures focused on supporting co-operative approaches. Among the costs covered, it supports farmer organizations, networking between members, and the recruitment of new members. In addition, it offsets the running cost of cooperation. These measures have been widely adopted in the current rural-development program of Andalusia (Junta de Andalucía, 2015) which incorporates measures aimed at supporting both the creation and the functioning of farmer groups and at providing the technical assistance to them.

Finally, we should mention several limitations of this study. First, the results refer only to the traditional olive orchard that can be mechanized. The impact of parcel fragmentation in the production costs of mountainous or non-mechanizable olive orchards are not identifiable with the methodology proposed. Second, we have not considered the dispersion of the parcels in the territory and as a consequence did not account for the time and costs farmers have to bear in order to move around their parcels. Third, the values of inefficiency have been calculated assuming a scenario of perfect cooperation between farmers. However, it is likely that some farmers will be unwilling to cooperate, and the exclusion of parcels from the aggregate will decrease the efficiency gained by joining the parcels. Finally, the generalization of this study to other areas or countries requires the prior characterization of the olive orchards at the parcel level. In the European Union, this task is straightforward because of common geographic information systems used for the payment and control of the aids to olive-oil production (Council regulation (EC) 1593/2000). However, for other countries this high level of information may be not available.

6. Conclusions

The production structure of traditional olive orchards in the Mediterranean countries is highly fragmented. Land fragmentation significantly raises production costs and lowers farm competitiveness.

In a context of continuous reduction of CAP support and intensifying international competition, it is necessary to find alternative production options that promote savings in production costs. Farmers' cooperation, as a way to reduce parcels fragmentation and in turn production costs, is a valuable alternative for this purpose.

At the same time, in line with the objectives of the forthcoming CAP midterm review and the next 2020 reform, there is a need of promoting farming systems that are in tune with environmental and social demands in Europe. Farmers' cooperation in olive groves may contribute to a greener olive farming, permitting agri-environmental and climate measures to be implemented on a wider scale.

Specific policies are needed to promote farmers' cooperation. These policies should have explicit financial aids to promote the creation of farmers' networking and social capital in addition to cover the running costs of cooperation.

[7] Social capital comprises the networks, shared norms, values, and understandings that facilitate cooperation within or among groups (OECD, 2001).

Acknowledgements

This research was financed by project P11-AGR-7515 funded by Andalusian Council of Economy Innovation, Science, and Employment (CEICE) and the Spanish Ministry of Economics and Competitiveness.

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