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Article

Assessment of Land Consolidation Processes from an Environmental Approach: Considerations Related to the Type of Intervention and the Structure of Farms

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Abstract: The process of Land Consolidation (LC) is deemed an important instrument of rural development in many countries, where it contributes to the economic development and viability of their rural areas. This paper aims to analyze three areas of Castilla y León in Northwestern Spain, all having similar agronomic features. The above areas have recently undergone LC processes. This research proves LC can contribute to reducing greenhouse gases (GHG) using the rationalization introduced in the layout of the agrarian exploitations. For this purpose, this paper analyzes the effects of LC actions on the size, shape, and level of scattering of the owners affected and compares the energy consumption in every journey from the exploitation to each plot, as well as the number of row-end turnings within the plots. GHG reductions present significant differences depending on the LC technique carried out, the size of the area consolidated, and the different degrees of intensification of agricultural exploitations. Through the three LC projects analyzed, a reduction in GHG emissions of 23.60% in SA1, 11.46% in SA2, and 9.85% in SA3 would have been obtained. In total, 1067.34 t CO_2 of GHG emissions would have been mitigated. In the light of the results obtained, LC can be considered an efficient process in the strategy of GHG reduction, all in line with the current commitments derived from the Paris Agreement. It is also necessary to continue to research the structure and importance of the consumption of fossil fuels in farming and its possible link to emission reduction policies.

Keywords: greenhouse gases; mitigation; emission reduction; fossil fuels; land consolidation; Castilla and León

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1. Introduction

The Paris Agreement achieved in December 2015 laid down the norms for GHG emission reduction as of December 2020, when the Kyoto Protocol expired. The Paris Agreement aims to keep the increase in the planet's mean temperature below 2 °C in 2100 and encourage additional efforts to limit such increase to 1.5 °C above the preindustrial levels. In November 2021, at the 26th UN Conference on Climate Change (Glasgow, UK), the commitment to reduce CO_2 emissions by 45% by 2030 [1] was assumed. These goals involve a coordinated global effort and the development of new technologies and strategies to reduce CO_2 emissions into the atmosphere. Farming significantly contributes to GHG global emissions through the production and the use of fertilizers, agrochemicals, and machinery [2,3]. Such emissions, mainly nitrous oxide (N_2O) and methane (CH_4), represented 10.30% of the total emissions in the EU-27, U.K., and Iceland, 6.2% in the U.S. [4], and about 10–12% of the world's emissions [5].

Various studies (see reviews [4,6–8] and papers [9–16]) have analyzed the possibility of reducing GHG emissions in farming activities, mainly focusing on working-reduction methods, fertilizer application methods, and land-use change. It can also be inferred from these studies the need to implement suitable GHG emissions assessment systems or the expected reductions, especially in transportation and journeys within the farm, whose value could be regarded as insufficiently assessed [14–16]. The studies focused on estimating the energy use in farming systems do not usually disaggregate the amount of fuel consumed in the journeys between the farm and the plots to supply raw materials, perform farming operations, or transport the harvest [17,18]. On occasions, distance mean values are used [19–22]. In the E.U., the 2030 energy and climate framework set goals for GHG emissions, including emissions and absorptions from agriculture and LULUCF [23]. According to De Cara et al. [24], farming can play a crucial role in fulfilling the global goal of GHG emission reduction. Nevertheless, the most suitable mitigation options require coherent information on their mitigation potentials and the related costs [13].

In this context of reduction of fossil fuel consumption in the agricultural sector, Land Consolidation (LC) could be a contributory tool. LC has a highly spatial establishment in Europe, as well as abundant regulatory development and expertise. Such a process, with its various variants and level of integration in other territorial policies, is also applied in multiple non-European countries [25–28].

In Spain, the process of LC has been, since its outset, an instrument of the planification of the sector, mainly agrarian, barely integrated into sectorial planning policies [25]. The competence of LC planning and execution lies in the Autonomous Communities.

In Castilla y León, LC is regulated by Laws 14/1990 [29] and 1/2014 [30]. LC also involves agrarian infrastructure works, which will grant access to the new plots and improve the quality and quickness of the journeys from the exploitation to the plots [31]. When it comes to plowed land, LC is finished or in progress on 96.8% of its surface [32].

The goal and methodology of LC are influenced by the specific conditions of the various countries and regions, their history and more recent policies, and their natural conditions [25,26,33,34]. LC is deemed an important instrument for modernizing agriculture and rural development [21,22,26,35–42].

In various studies, new methodologies based on computational algorithms are developed to improve the technical efficacy of the LCP [39,43–46] or new various metrical indexes, including the shape, size, and scattering of the plots [32,35,39,44,47]. It also analyzed the impact of these factors on the gross margins of the exploitations involved [21,22,30]. Recent research has also explored the potential of LC in mitigating GHG emissions, either with a theoretical approach [35,36,46–48] or focusing on other sectors, such as forestry [42], or in contexts quite different from the EU-27 [28,40,49].

Unlike some of the above-mentioned studies, this paper focuses on the analysis of actual implemented cases (3 LCP, 6 municipal areas, 23,026 ha, and 84 agricultural holdings) and is aimed at proving how LC can contribute to the reduction of GHG emissions taking advantage of the rational layout of the agricultural exploitations, using the increase in size and regular shape of their plots the lower scattering, as well as the improvement in the journeys(distance, time, quality) as a result of the new network of paths and annexed works in the LC. To reach this goal, we compared the energy used in the journeys from the farm to each plot modification of the number of row-end turnings within the plot prior to and after the LC in three areas with different sizes, diverse levels of scattering, and different degree of intensification.

2. Materials and Methods

2.1. Study Areas

The study areas are three Land Consolidation Projects (LCP) recently conducted in Castilla and León (NW Spain): Langayo (province of Valladolid) identified as SA1; Boadilla de Rioseco (province of Palencia), Villalón de Campos, Herrín de Campos and Villafrades de Campos (province of Valladolid) identified as SA2; Villagarcía de Campos (province of Valladolid) as SA3 (Figure 1). The surface of the three LCP total 23,026.24 ha. The three areas are located on a sedimentary basin of River Duero. The first of which is located on a moorland while the other two are located in the countryside area called "Tierra de Campos".

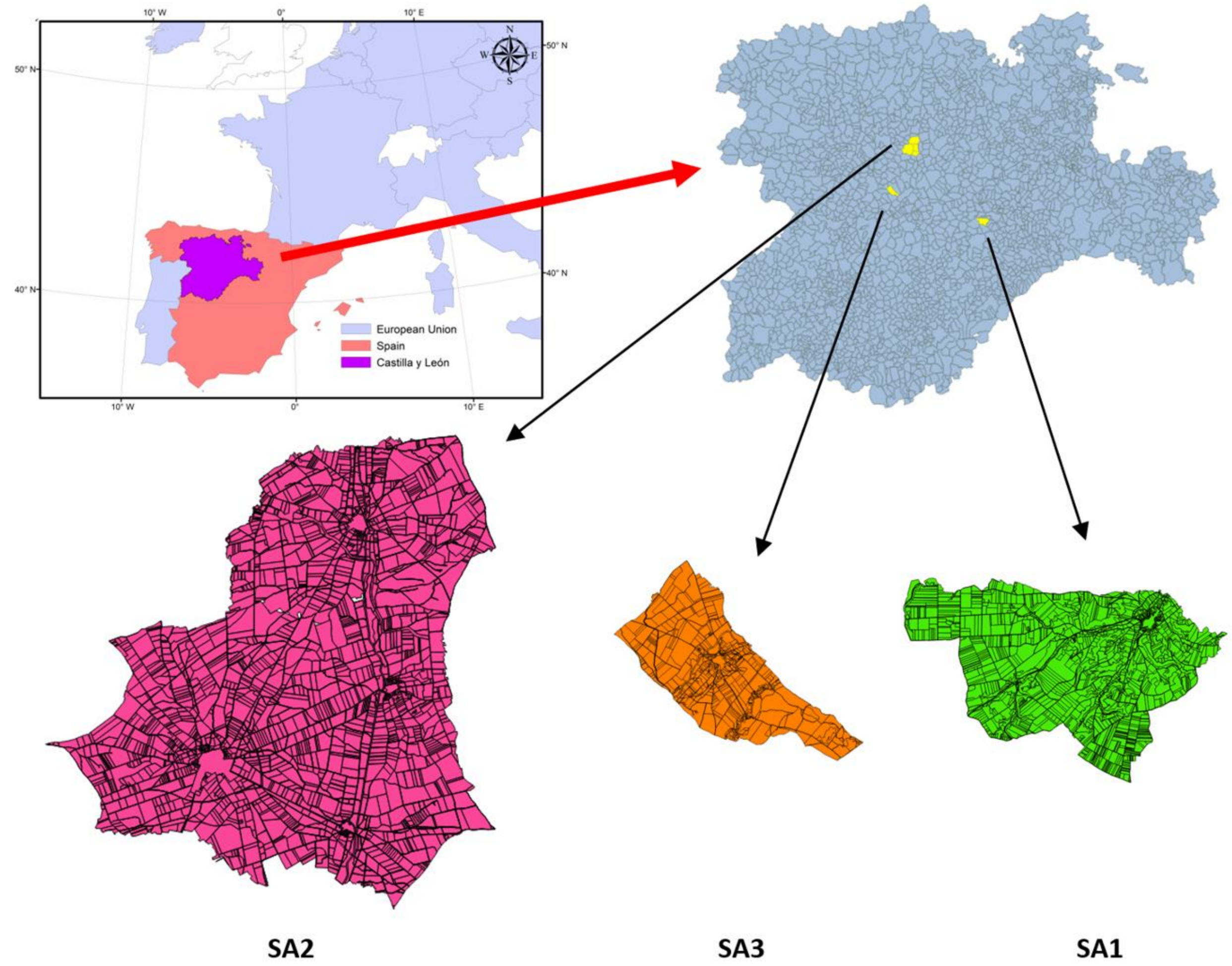


Figure 1. Location of the three study areas.

In the choice of these LCP, we prioritized environmentally similar areas, comparable in terms of usage of the soil and yield [50–52]. The LCP were of the same age and recent. Their graphic databases had to use SIG format or compatible and be executed under the same technical and legal framework [29].

The three case studies were expected to have different plots and productive structures and include one or more municipal areas:

- SA1 is the first LCP. It is located in a single municipal area with non-irrigated crops (>95% crop area),
- SA2 is the second LCP affecting four municipal areas with non-irrigated farming (>99% crop area),
- SA3 is an LCP in a single municipal area with non-irrigated and irrigated areas (ratio 2/1).

The parameters studied (fuel consumption and GHG emissions) will be analyzed pre and post each LC and among each other to compare three different LC approaches:

1. Non-consolidated areas versus areas with a first LCP: SA1 vs. SA2 and SA3;
2. The boundaries of the project involve various municipal areas or a single village: SA2 vs. SA1 and SA3;
3. Significant presence or lack of irrigated crops in the LC area: SA3 vs. SA1 and SA2.

2.2. Databases

This study includes the different Land Consolidation projects (LCP) and the alphanumeric (Table 1) and spatial (Figure 2) databases.

Table 1. Main parameters and technical indexes of each LCP.

	SA1	**SA2**	**SA3**
Period of execution 1st LC	2007–2010	1968–1975	1963–1967
Period of execution 2nd LC	-	2004–2009	2008–2011
Work execution period	2017–2019	2010–2015	2015–2017
LCP surface (ha)	4254.75	16,056.03	2715.46
Owners (n)	581	1258	245
Plots Ex ante-LC (n)	5676	4759	1111
Plots per owner Ex ante-LC (n)	9.77	3.78	4.53
Mean size of the plots Ex ante-LC (ha)	0.71	3.36	2.43
Plots Ex post-LC (n)	1068	2157	482
Plots per owner Ex post-LC (n)	1.84	1.71	1.97
Mean size of the plots Ex post-LC (ha)	3.77	7.42	5.52
RI [1]	5.31	2.21	2.30
LCI [2]	0.90	0.74	0.73

[1] RI (index reduction obtained) = P/Pc, P = plots, Pc = plots consolidated; [2] LCI (coefficient of consolidating obtained = (P − Pc)/(P − O), O = owners. Source: own elaboration from LCP databases.

Upon the analysis of the information gathered in the documents and LC plans, the spatial layout of the exploitations pre and post-LCP were defined.

The information on the structure, equipment, and home of the exploitation was complemented with personalized interviews [31] with the owners of the exploitations.

The information on the crops and use of each holding were obtained from the database of direct payments of the Common Agrarian Policy [52] in the periods 2017/18 and 2018/19.

Georeferenced layers were used (reference system ETRS89), generated in the LCP, corresponding to the path network pre and post-LCP, topography, and other elements on the site (hydrographic network, irrigation canals, etc.), which determine the journeys from the farm and the smallholdings). Data protection was observed throughout the project.

2.3. Election of the Study Sample

An ample statistical sample has been made: 84 exploitations. 2335 pre and post-LC plots and 560 post-LC exploitations, totaling 4000 ha (Table 2). The number of exploitations is based on the last Agrarian Census [50], eliminating the exploitations with no land or under 5 ha. The resulting list was compared to the information obtained from LCPs.

Figure 2. Pre and post LC layout of the plots in SA1 (**a**), SA2 (**b**), and SA3 (**c**).

Table 2. Structure of the sample considered in each area (Pre and post-LC).

	SA1		**SA2**		**SA3**	
	Pre-LC	**Post-LC**	**Pre-LC**	**Post-LC**	**Pre-LC**	**Post-LC**
Exploitations (n)	24		41		19	
Exploitations (%) [1]	43.64		33.34		48.72	
Exploitations < 30 ha (n)	4		26		7	
Exploitations 30.01–50 ha (n)	12		2		5	
Exploitations 50.01–100 ha (n)	5		5		4	
Exploitations 100.01–200 ha (n)	3		7		2	
Exploitations > 200.01 ha (n)	0		1		1	
Exploitation surface (ha)	1069.77	1059.31	1804.25	1934.60	1034.02	1018.27
Exploitation surface (%) [2]	26.51	26.25	11.36	12.18	38.33	37.75
Plots (n)	1384	204	548	205	403	151
Plots (%) [3]	24.38	19.10	11.52	9.50	36.27	31.33

[1] Percentage with respect to the total number of agrarian exploitations in each LCP after eliminating the marginal exploitations or those with no agrarian activity; [2] Ratio of the area of the sample holdings in relation to the adjusted surface of the LCP; [3] Relation between the number of plots in the sample and the total number of plots in each phase of the LCP. Source: own elaboration from the LCPs databases.

The exploitations were randomly picked and their analysis was organized according to exploitation size. The study has identified and georeferenced the exploitations based outside of the LCP. This affects 3 SA1 exploitations (12.50%), 16 SA2 exploitations (39.02%) and 5 SA3 exploitations (26.32). The sample represents 42.64% of the existing exploitations in SA1, 33.34% in SA2, and 48.72% in SA3.

2.4. Software Used

The work inherent to LCPs has been carried out using a specific application of Geographic Information System (GIS): DinaMap + Concen-2000, version 2003. The geographic data obtained have been jointly managed in SIG QGIS Desktop free software, version 2.14.5 [53] and CAD through AutoCAD version 2016 [54].

The shortest path algorithm was used to calculate the shortest journeys between the exploitation and the plots in code Python, QGIS Desktop, version 2.14.5 [53]. The application called route GEN [55] has been used in the journeys within each plot.

SAS, version 9.4 [56] has been used for the statistical analysis and OpenOffice, open code, has also been used to analyze the databases.

2.5. Design and Calculation Criteria

The journeys covered by the tractors, agrarian machinery, and other vehicles are compared for each exploitation of the sample, both in pre and post LC scenarios, considering two aspects: journeys to the plots and maneuvers within the plots. GHG expressed in kg of CO_2-eq [57,58], will be calculated from these fuel consumptions by the following Equation (1):

$$1 \text{ L of agricultural diesel} = 2.67 \text{ kg of } CO_2 \quad (1)$$

With the aim to compare pre and post LCP journeys and compare the various LCPs, all calculations will be referred to in km·ha^{-1}.

2.5.1. Spatial Organization

The definition of the block is the starting point of this study. A block is the extension of land that can be cultivated in a theoretical 8 h working day, including the time spent on the journey to the block. A block can comprise one or more plots, or simply a fraction of a larger plot, mainly sorted as irrigated or non-irrigated, belonging to one or more owners, but always within a single exploitation. Second and third-order blocks (also called sub-blocks) have been defined. By subgroups, we understand nearby plots or groups of plots. They are small enough, in comparison to other plots or blocks, to justify a journey to conduct a working day. Based on these field data, it has been admitted a 6% margin below and 12% over the working day. Thus, the working day may range from 7.5 to 9 h.

The size and shape of the block are decisive [22,27,59,60] as the time and energy required to carry out all farming and harvest work depend on them. The surface of each block, including its sub-blocks, is determined by various factors: the different land uses in each LCP in the period 2017/18 and 2018/19 [52], the most recurrent farming operations meant for those usages [31], the theoretical mean yield for the execution of the most recurrent operations, their geometric shape, and the working day time limitations.

The geometry of the blocks is defined by the methodology developed by González et al. [22,27]. This methodology combines the size and shape of the plots. The estimated mean yield of the "regular" blocks is 0.83 $h \cdot ha^{-1}$ (Appendix A). The yield assigned to "Irregular" blocks is 1.04 $h \cdot ha^{-1}$, while the "highly irregular" blocks are assigned 1.30 $h \cdot ha^{-1}$.

In the spatial definition of each block, the minimum distance between their centroids and the exploitation has been determined, and if applicable, between the centroid of the block and that of each associated sub-block. The journeys between the blocks and the exploitation, called R_{ij}, are calculated for pre and post-LC.

The analysis of those large blocks, whose work involves more than a full working day, will be disaggregated into various figures. The figures must be as orthogonal as possible. Necessary iterations will be carried out between the exploitation and the block until the works have been completed on the whole surface.

For calculating the minimum distance between homesteads of farms and all their blocks, it is considered the network of pre-LC tracks and right of way and the new network of tracks designed for each LC [61,62]. The network of tracks of towns adjoining LCP is obtained from the Land Registry database [63] and remains invariable during the analysis period. The pre and post-LC scenarios were studied of elements like roads, streams, irrigation canals, etc.

The headquarters of the exploitation is the place, generally an agricultural building, on occasions, the owner's dwelling, where the machinery and equipment are stored. The georeferenced coordinates of this point are the start and goal of all itineraries, which will subsequently be defined according to the type of crops of each exploitation. Those exploitations based outside the LCP have also been georeferenced.

Six types of routes have been defined: tracks with the surface in good shape (F), tracks with an inadequate surface (T1), unpaved tracks (T2), the crossing of agricultural plots or right of way (S), paved urban roads (U), and roads (C).

A coefficient of 1.00 is assigned to the consumption generated by journeys made on F-type roads. T1 path coefficient is 1.366, while the coefficient for unpaved roads (T2) is 1.535. The coefficient applied to the remaining roads is as follows: 2.089 to S, 0.992 to U, and 0.797 to C.

A number of improvements derived from the new road network, like the cost reduction in machinery and equipment maintenance, have not been considered in this study. The above is the result of improved road networks and the reduction of the multi-pass effect once the irregular plots have disappeared.

2.5.2. Calculations Linked to the Journeys to Each Block

The parameter R_{ij} is defined for each plot. This parameter is the aggregation of the distances in every cultivation operation (R_{NCI}), crop monitoring and surveillance operations (R_{seg}), and crop harvesting operations (R_{COS}) Equation (2).

The homestead of the farm is the starting point of the journeys. The calculations will be repeated for each pre-, and post LC.

$$R_{ij} = R_{NCI} + R_{seg} + R_{COS} \tag{2}$$

The fuel consumption (K_1) measured in $L \cdot ha^{-1}$, Equation (3) for each LC has been calculated considering the type of road and the energy requirements of each journey

$$K1 = \frac{\sum_{n=1}^{n} \left(\frac{\Sigma Rij * E * c}{s} \right)}{n} \tag{3}$$

R_{ij} = length of the journeys between the homestead of farm and the blocks, in km; E = coefficient according to the type of road; c = fuel consumption according to energy requirements (light or heavy) in $L \cdot km^{-1}$, s = surface of the plot, in ha; n = number of exploitations in each LC.

The shortest path algorithm was used to calculate the shortest journeys between the exploitation and the centroid of each block and between each block and the next one in the form of secondary ramifications, considering the working day time limitations. In each LC, the necessary iterations to conduct the most repeated operations for each type of crop [31] have been designed, differentiating irrigated and non-irrigated crops.

The type of road was also considered in each itinerary to weigh the fuel consumption per km [48] according to the type of surface and shape of each road. Nevertheless, two main criteria have been introduced in the calculation and design of post-LC minimum itineraries, though this may increase the distance in each itinerary: maximize safety and the environmental quality in urban areas. Thus, in the case of an alternative route along the newly designed paths, the use of the latter has been prioritized over the paved roads. Likewise, city centers have been avoided prioritizing the by-pass paths designed in the LC. Horticultural and fruit-tree areas have not been considered as their surface is not relevant (<0.5% total surface). Having considered the geomorphic and edaphologic features of the three areas of study, no significant differences were found in the soil. It can be deduced that all plots are homogeneous both internally and among each other. It can also be inferred that only the size and shape of the plot and the presence of obstacles or unevenness impeding the works will have an impact on the analysis of the yield (time and necessary consumption) of the cultivation works.

Nevertheless, interior obstacles have not been considered in this study. To compare the plots within each LC, a standardized plot was determined using the weighting of the different usages of the soil [31].

To determine the fuel consumption in the itineraries, the works in [19,62] y [64] have been adapted. The estimations were made taking as a hypothesis an 85 kW, 5200 kg unladen weight, a 10,000 kg trailer, and an average speed of 25 $km \cdot h^{-1}$.

The fuel consumption is identified as "c" in Equation (3). "Light" journeys mean consumption is 0.424 $L \cdot km^{-1,}$ while the "heavy" journeys range from 0.532 to 0.668 $L \cdot km^{-1}$ (Appendix B). These iterations are carried out in all blocks of each study area, both ex-ante and ex-post LC.

Regarding the itineraries generated to carry the harvest and the sub-products (R_{COS}), the journeys of a tractor carrying a trailer from and to the exploitation were considered. The journeys were measured from the exploitation to the centroid of each main block. The number of itineraries is based on the surface of the block, the type of crop (irrigated or non-regulated), and the trailer's maximum weight and volume capacity [65].

Based on the field results, the study determined the tracking during the development of the crops aimed at assessing the pest alerts, the efficiency of phytosanitary treatments during the harvesting, or aimed at the installation of mobile irrigation equipment.

The latter is not commonly considered in studies analyzing routes and distances run in the exploitations [66]. All these journeys are supposedly made in a light vehicle (consumption 0.11 $L \cdot km^{-1}$). It is necessary to make 8 annual itineraries in the non-irrigated lands and 22 in the irrigated lands.

The distance covered in such itineraries is estimated from a route that connects all the blocks having the same type of crop in the exploitation.

2.5.3. Calculation Linked to Row-End Turnings in Each Block

The geometric regularity and the size of the blocks can be regarded as factors that complete the above-mentioned to determine the fuel consumption [22,60,64,67–71]. In this section, we are quantifying the fuel consumption, measured in L·ha^{-1} caused by turns and maneuvers performed in each block, from the end of one course to the beginning of the next one. These turnings operations involve a substantial waste of time and especially fuel consumption [27,67–69,71–73]. The consumption is analyzed in the pre- and post-LC.

The consumption variation should be caused by the improvement of the block shape, which could be related to a bigger geometric regularity. The latter would result in a reduction in the number of turns for a single unit of the cultivable surface due to the removal of obstacles and hard-to-reach working. The variation is also a consequence of the increasing size of the plots.

The goal is not to determine the diesel fuel consumption in agricultural workings but to quantify the extra fuel consumption in turns in each block.

For each LC, the fuel consumption (K_2), measured in L·ha^{-1}, has been calculated due to the geometric regularity and the size of the blocks, adapting the methodology by [64] and [67] to the crop itineraries selected in each section of this study (13.9 in SA1, 13,1 in SA2, 13.4 in SA3-S, and 23.7 in SA3-R). The results obtained will be analyzed by comparing pre-LC consumption with post-LC consumption in the three LCPs.

3. Results

3.1. Adjustment of the Size of the Block According to Their Geometric Regularity

Following the criteria defined in the methodology, 993 blocks have been identified. They have been classified based on their geometric regularity (Table 3). The variation in their size (Table 4) and their relative value regarding the size of the exploitations pre- and post-LC have been analyzed.

Table 3. Classification of the block according to the pre-LC and post-LC geometric regularity.

	Regular (%)		**Irregular (%)**		**Highly Irregular (%)**	
	Pre-LC	**Post-LC**	**Pre-LC**	**Post-LC**	**Pre-LC**	**Post-LC**
SA1	39.71	51.00	49.29	42.00	11.00	7.00
SA2	27.52	24.24	43.12	61.62	29.36	14.14
SA3	16.00	27.03	53.60	62.16	30.40	10.81

Table 4. Mean size of the exploitations and their blocks (pre-LC and post-LC).

LCP		**n** [1]	**Mean Surface and Standard Deviation of the Exploitation (ha)**		**Mean Surface and Standard Deviation of the Block (ha)**	
			Pre-LC	**Post-LC**	**Pre-LC**	**Post-LC**
SA1	T [2]	24	44.60 ± 31.13	44.14 ± 31.26	6.86 ± 2.07	16.09 ± 8.25
	V [3]	3	19.56 ± 20.12	17.45 ± 18.50	5.88 ± 1.38	8.84 ± 3.80
SA2	T [2]	41	44.01 ± 57.29	47.19 ± 58.83	9.48 ± 5.90	18.73 ± 20.05
	V [3]	16	44.65 ± 68.60	46.37 ± 66.23	7.22 ± 4.37	18.92 ± 20.29
	E [4]	8	73.08 ± 85.88	76.46 ± 80.25	9.40 ± 4.32	27.14 ± 22.89
SA3	T [2]	19	54.09 ± 54.56	53.76 ± 53.97	9.79 ± 4.74	18.77 ± 12.86
	V [3]	5	21.91 ± 19.53	21.33 ± 18.89	9.17 ± 3.97	16.53 ± 17.19
	S [5]	14	45.83 ± 51.19	45.91 ± 51.65	10.36 ± 5.27	17.20 ± 12.33
	R [6]	5	77.22 ± 63.04	75.73 ± 60.14	8.17 ± 2.53	23.17 ± 14.76

[1] n = number of exploitations; [2] T = total sample of LCP area; [3] V = partial sample of the LC area, which only includes the exploitations with blocks in different municipal areas; [4] E = partial sample of the LC area, which only includes the exploitations with blocks in different municipal areas and based within the LC; [5] S = SA3-S; [6] R = SA3-R.

While the mean size of the exploitations has barely changed upon LC, the mean size of the block has suffered significant variations. The mean size of the block, with its standard deviation, has increased from 6.86 ± 2.07 ha to 16.09 ± 8.25 ha in SA1 and from 9.48 ± 5.90 ha to 18.73 ± 20.05 in SA2. In SA3, it increases from 9.79 ± 4.74 ha to 18.77 ± 12.86 ha, while in non-irrigated blocks, the mean size increases from 10.36 ± 5.27 ha to 17.20 ± 12.33 ha. (pre-LC). The mean size increases from 8.17 ± 2.53 ha (pre-LC) to 23.17 ± 14.76 ha (post-LC) in irrigated areas.

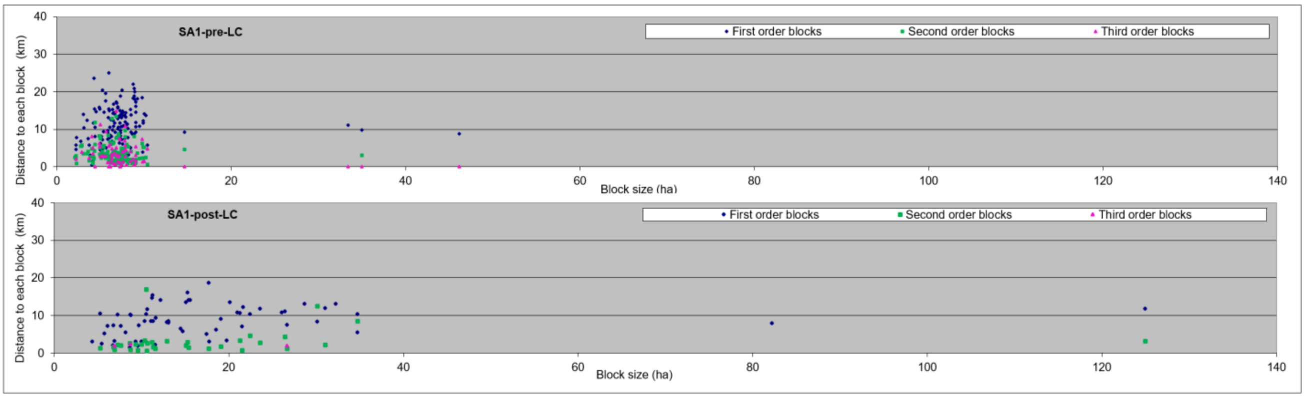
Of the 993 blocks analyzed, 761 were pre-LC and 236 were post-LC. This adjustment is notable in the first-order blocks: 145 in SA 1, 162 in SA2, and 96 in SA3 (pre-LC) became 62 in SA1, 88 in SA2, and 43 in SA3 (post-LC).

Upon the adjustment of the theoretical working day, 231 pre-LC second-order blocks were obtained (SA1: 138; SA2: 55; SA3: 38), and 107 third-order blocks (SA1: 64; SA2: 20; SA3: 23). These blocks were reduced to 56 post-LC second-order blocks (SA1: 33; SA2: 11; SA3: 12) and only 3 third-order blocks in SA1. While the number of blocks decreases, their size and the distance covered to reach them increase.

3.2. Fuel Consumption Linked to the Itineraries of Each Block

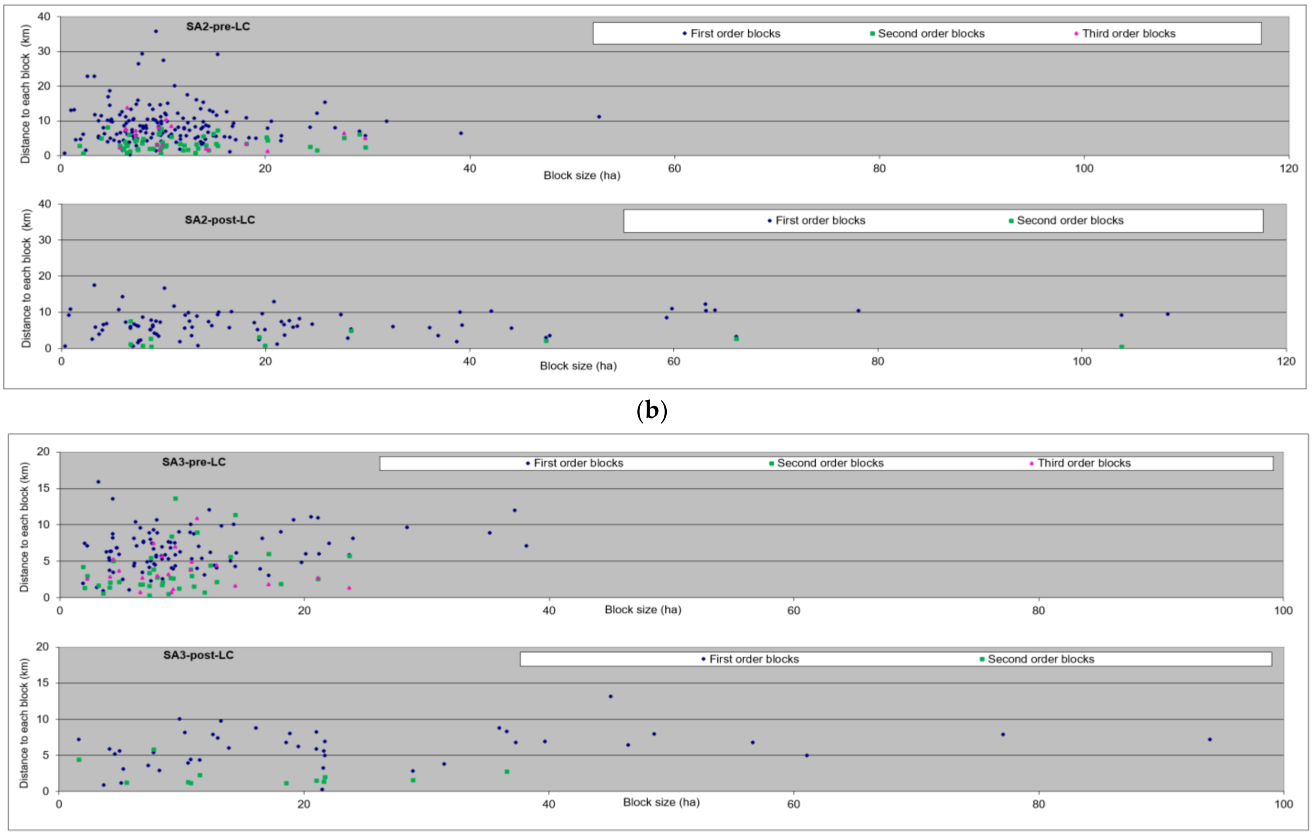
The distances covered by each block are compared in Figure 3 using the shortest path algorithm. The journeys to the main blocks are differentiated from the journeys to the sub-blocks (secondary and tertiary itineraries from the main block).

As a result of the work each LC involves, there has been a notable transformation in the relative importance of the type of road used in each LCP (Figure 4).



(**a**)

Figure 3. *Cont.*



(**b**)

(**c**)

Figure 3. Variation of the typology, size, and spatial scattering of the blocks (pre and post-LC) SA1 (**a**), SA2 (**b**), and SA3 (**c**).

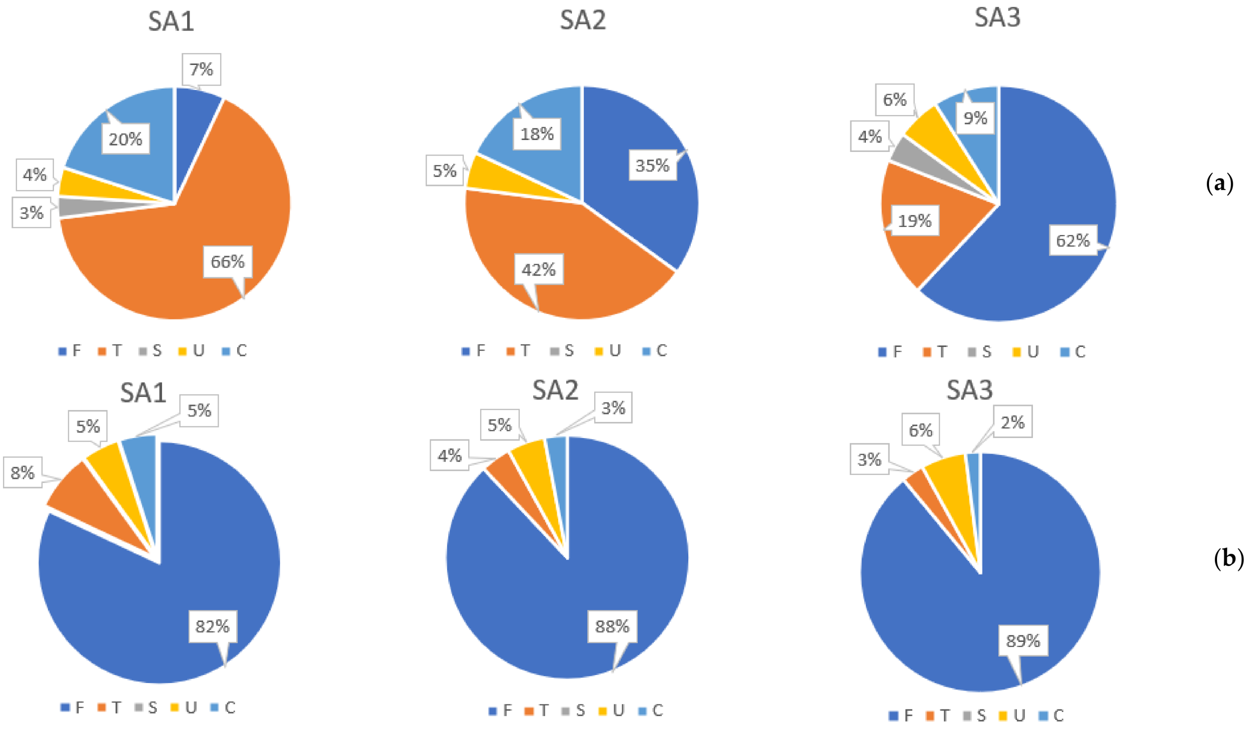


Figure 4. Variation of the number of km covered according to the type of road (F: asphalted, T: poorly asphalted or non-asphalted, S: right of way, U: urban roads, C: roads), both pre-LC (**a**) and post-LC (**b**) for each LC.

Tables 5 and 6 show the distances covered in pre and post LC. The total number of journeys within the exploitation and the relative journeys per block and hectare have been determined.

Table 5. Distances per block and hectare in situations pre and post-land consolidation.

LCP		n [1]	Distance Covered (km·Block^{-1})		Variation (%)	Distance Covered (km·ha^{-1})		Variation (%)
			Pre-LC	Post-LC		Pre-LC	Post-LC	
SA1	T [2]	24	441.14 ± 106.82	326.70 ± 153.00	−25.94	68.81 ± 24.55	22.04 ± 11.46	−67.97 **
	V [3]	3	369.45 ± 69.09	128.59 ± 63.06	−65.19	66.95 ± 26.34	14.23 ± 3.21	−78.75
SA2	T [2]	41	313.98 ± 171.30	235.40 ± 155.72	−25.03	53.07 ± 60.93	30.64 ± 60.06	−42.26 **
	V [3]	16	341.47 ± 247.17	224.52 ± 174.60	−34.25	56.75 ± 47.63	18.19 ± 13.90	−67.95
	E [4]	8	488.38 ± 234.96%	343.85 ± 140.47	−29.59	69.51 ± 60.32	16.50 ± 6.55	−76.26
SA3	T [2]	19	307.45 ± 101.46	367.72 ± 199.74	19.60	34.75 ± 18.92	22.04 ± 10.51	−36.58 **
	V [3]	5	254.93 ± 176.10	274.69 ± 205.60	7.75	25.39 ± 14.57	18.41 ± 14.56	−27.49
	S [5]	14	298.72 ± 113.48	318.77 ± 159.92	6.71	30.20 ± 11.15	21.17 ± 11.06	−29.90
	R [6]	5	331.88 ± 58.50	504.78 ± 254.06	52.10	47.50 ± 30.53	24.45 ± 6.12	−48.53

[1] n = number of exploitations; [2] T = total sample of LC area; [3] V = partial sample of the LC area, which only includes the exploitations with blocks in different [4] E = partial sample of the LC area, which only includes the exploitations with blocks in different towns and based within the LC; [5] S = SA3-S; [6] R = SA3-R. ** Significant in level 0.01.

Table 6. Distribution of the journeys according to the size of the exploitations (pre-LC and post-LC).

LCP	n [1]	Total Journeys (km·Block^{-1})		Variation (%)	Total Journeys (km·ha^{-1})		Variation (%)
		Pre-LC	Post-LC		Pre-LC	Post-LC	
Exploitations < 25 ha							
SA1	5	498.19 ± 208.54	250.93 ± 260.57	−49.63	95.48 ± 40.63	26.01 ± 23.28	−72.75
SA2	25	327.97 ± 204.47	181.44 ± 106.69	−44.68	70.95 ± 70.70%	42.95 ± 74.79	−39.47
SA3	7	274.75 ± 150.69	238.62 ± 139.19	−13.15	38.89 ± 30.44	26.51 ± 13.90	−31.83
SA3-S	5	245.14 ± 166.76	220.74 ± 161.21	−9.65	27.26 ± 14.74	24.83 ± 16.52	−8.91
SA3-R	2	348.77 ± 98.32	283.33 ± 81.73	−17.33	67.97 ± 48.16	30.73 ± 4.22	−54.79
Exploitations 25–50 ha							
SA1	12	435.05 ± 72.44	348.82 ± 118.47	−19.82	64.44 ± 8.07	23.25 ± 5.30	−65.52
SA2	3	358.88 ± 151.22%	261.30 ± 136.80	−27.19	24.46 ± 10.55	17.09 ± 4.83	−30.14
SA3	5	328.07 ± 64.46	350.04 ± 105.16	6.70	35.21 ± 9.74	20.74 ± 11.78	−41.10
SA3-S	5	328.07 ± 64.46	350.04 ± 105.16	6.70	35.21 ± 9.74	20.74 ± 11.78	−41.10
SA3-R	0	N/A	N/A		N/A	N/A	N/A
Exploitations 50–100 ha							
SA1	4	405.64 ± 45.19	342.95 ± 102.20	−15.45	60.02 ± 5.06	21.55 ± 3.58	−64.09
SA2	6	268.88 ± 79.19	220.95 ± 74.52	−17.83	21.41 ± 7.43	11.36 ± 4.77	−46.95
SA3	4	296.45 ± 43.84	337.33 ± 70.14	14.80	32.58 ± 2.45	18.22 ± 2.94	−44.08
SA3-S	3	305.58 ± 46.21	312.82 ± 61.42	2.37	25.99 ± 10.86	17.45 ± 3.07	−32.86
SA3-R	1	291.55	410.88	40.93	36.09	20.54	−43.09
Exploitations 100–150 ha							
SA1	3	417.74 ± 24.63	342.86 ± 149.54	−17.93	41.59 ± 13.27	11.22 ± 5.50	−73.02
SA2	2	301.85 ± 108.16	655.01 ± 288.42	117.00	18.08 ± 10.09	10.01 ± 2.46	−44.64
SA3	2	335.15 ± 44.09	773.17 ± 23.22	130.69	32.72 ± 1.72	20.14 ± 0.64	−38.44
SA3-S	0	N/A	N/A		N/A	N/A	N/A
SA3-R	2	335.15 ± 44.09	773.17 ± 23.22	130.69	32.72 ± 1.72	20.14 ± 0.64	−38.44
Exploitations > 150 ha							
SA1	0	N/A	N/A		N/A−	N/A	N/A
SA2	5	245.08 ± 30.83	261.94 ± 30.13	6.88	19.78 ± 2.17	8.93 ± 2.0 pre2	−54.83
SA3	1	421.87	670.45	58.92	23.45	16.28	−30.58
SA3-S	1	421.87	670.45	58.92	23.45	16.28	−30.58
SA3-R	0	N/A	N/A		N/A	N/A	N/A

[1] n = number of exploitations.

SA1 exploitations mean distance was 2615.43 km a year before the LC. This figure was reduced to 853.00 km after the LC.

The mean distance in SA2 reduced from 1142.94 km·year^{-1} to 529.51 km·year^{-1}, while in SA3, the reduction was from 1621.97 km·year^{-1} to 1052.80 km a year after the LC.

Table 7 shows the values of fuel consumption on the journeys to each block, expressed in L·ha^{-1} (Pre and post-LC). Reductions above 50% are seen in post LC.

Table 7. Fuel consumption (L·ha^{-1}) is linked to the journeys to each block (pre and post-LC).

LCP		**n** [1]	**Consumption Per Journey to Each Block (L·ha^{-1})**	
			Pre-LC	**Post-LC**
SA1	T [2]	24	32.81 ± 12.75	8.42 ± 3.91 **
	V [3]	3	35.27 ± 12.74	5.46 ± 0.75
SA2	T [2]	41	23.92 ± 27.31	10.96 ± 20,44 **
	V [3]	16	24.48 ± 22.14	6.69 ± 4.80
	E [4]	8	29.98 ± 29.60	6.45 ± 2.36
SA3	T [2]	19	16.19 ± 7.07	6.41 ± 2.74 **
	V [3]	5	13.22 ± 7.18	5.48 ± 3.91
	S [5]	14	14.65 ± 4.86	6.09 ± 3.12
	R [6]	5	20.53 ± 10.79	7.31 ± 0.96

[1] n = number of exploitations; [2] T = total sample of LC area; [3] V = partial sample of the LC area, which only includes the exploitations with blocks in different; [4] E = partial sample of the LC area, which only includes the exploitations with blocks in different towns and based within the LC; [5] S = SA3-S; [6] R =SA3-R. ** Significant in level 0.01.

The main decrease can be seen in the exploitations with blocks in various municipal areas.: −84.5% in SA1-V, −72.7% in SA2-V, −78.5% in SA2-E, and −58.5% in SA3-V.

3.3. Consumption Linked to Row-End Turnings in Each Block

This consumption is related to the journeys within each block, considering two indexes: the length/width ratio, which will enable us to identify the geometric regularity and the total surface of the block for the size (Table 8). Comparing the pre and post-LC consumption, mild reductions in all the areas and samples studied are found. The reductions are mainly linked to the increasing size of the blocks. There are barely any variations in the consumption linked to the geometric regularity of the blocks in SA2-V, SA2-E, and SA3-S, while the consumption in SA3-V has increased.

Table 8. Fuel consumption (L·ha^{-1}) is linked to the size and geometric regularity of the blocks (Pre and post LC).

LCP		**n** [1]	**Consumption According to the Geometric Regularity (L·ha^{-1})**		**Consumption According to the Size of the Block (L·ha^{-1})**	
			Pre-LC	**Post-LC**	**Pre-LC**	**Post-LC**
SA1	T [2]	24	4.17 ± 0.37	3.80 ± 0.94 *	7.17 ± 1.38	2.59 ± 0.54 **
	V [3]	3	4.26 ± 0.22	2.65 ± 1.07	7.64 ± 0.96	2.91 ± 0.48
SA2	T [2]	41	3.78 ± 1.08	3.35 ± 1.54 ns	4.38 ± 2.17	2.86 ± 1.99 **
	V [3]	16	3.95 ± 1.10	3.93 ± 1.46	4.71 ± 2.56	3.19 ± 2.74
	E [4]	8	4,04 ± 1.30	4.02 ± 1.17	3.33 ± 0.83	2.27 ± 0.82
SA3	T [2]	19	4.21 ± 1.56	3.72 ± 1.69 ns	5.00 ± 2.87	2.80 ± 1.13 **
	V [3]	5	3.7 ± 0.88	4.34 ± 1.75	3.50 ± 0.85	2.67 ± 0.66
	S [5]	14	3.64 ± 1.20	3.60 ± 1.09	4.18 ± 0.96	2.66 ± 0.87
	R [6]	5	5.82 ± 1.34	4.06 ± 0.85	7.30 ± 5.00	3.18 ± 1.74

[1] n = number of exploitations; [2] T = total sample of LC area; [3] V = partial sample of the LC area, which only includes the exploitations with blocks in different; [4] E = partial sample of the LC area, which only includes the exploitations with blocks in different municipal areas and based within the LC; [5] S = SA3-S; [6] R = SA3-R. * Significant in level 0.05. ** Significant in level 0.01; ns Not significant.

4. Discussion

4.1. Adjustment of the Size of the Blocks According to the Geometric Regularity

Comparing the pre and post-LC layout of each of the areas, the main effects of this process are seen: the number of parcels has noticeably reduced. Their mean size has increased while their spatial scatter has reduced. This simple consideration gains greater quantitative and qualitative importance at the exploitation level, not owners. This remarkable reduction of the number of blocks is greater in the case of second-order blocks, while third-order blocks virtually disappear. These decreases are in line with the reduction indexes, RI, observed: 5.31, 2.21, and 2.30 in SA1, SA2, and SA3, respectively, and slightly higher than those observed in other case studies [21,47]. In [74], by reducing the mean number of exploitations on a municipal level from 22.5 to 14.5, profit is estimated to increase by 4987 € per exploitation.

The greater size rises on a block-level have been obtained in the non-previously LC area (235% in SA1) when an LC has been simultaneously conducted in various municipal areas (262% in SA2, reaching 289% in the case of exploitations with plots in different municipal areas) and irrigated blocks (284% in SA3-R). No substantial improvements are found in SA1 and SA3 for exploitations based outside such LC areas. It must be noted that this effect is not easily assessed as they are LCs in a single municipal area, having identified only 3 exploitations in SA1 and 5 in SA3 with plots in different municipal areas. The results are similar in magnitude to those observed in previous research [21,36,38].

4.2. Variation of the Fuel Consumption According to the Journeys to Each Block

Regarding the distances of the journeys to each block, there is a significant reduction in all areas, both the absolute value (mean distance required to do all the farm working every block and sub-block) and relative. The reduction is also due to the lower statistical scattering in all series.

It is especially noticeable the reductions in SA1 as well as in exploitations with plots in various municipal areas, particularly in SA2-E, and the journeys in SA3-R exploitations.

The journey reduction observed is similar to that observed in previous studies [46,75] and notably higher than that determined by [22,38,41] and notably higher than the slight reductions (3 and 6%) mentioned by Finland's Hiironen and Niukkanen [36] and Hiironen and Riekkinen [21].

According to the latter, LC is a useful tool to increase the mean size of the plot [36] or reduce the number of plots [21]. However, it is not useful when reducing the distance between the exploitations and their plots; as in the case of Finland, most LC projects involve a single municipal area.

Considering the absolute values obtained in this study, the journey reductions obtained are notably higher than those obtained in previous studies [21,26,36,46,47,75] limited to working in a single municipal area.

As a result of the lower Post LC plot scattering, the secondary itineraries have noticeably decreased, and those of third-order have almost disappeared in the three areas analyzed. The new spatial lay generated by the three LCPs has reduced the distance covered by 593,650 km.

The post LC relative variation of the distance covered to reach each block is similar in every size stratum of the exploitations. However, the greatest relative reduction in every size stratum is obtained in SA1. Considering the absolute values, the effect of the spatial consolidation is lesser in the exploitations <25 ha in any of the study areas. The journeys necessary per hectare were reduced in the >50 ha exploitations in SA1 and >25 in SA2 and SA3. For non-irrigated lands in SA3, this optimal minimum is only obtained over 150 ha, while in the case of SA3-R, it is obtained from 50 ha. It must be noted that the low absolute values obtained in >50 ha exploitations in SA2.

The size factor is directly linked to the optimization of fuel consumption [46], the biggest reductions being obtained in exploitations between 5 and 20 ha, followed by the largest exploitations (>40 ha), as shown in previous research on the effect of LC with a socioeconomic approach [39,76] regarding and increased efficacy of agricultural supplies [37,77] or energy consumption at the exploitations [78,79].

This noticeable journey reduction has been achieved even by complying with the road safety restrictions (avoiding asphalt roads) and environmental quality restrictions assumed in the design of the research. Moreover, SA1 topography, more uneven than that of SA2 and SA3, has not proved to raise the distances covered.

Works inherent to the LCP have completely transformed the road network in the study areas. The post-LC scenario has removed all rights of way, thus allowing for direct access to all plots and minimizing the number of journeys along roads and urban areas. Using granulometric road surfaces on most roads has improved vehicle circulation and reduced fuel consumption [46,48,80].

The variation in consumption linked to the journeys to each block as a result of the LC is the most determinant factor in the reduction of fuel consumption in the areas: 83.13% in SA1, 86.92% in SA2, 78.43% in SA3, 84.58% in SA3-S, and 69.21% in SA3-R. In the 84 exploitations analyzed, there were reductions in fuel consumption on account of this parameter. The positive results observed in SA2 align with the conclusions by [36] and are higher than those obtained in [21].

In a more econometric approach [74], reducing the mean distance between one certain hectare and the exploitation by 500 m would increase the operating profit by 5862 €. In [67], fuel consumption increases by 0.5–0.6 L·ha^{-1} for every km the plot is moved away from the exploitation.

Under the premises above, the reduction of fuel consumption linked to the journeys to each block as a consequence of the LC is 103,782.84 L in SA1, 208,060.68 L in SA2, and 27,413.84 L in SA3, of which 15,569.56 L in non-irrigated areas and 11,844.28 L in irrigated areas.

4.3. Variations of the Fuel Consumption Considering the Turning Operations within Each Block

The geometric regularity in each LC has varied irregularly, being the best results obtained in SA3. LC has not significantly improved the regularity in SA1, while there has been a relative loss of regular blocks in SA2. No area shows an increase in the number of the most regularly-shaped blocks. These results, which could be considered below post-LC expectations [22,64], are coherent with the plot design used in this study. These blocks normally bind together a number of plots which, while individually analyzed, are geometrically regular. However, when combined, they can result in more irregular blocks or a worse width/length ratio. While this is a minor factor compared to the estimated fuel consumption generated in the journeys to the plots, it is considered relevant to this study since the parameters to analyze (shape and size of the plots) are closely related to the noticeable changes introduced by LC.

The variation of the consumption linked to the geometric regularity of the blocks as a result of LC is a significant part of the reduction of fuel consumption in all areas.

In previous studies analyzing the fuel consumption according to the shape of the plots, GHG reductions of as much as 18.46% were obtained as the plots' length grew from 200 to 1000 m on its longest side [69]. It was also observed that the specific consumption improved by 4 L/ha [81], and the CO_2 emissions rose between 4.59% and 5.78% when the rectangular plots were transformed into square plots [71]. Higher fuel consumption efficacy is strongly related to the shape and size of those plots that generate the lower number of turns and the "non-working distance" [68,72,81].

The variation of fuel consumption according to the size of the block is significant in all LCs, although it is the lowest providing factor to the reduction of fuel consumption in all areas. The main fuel reduction was generated by improving the parameter size only in one SA2's exploitation. As an absolute value (L·ha^{-1}), the biggest reductions have been obtained in areas not previously consolidated (SA1) and irrigated areas in SA3. These results align with those obtained in previous studies [48,61,67,70,82], according to which the difference in consumption tends to be less significant on surfaces over 5 ha [61]. Hardly any variations are found on the surface over 8 ha [48] and 10 ha [67].

As the size of the plot, or the block, in this case, increases, the effect of the shape decreases. The layout of blocks developed in this study does not allow us to maximize this parameter. It also generates a mean size of the blocks well over the optimal dimension. Additionally, the increase in the size of the plots is the main goal behind the LCs. It is closely related to the improvement in the productivity of agrarian exploitations [21,26,37,39,40,74,83], investments [84], or the optimization of other supplies [37,82].

Light increase in fuel consumption (+0.1–5%) has been observed in 31 exploitations compared to pre LC scenario due to the geometric parameters of size and shape of the blocks. In 27 exploitations, this increase was due to the loss of geometric regularity (7 in SA1, 10 in SA2, and 10 in SA3). In 4 exploitations, the combination of both geometric parameters increased consumption (three exploitations in SA2 and one in SA3). In all cases, these increases were offset by reductions in consumption associated with the journeys made to each block.

The reduction in fuel consumption linked to the size and geometric regularity following the LC amounted to 21,033.98 L in SA1, 31,367.00 L in SA2, and 8096.08 L in SA3, of which 2830.16 L are in the rainfed area, and 5265.92 L are in the irrigated area.

5. Conclusions

Considering the mean value of per-exploitation fuel consumption [85], the sum of all fuel reduction amounts to a mean reduction of 23.60% in SA1, 11.46% in SA2, 9.85% in SA3, 8.06% in SA3-S, 14.87% in SA3-R, and 18.54% in SA 2 exploitations with blocks in various municipal areas. Transforming these reductions in fuel consumption into GHG, the following mitigations can be found in the LC analyzed: 333.261 t CO_2-eq in SA1, 639.272 t CO_2-eq in SA2, and 94.811 t CO_2-eq in SA3.

In line with the sections above, the best levels of GHG emission reduction per unit of surface are obtained in SA1 (reduction of 78.33 kg CO_2-eq ha^{-1}), SA3-R (reduction de 50.98 kg CO_2-eq ha^{-1}), and SA2 (39.82 kg CO_2-eq ha^{-1}). In SA3, the mean reduction was 33.31 kg CO_2-eq ha^{-1} and in SA3-S 27.00 kg CO_2-eq ha^{-1}.

According to the results in this study, the main contributions of LC as a GHG mitigating factor are due to:

- generation of new restructuring of the plots,
- land consolidation of irrigation plots,
- creation of LC areas taking various municipal areas,
- consideration of the plots based outside of the LC perimeter.

The extrapolation of such estimates, in accordance with LC, planned in the Castilla y León Rural Development Program for the period 2014–2022 (22,900 ha of the annual consolidated area of which 8600 would be irrigated and under the premise that 20% of this surface would never undergo an LCP [86]) would allow an annual reduction of GHG linked to LCPs of 1044.662 t CO_2-eq.

The model developed and assessed positively in our research could be used to conduct an environmental assessment of other areas where LC is planned or in areas that have already been concentrated. In view of our results, it can be concluded that LC can be regarded as a useful process in the GHG reduction strategy, in line with the Paris Agreement's current commitments.

Further studies could evaluate these journeys using friction matrices [66], considering the usages of the soil, type of road, or its gradient, or using route planning algorithms [60,68], all aimed at analyzing the impact of the improved geometric regularity of the blocks on the reduction of fuel consumption, and consequently, on GHG, this leading to new LC criteria. Likewise, a life cycle analysis is deemed relevant, aiming to evaluate both the carbon footprint in land LCP [28] and carbon emission/capture balance in the complete development of LCP [42,49].

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Appendix A

The methodology developed by González et al. [22,27] is used to define the geometry of the blocks. This methodology combines the size and shape of the plots. The above-mentioned authors identify 36 basic shapes grouped in 9 typologies: (TRZ, CHA, REC, TRA, ELE, SAL, TRI, RCB y ENT). These nine typologies have been subsequently gathered in three groups [61]: "regular" (those, rectangular and trapezoidal right-angled blocks, comprising typologies TRZ, CHA y REC, except for shape REC-A), "irregular" (blocks of shape close to those defined as regular, but lacking orthogonality, having one or more curved edges, or made up of two regular plots. They correspond to typologies TRA, ELE, SAL and the shape REC-A. The latter is penalized in studies that analyze the effect of the plot shape on energy saving [62]) and "highly irregular" (triangle- polygonal shaped, with Sharp protrusions. Curved edges resembling typologies TRI, RCB y ENT).

Table A1 shows the calculation of the average yield for the ''regular" blocks according to the different land uses (CH: arable crops, 82% of the area; CF: fodder crops, 15% of the area; OR: other crops and irrigated crops, 3% of the area) for the 2017/18 and 2018/19 cropping seasons [52] in each LC. The main cropping operations [31] have been considered, differentiating for each of them two or three machinery options, with different percentages of use and their respective working capacities.

In order to be able to compare all farms, the cultivation operations in each of the land uses are considered to be constant over the years and for the three zones. According to [31], the yield estimates for the cultivation operations are made considering a tractor with a power of 85 kW. The estimated mean yield of the ''regular" blocks is 0.83h·ha^{-1}. The yield assigned to "irregular" blocks is 1.04 h·ha^{-1} while the ''highly irregular" blocks are assigned 1.30 h·ha^{-1}.

Table A1. Determination of the average mean yield (h/ha).

Farming Operations	**Features Implement/Machine**			**C (h/ha)** [1]	**% Use** [2]	**CR** [3]			**CUS** [4]		
									CH [5]	**CF** [6]	**OR** [7]
						CH [5]	**CF** [6]	**OR** [7]	**0.82**	**0.15**	**0.03**
Primary tillage						1	1	1	0.86	0.16	0.03
Mouldboard or disc plough	4 c–14″	1.42 m	25 cm	1.18	0.1						
Mouldboard or disc plough	3 c–16″	1.22 m	32 cm	2	0.2						
Chisel plough	2.0 m	18 cm		1.2	0.3						
Heavy cultivator	3.0 m	18 cm		0.44	0.4						
Secondary ploughing 1						2	2	2	1.47	0.27	0.05
Disc harrow	4.5 m	15 cm		0.37	0.1						
Cultivator	2.5 m	15 cm		1.1	0.5						
Power harrow	3.0 m	15 cm		0.78	0.4						
Secondary ploughing 2						1	1	1	0.37	0.07	0.01
Roller	5.0 m		300 kg/m	0.31	0.3						
Roller	3.0 m		300 kg/m	0.52	0.7						
Sowing						1	0.5	1	0.71	0.06	0.03
SC + R [8]	5.0 m		boot	0.91	0.8						
Direct seeding	3.0 m		disc	0.69	0.2						
Chemical fertilisation						1	3	4	0.15	0.08	0.02
Suspended fertiliser spreader	1 disc	12.0 m	650 L	0.21	0.06						
Suspended fertiliser spreader	1 disc	16.0 m	800 L	0.13	0.2						
Large hopper fertiliser spreader	2 discs	24.0 m	1400 L	0.08	0.2						
Organic fertilisation						0.33	0.1	0.67	0.27	0.01	0.02
Manure distributor	4 t	3.20 m		1.05	0.9						
Slurry distribution tank	5 m^3	7.00 m		0.51	0.1						
Crop protection						0.6	2	3	0.3	0.11	0.04
PBS [9]	16 m	1200 L		0.13	0.3	0.2					
PBS [9]	6 m	400 L		0.54	0.6	0.2					
PBA [10]	24 m	3000 L		0.08	0.1						
Recolection MAT [11]						0	4	0.4	0	1.19	0.02
Mower	discs	2.50 m	tdf [15]	0.82	0.8						
RHA [12]	pinwheel	8.00 m	t df [15]	0.2	0.8						

Table A1. *Cont.*

Farming Operations	Features Implement/Machine			C (h/ha)[1]	% Use[2]	CR[3]			CUS[4]		
									CH[5]	CF[6]	OR[7]
						CH[5]	CF[6]	OR[7]	**0.82**	**0.15**	**0.03**
Classic baler	heavy	2.00 m	5 t/h	1.17	0.8						
Round baler-E[13]	10 t/h	5.00 m		1	0.1						
Macro baler	20 t/h	6.00 m		0.37	0.1						
Self-loading wagon	35 m^3	5.00 m		0.48	0.2						
Recolection MAP[14]						1	0	0.6	0.31	0	0.01
Harvester	6 m	1000 h	3 t/ha	0.39	0.7						
Harvester	7 m	1000 h	5 t/ha	0.34	0.3						
						Average 9 farming operations			0.56	0.24	0.03
						Average mean yield (h/ha)				**0.83**	

[1] C = capacity of the implement or machine executing the agricultural operation measured in h/ha; [2] % use = percentage of use of each type of machine, expressed for each of the farming operations; [3] CR = repetition rate of a farming operation for each land use groups; [4] CUS = distribution coefficient of the different land use groups; [5] CH = herbaceous crops, expressed as a percentage of one; [6] CF = fodder crops, expressed as a percentage of one; [7] OR = other crops and irrigated crops, expressed in per cent; [8] SC + R = seed drill with roller; [9] PBS = boom sprayer; [10] PBA = trailed boom sprayer; [11] Recolection MAT = harvesting by tractor-driven machines; [12] RHA = windrow rake + conditioner; [13] Round baler-E = round baler with wrapper system (150 CV); [14] Recolection MAP = harvesting by self-propelled machines; [15] tdf = driven by tractor power take-off. Source: own elaboration based on MAGRAMA (2014) [87] and data collected from the farms included in the research.

Appendix B

The fuel consumption estimations in the itineraries were made taking as a hypothesis a tractor 85 kW, 5200 kg unladen weight, a 10,000 kg trailer, and an average speed of 25 km·h^{-1} [19,62,64]. Depending on the level of energy requirements for farming operations, the itineraries were sorted between ''light" and ''heavy". Light journeys are those requiring low energy consumption, like the journey to the plot carrying the tools, or with an unladen trailer. Heavy journeys are those which require medium or medium-high energy consumption (laden trailer) (Table A2).

In a complete itinerary, from and bound to the exploitation, there can be a ''light" itinerary (journey bound to the plot with unladen trailer, or return journey with an empty manure spreader), followed by a ''heavy" journey (journey back to the exploitation with a grain-loaded trailer o plot-bound with a laden manure spreader). These iterations are carried out in all blocks of each study area, both ex ante and ex post LC.

Table A2. Correspondence between farming operations and itineraries according to the energy required.

Farming Operation	Itinerary	Energy
Deep ploughing	single	light
Deep ploughing	return	heavy
Cultivator + roller	round trip	light
Fertilization (autumn)	single	heavy
Fertilization (autumn)	return	light
Harrow + roller	round trip	light
Sowing	round trip	light
Phytosanitary treatment (fungi)	round trip	light
Phytosanitary treatment (insects)	round trip	light
Fertilization (spring)	single	heavy
Fertilization (spring)	return	light
Mulching	single	heavy
Mulching	return	light
Forage mowing	round trip	light
Forage tedding and swathing	round trip	light
Forage baling	round trip	light
Installation of irrigation equipment	round trip	light
De-installation of irrigation equipment	round trip	light

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