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Optimizing lambing efficiency: Alternative management strategies for Assaf ewe flocks

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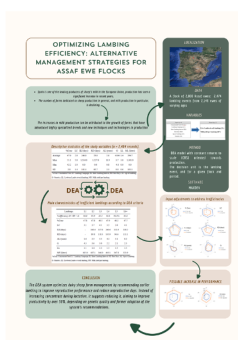
HIGHLIGHTS

- Spain leads the EU in sheep milk production, with growth driven by specialised breeds and technologies, despite a decline in the number of farms.
- In a novel approach to farm management optimisation, Data Envelopment Analysis (DEA) was used to evaluate the technical efficiency of individual lambing events on an Assaf dairy sheep farm.
- The most efficient lambing (third) involves a lambing interval of 317.5 days, a rest period of 79.5 days before the next lambing and an average milk yield of 495.8 litres per lactation.
- Inefficient lambing is characterised by a longer lambing interval (over 310 days), a higher number of rest days and a genetic value that decreases with each subsequent lambing.
- Production efficiency, lamb numbers and milk yield could be improved by bringing forward the first lambing to 1.2 years and reducing the lambing interval to <300 days.

GRAPHICAL ABSTRACT



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ABSTRACT

Context: Spain is a leading sheep milk producer in the EU, characterized by a wide variety of production systems across different regions and breeds. Achieving productive efficiency is critical for ensuring the economic viability of sheep farms, particularly in less favored territories.
Objective: This study aims to evaluate management efficiency in sheep farming by using lambing and its influencing factors as the fundamental reference element (Decision-Making Unit: DMU).
Method: The study employs the Data Envelopment Analysis (DEA) method to assess the efficiency of various farming systems. We analyzed 2474 lambings of Assaf dairy ewes of different ages, collecting both productive

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and economic data from the study farm. The variables considered include the percentage of concentrated feed used during milking, lambing campaign, inter-lambing interval, rest days, age at lambing, number of lambings per ewe, genetic level, liveborn lambs, and milk production per lambing. The DEA method was utilized to calculate the technical efficiency of DMUs based on the best observed practices, each DMU was compared with others using six inputs and two outputs through MAXDEA software.

Results and conclusions: The results reveal that the third lambing is the most efficient, while the first lambing is the least. The model suggests a reduction in concentrate feed during lactation by 7 to 9.4 %. Optimal lambing should occur between February and April, with matings between September and November, thus avoiding the costs associated with estrus synchronization, though this may challenge continuous year-round milk production. The model also recommends reducing the inter-lambing interval to below 300 days and cutting resting days by 33.3 % to 58.5 %. The age at first lambing should be lowered to 15 months, with selection for rebreeding advised within the first three lambings. The highest number of lambs born is observed in the fourth lambing, averaging 2.4 offspring, while the most significant improvement in milk production is seen after the first lambing.

In conclusion, the DEA method optimizes the management of dairy sheep farms, leading to improved productive and economic outcomes. It suggests improving reproductive performance in order to reduce the number of days that animals remain unproductive. This involves reinforcing matings during the milking period, reducing the number of 'open' days, shortening the interval between lambings and removing unproductive animals from the flock. Contrary to traditional resource-intensive approaches, the model recommends reducing concentrate feed consumption during lactation.

Significance: The significance of this study is twofold: First, it introduces a novel dimension to management efficiency analysis by using lambing as a decision variable, offering new avenues for studying productivity. Second, it underscores the importance of such studies in providing valuable management tools that can boost the economic performance and resilience of farms in increasingly complex and dynamic environments.

1. Introduction

Spain is one of the leading producers of sheep's milk in the European Union, accounting for 28.1 % of the total in 2022. Production has seen a significant increase in recent years, rising from 392 million liters in 2000 to 623 million liters in 2022. Castilla y León is the largest producing region in the country, with an average production of nearly 278.3 million liters in 2022, representing 55.3 % of the national total (MAPA, 2023).

However, the number of farms dedicated to sheep production in general, and milk production in particular, is declining (MAPA, 2023). The increases in milk production can be attributed to the growth of farms that have introduced highly specialized breeds and new techniques and technologies in production (Á. R. Mantecón and Lavín, 2001; Riveiro et al., 2013).

The edaphoclimatic differences in Mediterranean regions cause significant inequalities in pasture production (Pereira et al., 2004) These disparities, combined with the specific characteristics of each farm, lead to the development of various sheep management systems (Pérez et al., 2007).

In dairy sheep production, different farm management systems can be observed, ranging from highly intensive systems, where supplementary feeding predominates with little or no grazing, to highly extensive systems based on natural pastures (A. R. Mantecón et al., 2007). Animal feeding is a decisive factor in determining the management system of each farm (Zervas and Tsiplakou, 2011). Consequently, several studies have examined the characteristics of each system in different Spanish regions, comparing their structure, operation, production, and product quality (Milán et al., 2011; Plaza Isabel; Nieto, Jaime; Hidalgo, Cristina; Sánchez-García, Mario; Palacios, C., 2021).

The analysis of the efficiency of agricultural systems is a prominent area of scientific research. Among the various methods available for this evaluation, two approaches are most widely used in academic literature: the parametric route, involving the determination of the stochastic frontier, and the non-parametric option, led by the Data Envelopment Analysis (DEA) method. Liu et al. (2013) provide an initial chronology of the use of DEA for analyzing agricultural systems. Coelli (1995) begins with the work of Färe et al. (1985) and Ray (1985), who pioneered this type of analysis in the Philippines and India, respectively. In the same work, Coelli (1995) compares parametric and non-parametric methods for measuring efficiency and suggests their potential applications in agricultural economics. Sharma et al. (1997) also analyze the efficiency of pig production in Hawaii using both types of analysis, concluding that the DEA method is more robust for measuring efficiency than the parametric approach. Iráizoz et al. (2003) compare the results obtained by parametric and non-parametric techniques in Spanish horticultural production, finding similar and consistent results. The non-parametric technique has an initial advantage due to its ease of application, as it does not require the assumption of profit maximization or any specific functional form for the underlying technology (Tauer and Stefanides, 1998).

Following these initial steps and continuing within the framework of agricultural production, the DEA method has remained a valuable operational tool for analysis over time. For example, Laurinavičius and Rimkuvienė (2017) used it to estimate the technical efficiency of agricultural systems in several European countries, and Latruffe et al. (2017) applied it to measure the impact of financial subsidies on the efficiency of dairy farms in the European Union.

Examining the scale of analysis within the agricultural sector and approaching the focus of this paper, Dalgic et al. (2018) analyzed sheep farms in the province of Isparta, concluding that overcapacity leads to a significant reduction in efficiency levels. They proposed the need for an active organization of producers to share costs, especially among smaller farms.

Another interesting perspective is provided by Conradie and Piesse (2015), who reversed the traditional view of using the farm as the explanatory element and instead worked with the sheep as the productive unit, a direct precursor to the analysis developed in this paper. The authors analyzed 46 extensive sheep farms in the Karoo region of South Africa, evaluating their results in terms of production intensity. Their findings show that 70 % of the farms analyzed could improve their efficiency by further intensifying production, and that productivity is strongly correlated with unit production costs and profitability.

In the present work we try to use the Data Envelopment Analysis (DEA) method to evaluate the effectiveness of management in a dairy sheep farm working with lambing as a productive unit. This is because lambing triggers production events on the farm, such as the birth of lambs, the start of milk production, and the organisation of the lambing pen, labour, milking, and facilities. However, producers and technicians tend to maintain a traditional view, inherited from cattle farming, that centres on the sheep as a production unit and assumes a single annual lambing per animal, which is increasingly rare in current systems. Our aim is to use this approach to propose recommendations that will improve the efficiency and profitability of sheep dairy farms.

2. Material and methods

2.1. Farm location and database

Production and economic data were collected from an Assaf dairy sheep farm located in Valoria la Buena (41°47′48''N, 4°35′16''W, 706 m.a.s.l.), which operates on its own land in the province of Valladolid, Spain. This farm maintains a flock of 2000 Assaf ewes, each weighing between 50 and 80 kg. The sheep are organised into different groups and fed via a conveyor belt system. This is supplemented by a unifeed mixer wagon which records the amount of feed distributed to each belt on a wet matter basis. Each belt corresponds to two groups of sheep, enabling precise tracking of the feed consumed by each productive group.

For this study, 2474 lambing events were recorded from 2146 ewes of varying ages (during the period studied in this work, each sheep had more than one birth). The lambings were categorized based on the number of previous lambings for each ewe, resulting in the following distribution: first lambing (L1) - 20.6 %, second lambing (L2) - 18.6 %, third lambing (L3) - 15.6 %, fourth lambing (L4) - 15.4 %, fifth lambing (L5) - 12.3 %, and sixth or subsequent lambings (L6+) - 17.4 %.

For each recorded lambing event, additional data were collected to characterize the specific scenario in which the lambing occurred. The selection of input and output variables for the DEA model was carried out through a combination of practical and academic guidance. Farm technicians were consulted to identify which operational factors most directly influenced efficiency at the production level. Their insights helped ensure that the model reflected the realities of farm management. In parallel, academic experts in animal production reviewed and validated the structure of the model, ensuring alignment with theoretical principles and sector-specific knowledge. This collaborative approach provided both practical relevance and methodological rigor to the choice of variables.

The set of collected variables included:

- Concentrate Feed (%Conc): Percentage of concentrate fed to the ewe during lactation, obtained from the farm's feed purchase records. The proportion of concentrates (such as grains, feed and flour) in relation to the total food consumed by the animals was calculated and expressed on a dry matter basis. It was supplied via a Unifeed cart and distributed using a feed belt.
- Lambing Campaign (LC): Refers to the practice of scheduling lambing to sell lambs at specific times. On the study farm, five annual lambing campaigns are planned, occurring in February (LC1), April (LC2), July (LC3), September (LC4), and November (LC5). Besides other economic factors such as ewe feeding, the most favorable lambing periods in Spain are from June to October or early November. This aspect refers to the months scheduled for managing ewe lambings. These months are strategically distributed throughout the year to allow for the division of labour among several groups, ensure continuous milking and concentrate lambing periods. This organisation also enables months to be designated as 'lambing-free', during which essential tasks such as disinfection, cleaning and facility maintenance can be carried out. These measures are regarded as fundamental for controlling diseases in both lambs and ewes.
- Inter-Lambing Interval (ILI): The number of days in the lactation period plus two months (Requejo et al., 2010). This represents the reproductive intensity of the flock; a shorter interval indicates higher reproductive intensity, meaning the ewes are prepared for post-lambing sooner, leading to earlier fertile lambings. In our case, it is the number of days between each birth, which is obviously related to the time of mating during the milking process. If animals are highly productive but pregnant, those with high milk production must be dried off (stopped from being milked) so they can rest before giving birth again. The farmer must control this process, as if it is not managed correctly, the animals may stop producing milk without a rest period.
- Rest Days (RD): The number of days between the end of lactation and the next lambing. Correspond to the period between the last milking and subsequent calving. The days between calvings are the days between each calving and are obviously related to the mating period during the milking cycle. If animals are highly productive and pregnant, they must be forced to dry off (i.e. stop milking) so that they can rest before giving birth again. The farmer must control this process, as if it is not enforced, the animals may stop milking without a rest period.
- Age at Lambing (AL): The age in years of the ewe at lambing. The first lambing usually occurs when the ewes are between one and a half and two years old. After this, they usually lamb three times every two years.
- Ewe lambing number (NL): The number of times the ewe has given birth during the studied lactation period. The number of times she has given birth in her lifetime.
- Genetics: This was calculated from the Stablemate Index (Deng et al., 2024) for each lambing. This indicator is calculated by comparing the milk production of each lambing with that of all the ewes in the flock, as well as with ewes that lambed in the same month and with those that lambed the same number of times. This provides an indication of comparative milk production.
- Liveborn Lambs at each lambing (LL): The number of liveborn lambs at each lambing. This indicator shows how prolific each birth is and how viable the lambs are at birth.
- Milk yield per lambing (MY): The liters of milk produced by the ewe at each lambing. This indicator shows the amount of milk produced for each studied birth. This theoretical calculation is performed using the ICAR methodology for official milk monitoring (ICAR, 2023).

2.2. DEA methodology

Farrell (1957) was the first to introduce the theoretical framework for measuring efficiency. He defined the efficiency of a decision-making unit (DMU) as the most appropriate way of using productive resources given the existing technology. Farrell divided efficiency into technical and allocative efficiency. Technical efficiency refers to the ability of a DMU to obtain the maximum level of output from a given set of inputs, while allocative efficiency determines how to achieve a given level of output with the least possible combination of inputs. The combination of both technical and allocative efficiency determines economic efficiency (Arzubi and Bercel, 2022).

In this conceptual framework, two methods have been developed to measure technical efficiency (TE): parametric and non-parametric techniques. This study opts for the non-parametric method and employs Data Envelopment Analysis (DEA), originally developed by Charnes et al. (1978). Using mathematical programming, DEA calculates measures of technical efficiency for a set of DMUs (Coll and Blasco, 2006), referencing a frontier composed of the best production practices observed within the set. The model establishes an efficiency frontier, where DMUs that use their resources adequately are deemed 100 % efficient relative to the total evaluated DMUs (Nathanson et al., 2003). This method allows for comparison of efficiency among the set of DMUs, positioning each unit relative to others (Cooper et al., 2006). DEA also identifies sources of inefficiency by indicating which resources are being overutilized (Thanassoulis, 1993).

The DEA model can be either input-oriented or output-oriented (Charnes et al., 1978). Input-oriented models seek the maximum proportional reduction in inputs for a given level of output, indicating a unit is inefficient if any input can be reduced without altering the output. Output-oriented models determine the maximum proportional increase in outputs given a level of inputs, while remaining within the production possibilities frontier.

Another important aspect of evaluating efficiency is determining the type of performance in which the DMU operates. The most common models are the constant returns to scale (CRS) model proposed by

Table 1
Rules for DEA Model Dimensionality.

$p = 6; q = 2$	
L1 ($n = 509$)	Sufficient dimensionality
L2 ($n = 461$)	Sufficient dimensionality
L3 ($n = 386$)	Sufficient dimensionality
L4 ($n = 382$)	Sufficient dimensionality
L5 ($n = 305$)	Sufficient dimensionality
L6+ ($n = 431$)	Sufficient dimensionality

Charnes et al. (1978) and the variable returns to scale (VRS) model by Banker et al. (1984). In the CRS model, each DMU is compared with all the DMUs in the sample and evaluated based on their performance, making this model essentially a measure of overall technical efficiency (TE). The TE coefficients in the CRS model are a non-additive combination of pure technical efficiency and scale efficiency. Assuming that efficiency results from management skills and scale effects, the CRS model results can be interpreted as a reflection of management skills. If a DMU is fully efficient in CRS (TE=1), it means it is operating at the most productive scale size (Arzubi and Bercel, 2022).

The theoretical development of the model is based on a production function where a set K ($k = 1,\ldots,n$) of DMUs is assumed to use a vector of inputs $x = (x_1, \ldots, x_M)$ to produce a vector of outputs $y = (y_1, \ldots, y_R)$. DEA defines the efficiency of a DMU as the maximum value of a ratio that transforms its inputs into outputs. The model relates the values of the variables (inputs/outputs) of each DMU by comparing them and determining which are the most efficient in the set. The full methodological development of the method and relevant applications can be found in multiple sources (Boussofiane et al., 1991; Charnes et al., 1994; T.J. Coelli et al., 2005; Coll and Blasco, 2006; Cooper et al., 2007; El-Mahgary, 1995).

Regarding the functional form of the production function, the DEA methodology has the advantage of not requiring any assumptions about its functional form (Rajiv D. Banker and Chang, 2006). The choice of variables is another key aspect in the successful application of the DEA method. Dyson et al. (2001) highlight the characteristics that the selected inputs and outputs must verify, including: covering the available resources, encompassing all levels of activity, and being common to all units.

Within this methodological framework, the present work utilizes a DEA model with constant returns to scale (CRS) oriented towards production. The decision unit is the lambing event, and for a given flock and period, the TE coefficients for L1 through L6+ have been estimated. Using parturition as a DMU is a significant contribution to the application of this methodology, which has no precedent in the specialized literature that typically focuses on the flock or individual ewe. The "lambing" concept offers a powerful tool for efficient flock management, providing an individualized view of results and enabling the establishment of adjustment strategies to improve farm outcomes.

Another important aspect in the application of the DEA model is its dimensionality (number of variables and units). An excessive number of DMUs and variables tends to result in a greater number of DMUs with TE = 1, causing the model to lose its discriminatory capacity (Nunamaker, 1985). There are three common rules to determine the correct dimensionality of the method, proposed by Golany and Roll (1989) - $n \geq 2\,(p + q)$, Charnes et al. (1990) - $n \geq 3\,(p + q)$, and Murias (2003) - $n \geq (p \times q)$. Here, n is the number of DMUs, p is the number of inputs, and q is the number of outputs.

In the present study, we verified that all groups under analysis satisfy these dimensionality requirements. As detailed in Table 1, the number of DMUs in each group exceeds the most restrictive of the proposed thresholds. This ensures that the model retains sufficient discriminatory power and that the efficiency estimates are robust and reliable. Including this validation strengthens the methodological soundness of the DEA application and aligns with best practices in the efficiency analysis literature.

The model specification follows the traditional scheme of a production function, in this case with six inputs and two outputs (Fig. 1). The software used was MaxDEA (MaxDEA Software LTd.,) (Gang, 2014).

3. Results and discussion

3.1. Mean values of the study lambings

The average milk production for the 2484 lambings studied was 394.7 liters, which is comparable to published records for Lacaune ewes, the main competitor in terms of milk production, with an average of 350 kg over a milking period of 150 days (MAPA, 2024b). In contrast, the Churra breed has an average production of 77 liters per ewe (A. Mantecón and Lavín, 2000).

An average fertility of 1.40 live-born lambs per lambing was determined (Table 2). This value is low compared to other studies. The National Association of Sheep Breeders of the Assaf breed (ASSAFE, 2024) reports that Assaf breed females have an average fertility of 1.60 offspring per lambing, while for the Rasa Aragonesa breed, it is 1.68 offspring per lambing (Pérez et al., 2007).

The average percentage of concentrate feed per lactation was 47.0 %. It is established that when the level of concentrates exceeds 50 % of the dry matter in the ration, it promotes rumen acidity, which in turn reduces the fat and protein content of the milk (Elhadi et al., 2017). Another study found that the average level of concentrate consumption during the lactation period (early, mid, and late lactation) was 54.4 % for Assaf and Awassi breed ewes reared on farms in Castilla y León (Milán et al., 2011).

In Spain, lambing is mostly concentrated between April and June (2.8 lambings); ideally, lambing should be concentrated at the end of winter and in spring to optimize natural resources (Simões et al., 2021).

The average interval for ewes to lamb again is 248.8 days (8.3 months), achieving three lambings in three years. In the study by Milán et al. (2011) on Assaf and Awassi ewes, the mean interval between lambings was 9.6 months.

Ewes rest for an average of 59 days before their next lambing after dry-off. It has been reported that Lacaune breed ewes that rest between 30 and 90 days have higher productivity in their next lactation (Hernández-Díaz, 2016).

The mean ewe mating index is −0.04, and the mean age of the ewe at

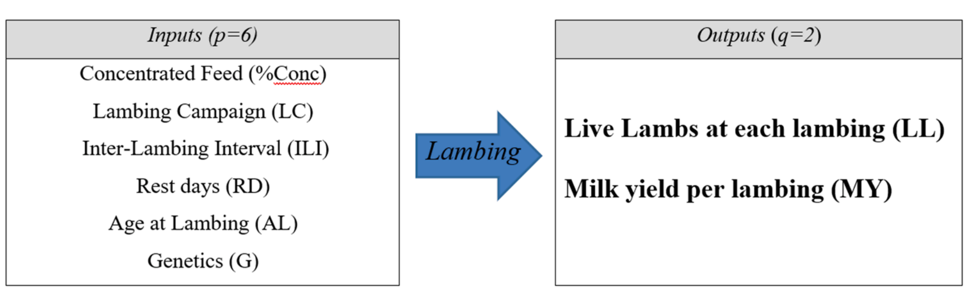

Fig. 1. Traditional scheme of a production function.

Table 2
Descriptive statistics of the study variables (n = 2484 records).

	%Conc	LC	ILI (days)	RD (days)	AL (years)	G	LL	ML (liters)
Average	47.0	2.8	248.8	59.0	3.6	−0.04	1.4	394.7
Max	51.1	5.0	1514.0	1227.0	11.9	3.7	3.0	1301.0
Min	42.2	1.0	0.0	0.0	0.8	−4.0	0.0	0.0
SD	2.8	1.4	145.4	65.7	2.1	0.8	0.6	193.1

%Conc: Concentrate Feed, LC: Lambing Campaign, ILI: Inter-Lambing Interval, RD: Rest Days, AL: Age at Lambing, G: Genetics, LL: Liveborn Lambs at each lambing, MY: Milk yield per lambing.

Table 3
Main characteristics of efficient lambings according to DEA criteria.

Lambings	L1	L2	L3	L4	L5	L6+
% Efficiency (TE = 1)	*2.0*	*4.1*	*14.5*	*6.2*	*5.6*	*7.2*
%Conc	44.9	46.6	46.3	45.7	45.79	46.52
LC	1.8	2.1	1.8	2.5	2.35	1.87
ILI (days)	-	259.2	317.5	292.8	263.06	294.23
RD (days)	-	60.1	79.5	60.2	57.18	64.00
AL (years)	1.5	2.0	3.2	3.8	4.59	7.11
G	2.1	2.9	2.2	1.3	1.23	1.59
LL	2.1	1.9	1.9	2.4	2.06	2.23
MY (liters)	487.5	555.1	495.8	499.7	508.35	482.42

%Conc: Concentrate Feed, LC: Lambing Campaign, ILI: Inter-Lambing Interval, RD: Rest Days, AL: Age at Lambing, G: Genetics, LL: Liveborn Lambs at each lambing, MY: Milk yield per lambing.

Table 4
Main characteristics of inefficient lambings according to DEA criteria.

Lambings	L1	L2	L3	L4	L5	L6+
% Efficiency (0< TE < 1)	*98.0*	*95.9*	*85.5*	*93.8*	*94.4 %*	*92.8*
%Conc	47.8	47.8	48.5	47.9	48.2	47.7
LC	3.1	3.7	4.1	3.5	3.8	4.1
ILI (days)	-	343.4	337.8	340.6	313.9	338.2
RD (days)	-	89.8	118.3	105.9	96.6	111.1
AL (years)	1.6	2.3	3.5	4.2	5.1	8.2
G	4.3	3.6	3.0	2.2	2.1	2.3
LL	1.1	1.4	1.3	1.5	1.5	1.5
MY (liters)	415.0	437.1	366.0	403.1	367.8	321.9

%Conc: Concentrate Feed, LC: Lambing Campaign, ILI: Inter-Lambing Interval, RD: Rest Days, AL: Age at Lambing, G: Genetics, LL: Liveborn Lambs at each lambing, MY: Milk yield per lambing.

lambing is 3.6 years. Milk yield reaches a maximum value of 1301 liters with a standard deviation of 193.1. Live births have a maximum value of 3 lambs with a standard deviation of 0.6.

3.2. Characteristics of efficient lambing according to DEA

Table 3 shows the main characteristics of efficient lambings (TE=1), according to DEA criteria. Only 2.0 % of the lambings are efficient in the first lambing, and 4.1 % are efficient in the second lambing. The highest efficiency is observed in the third lambing, which reaches 14.5 %. More positive results were obtained in a study conducted in South Africa on ewes producing milk, wool, meat, or for mixed production, where the average value of total efficiency was 67.40 % (Conradie and Piesse, 2015). However, in a study on ewes from Turkey, the average value of lambing efficiency ranged between 41–48 % (Dalgic et al., 2018).

Focusing on the third lambing, which yielded the best results, the ewes spent 46.3 % on concentrates during milking. This figure was higher (60.5 %) during the high milk production stage of Assaf and Awassi ewes in the study by Milán et al. (2011).

The third lambing of our ewes mainly occurred between February and April (1.8), with an average interval between lambings of 317.5 days, resulting in 1.16 lambings per year. The ewes dried off after milking and rested for 79.5 days before the next lambing, producing an average of 495.8 liters per lactation, with 1.9 lambs born per lambing. The genetic index of the ewes during this third lambing is 2.2. Although they are not the most productive, the genetic index of the ewes in the efficient group for the second lambing is 2.9.

The first calving is often a difficult time for the animal, as it experiences circumstances that are new to it physiologically. It may not reach sufficient weight or development, or it may not adapt correctly to milking routines, the milking machine, and so on. This inefficiency may be due to this. However, by the third calving, the animal is fully developed and has acquired the experience and routines necessary to become much more efficient.

Table 5
Adjustments to the inputs proposed by the DEA method, expressed in %.

Lambings	L1	L2	L3	L4	L5	L6+
%Conc	−9.2	−7.7	−9.4	−8.8	−9.3	−7.1
LC	−42.4	−42.0	−43.6	−39.2	−26.2	−27.3
ILI	-	−18.6	−21.5	−17.2	−18.4	−17.4
RD	-	−44.7	−33.4	−44.9	−58.5	−42.7
AL	−20.4	−15.4	−12.9	−11.0	−11.5	−17.5
G	−31.7	−14.7	−14.2	−23.1	−17.3	−19.5

%Conc: Concentrate Feed, LC: Lambing Campaign, ILI: Inter-Lambing Interval, RD: Rest Days, AL: Age at Lambing, G: Genetics.

3.3. Characteristics of inefficient lambing according to DEA

Table 4 shows the main characteristics of inefficient lambings (0< TE < 1), according to DEA criteria. The most inefficient lambing corresponded to the first lambing of the ewes, with 98.0 % of these first lambings being inefficient.

The use of concentrates during the milking of inefficient lambings ranged from 47.7 % for L6+ to 48.5 % for L3, with a variation of <1 %. In principle, farmers increase the concentrate consumption of their animals in accordance with their production level. Therefore, it would be anticipated that the lambing with the highest milk production (L2: 437.1 liters per lactation) would exhibit the highest concentrate consumption. However, the results of the analysis suggest that there is no direct relationship between the two variables. The system highlights excessive concentrated feeding in group feeding systems on livestock farms. As a general rule, farmers feed animals in groups based on calving time rather than individually. While this meets the needs of the highest producers, the rest are overfed, which may be responsible for this inefficiency.

In Spain, the season of inefficient lambings is between July and September or between September and November, with values varying between 3.15 and 4.1. The interval between lambings is over 310 days in all cases, with a maximum of 343.3 days for L2. The lambing period of the ewes exceeds 3 months, reaching 4 months in L3. Ewe age at lambing ranges from a maximum of 8 years for L6+ to one and a half years for L1. The genetic value (G) tends to decrease as the number of lambings increases, ranging from 4.34 at L1 to values around 2 from L4 onwards.

3.4. Management adjustments proposed by the DEA system

Based on the results presented in Table 3, the DEA method suggests

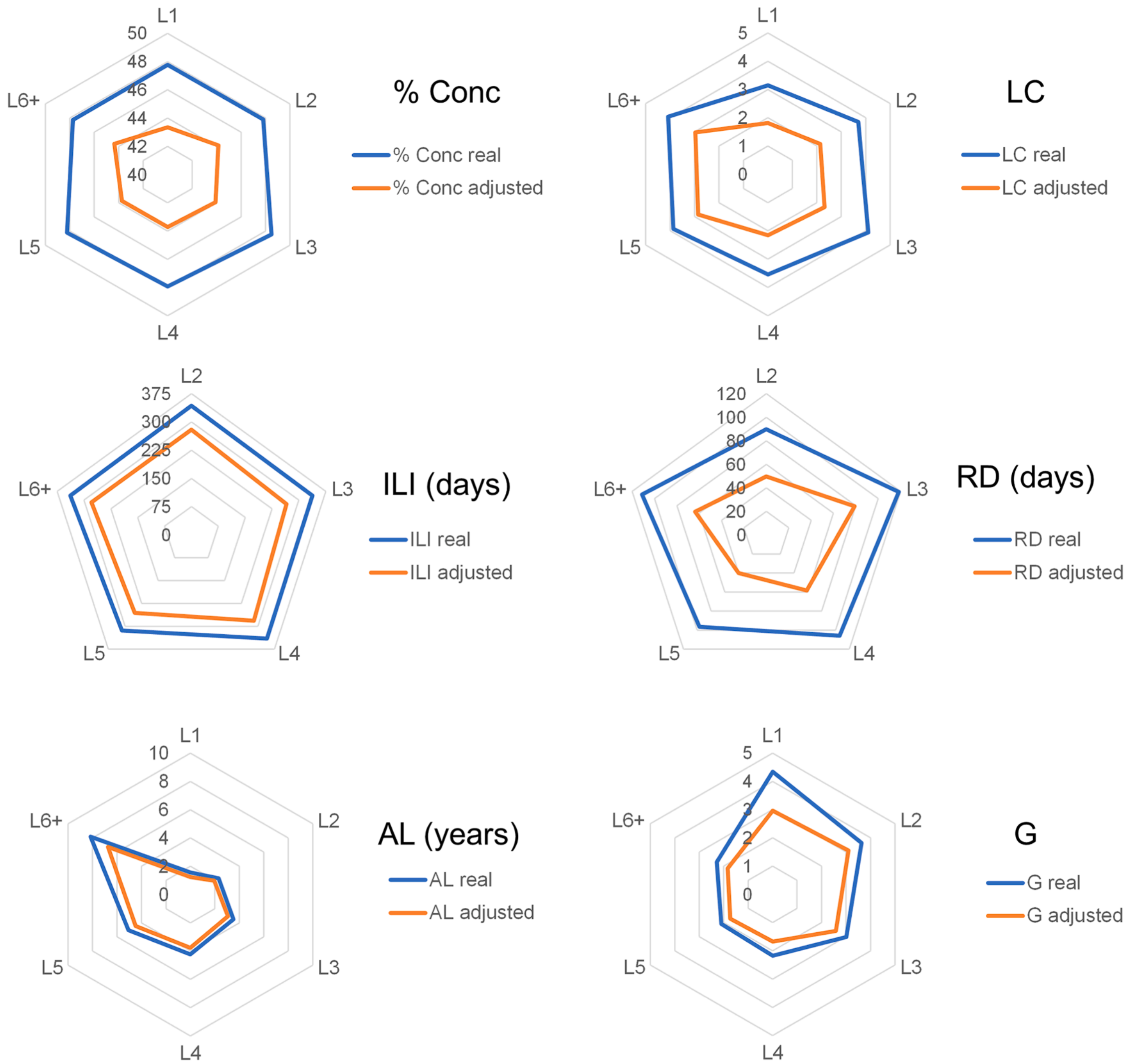

Fig. 2. Real and adjusted values for inputs. %Conc: Concentrate Feed, LC: Lambing Campaign, ILI: Inter-Lambing Interval, RD: Rest Days, AL: Age at Lambing, G: Genetics, LL: Liveborn Lambs at each lambing, MY: Milk yield per lambing.

the necessary input adjustments to address inefficiencies (see Table 5 and Fig. 2).

Concerning LC, the method suggests scheduling the first campaign between February and April, ensuring that young animals are mated between September and November, coinciding with their natural estrus cycle influenced by the photoperiod's effect on melatonin secretion (Balasse et al., 2024). Nulliparous ewes should ideally be born between November and February of the same mating year, facilitating natural mating without the expense of hormonal synchronization, which can cost approximately 9 euros per ewe in the case of artificial insemination (A. R. Mantecón, 2021). Fig. 2 illustrates the largest deviation between real and adjusted campaigns occurring at lambing 3, with a reduction value of 1.8, and the smallest at lambing 5, with a reduction of 1.0.

Overall, the model recommends directing lambing towards spring and, ideally, June, which poses challenges for large farms and systems with continuous milk production needs throughout the year. For instance, farms employing a controlled weekly mating system require careful organization to manage labor efficiently, reduce workloads, and ensure long-term sustainability (Requejo et al., 2010).

A study on a 3000-ewe intensive milking farm operating in two shifts revealed that routine labor averaged 7 h per ewe per year, with an additional 1.5 h per lambing event, amounting to an average workload of 24.1 h/day. According to the General Workers' Agreement, this translates to an average of 4.93 workers per farm, or 203 ewes per person. However, this figure often does not align with the actual operational demands of the farm (Requejo et al., 2010).

The model proposes a significant reduction in the ILI to below 300 days for all lambings (MAPA, 2024a), which is on average 285 days for this breed. Reductions range from 21.5 % for L3 to 17.4 % for L6+, effectively shortening the period between lambings by approximately two months. However, advancing the fertile mating period by two months, as suggested, can be challenging due to the animal's productive level or the farm's reproductive organization. Palacios (2008) notes that mating between the third and fifth month postpartum negatively affects milk production, with high milk yield adversely impacting reproductive activity. Fig. 2 illustrates reductions in days for L3 from 337.8 (real) to 265.2 (adjusted), totaling 72.6 days, and for L6+, from 338.2 (real) to 279.4 (adjusted), a reduction of 58.8 days.

For the RD input, the model recommends a reduction of 33.3 % for L3 to 58.5 % for L5, equivalent to approximately two months. This approach mirrors recommendations for beef cattle, where dry periods are crucial for optimal milk production, allowing milk-secreting cells to involute and prepare for the next lactation. Srivastava et al. (2015) highlight that without a dry period, milk production in dairy cattle could decrease by 25–30 %. Fig. 2 indicates the proposed reductions in rest days, with L3 expected to decrease by 39.5 days (from 72.6 real to 33.1 adjusted) and L5 by 56.5 days (from 96.6 real to 40.1 adjusted) (MAPA, 2024a).

Table 6
Adjustments to the ouputs proposed by the DEA method, expressed in %.

Lambings	L1	L2	L3	L4	L5	L6+
LL	91.3	66.3	58.1	63.6	68.2	60.3
MY	95.5	62.8	63.4	71.5	82.6	68.5

LL: Liveborn Lambs at each lambing, MY: Milk yield per lambing.

The model also suggests advancing the AL across all scenarios. For instance, L1 is proposed to occur at 1.2 years (15 months) instead of 1.6 years (19 months). Jurado and Jiménez (2013) suggest that advancing the first lambing before 15 months enhances production efficiency in Assaf ewes, leading to more lambs during their productive life (4.89 lambs compared to 4.72–4.73 lambs for ages above 15 months). Achieving this involves mating young animals between 9 and 10 months of age, ideally born in November or December, aligning with the breed's average age at first lambing of 15 months. The model recommends reducing the age at first lambing and increasing the flock's prolificacy, which are factors that farmers can actively influence through their decision-making. Proper feeding during the rearing and growth phases, standardising groups to achieve better development in less time and improving nutrition at mating time can lead to better reproductive results in young animals and higher prolificacy.

Regarding G selection, the model emphasizes choosing ewes with higher productivity, particularly in the first three lambings. However, despite the recommendations, inefficient lambings often involve ewes with lower productive qualities, indicating that genetic selection alone may not always achieve desired breeding objectives. Fig. 2 illustrates the largest deviation between real and adjusted data in the first lambing, with a difference of 1.3 (real 3 vs adjusted 4.3).

Regarding lambing production outcomes (Table 6 and Fig. 3), the average number of LL increases by 68 %. The highest number is observed at L4 with 2.4 offspring, while the most significant increase occurs at L1, doubling from 1.1 to 2.2 lambs (MAPA, 2024a), highlighting the Assaf breed's average fertility of 1.8 lambs per lambing.

In terms of MY, the average improvement reaches 74.0 %, with the highest increase observed in L1, projecting a rise of 95.5 % (from 415 to 811.4 liters). Following closely, L5 is expected to increase from 367.8 to 671.6 liters, marking an 82.6 % improvement. The remaining lambings show improvements ranging from 62.8 % to 71.5 %. According to data from MAPA (2024b), the Assaf breed typically averages 400 kg of milk over a 180-day lactation period, indicating a substantial increase over these standard values.

4. Conclusions

The DEA system offers a method to optimize the management of dairy sheep farms, aiming to enhance productivity and consequently improve economic outcomes. These findings emphasise the importance of improving reproductive performance by delaying the age at first lambing. This will optimise productive efficiency and reduce periods of inactivity within the flock.

Contrary to the conventional approach of maximizing resource intensification, the system proposes reducing concentrate consumption during lactation. This contrasts with the typical practice among farmers, who often increase concentrate intake to boost production.

The degree of improvement suggested by the system, exceeding 50 % across all lambings, hinges on the genetic quality of the animals and the farmer's willingness to implement recommended management adjustments.

As the pilot farm used in this study is representative of a general model of a farm specialising in sheep milk production, the results obtained are highly applicable to other specialised farms. All the actions required to optimise the flock are based on the farmer's planning, making them easily manageable. The next steps to be explored are the economic and technical implications of global decision-making relating to the organisation of farm production systems. It is important to identify the economic and technical optima that should be maintained in each system to achieve maximum efficiency. The ultimate goal is to use the platform to support farmers in making decisions.

It is essential to ensure that the knowledge generated from studies like this reaches a broader audience. We will make every effort to disseminate the results through digital platforms and social media in order to enhance public understanding of livestock farming. Previous research has shown that platforms such as Instagram can effectively communicate complex technical information (Lamanna et al., 2025), thereby supporting knowledge transfer and stakeholder engagement.

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Data statement

The data that support this study will be shared upon reasonable request to the corresponding author.

CRediT authorship contribution statement

Cristina Hidalgo-González: Writing – original draft, Supervision, Formal analysis, Visualization, Methodology, Data curation, Writing – review & editing, Validation, Investigation, Conceptualization. **M.Pilar Rodríguez-Fernández:** Validation, Data curation, Methodology, Conceptualization, Writing – original draft, Formal analysis. **Jaime Nieto:** Validation, Supervision, Writing – original draft, Investigation. **M.Elena Pérez-García:** Writing – original draft, Investigation. **Javier Plaza:** Writing – review & editing, Investigation, Writing – original draft, Data curation, Validation. **Carlos Palacios:** Writing – original draft, Investigation, Validation, Data curation, Writing – review &

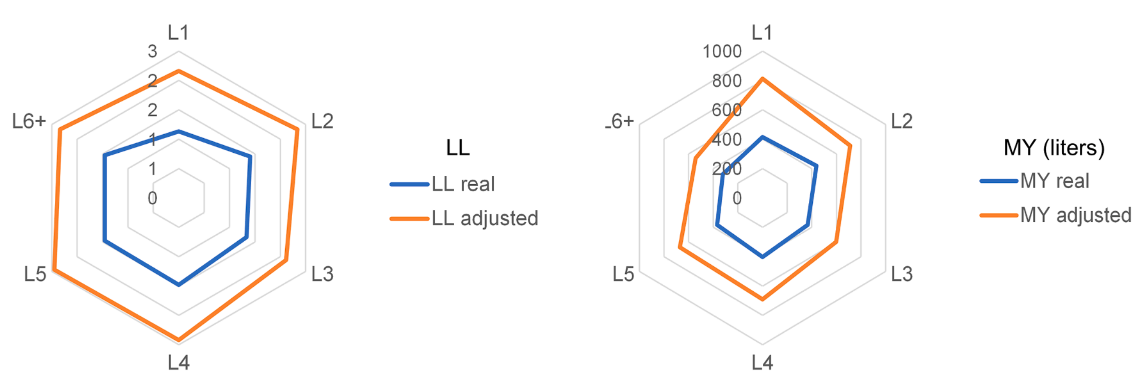

Fig. 3. Real and adjusted values for outputs. LL: Liveborn Lambs at each lambing, MY: Milk yield per lambing.

editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Arzubi, A., Bercel, J., 2022. Determination of efficiency indices by DEA in dairy farms in Buenos Aires. [Spanish]. Investig. Agrar. Prod. Sanid. Anim. 17, 103–124.

ASSAFE. (2024). *National Association of Sheep Breeders of the Assaf breed.*

Balasse, M., Chemineau, P., Parisot, S., Fiorillo, D., Keller, M., 2024. Experimental data from Lacaune and Merino sheep provide new methodological and theoretical grounds to investigate Autumn lambing in past husbandries. J. Archaeol. Method Theory 31 (1), 75–92. https://doi.org/10.1007/s10816-022-09600-7.

Banker, R.D., Charnes, A., Cooper, W.W., 1984. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci. 30 (9), 1078–1092. https://doi.org/10.1287/mnsc.30.9.1078.

Banker, Rajiv D., Chang, H., 2006. The super-efficiency procedure for outlier identification, not for ranking efficient units. Eur. J. Oper Res. 175 (2), 1311–1320. https://doi.org/10.1016/j.ejor.2005.06.028.

Boussofiane, A., Dyson, R.G., Thanassoulis, E., 1991. Applied data envelopment analysis. Eur. J. Oper. Res. 52 (1), 1–15. https://doi.org/10.1016/0377-2217(91)90331-O.

Charnes, A., Cooper, W.W., Huang, Z.M., Sun, D.B., 1990. Polyhedral cone-ratio DEA models with an illustrative application to large commercial banks. J. Econ. 46 (1–2), 73–91. https://doi.org/10.1016/0304-4076(90)90048-X.

Charnes, A., Cooper, W.W., Lewin, A.Y., Seiford, L.M., 1994. Basic DEA models. Data Envelopment Analysis: Theory, Methodology, and Applications. Springer Netherlands, pp. 23–47. https://doi.org/10.1007/978-94-011-0637-5_2.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2 (6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8.

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J., Battese, G.E., 2005. An Introduction to Efficiency and Productivity Analysis, 2nd ed. Springer, New York, NY, United States. https://doi.org/10.1007/b136381. *2nd ed.*Springer.

Coelli, Tim J., 1995. Recent developments in frontier modelling and efficiency measurement. Aust. J. Agric. Econ. 39 (3), 219–245. https://doi.org/10.1111/j.1467-8489.1995.tb00552.x.

Coll, V., Blasco, O.M., 2006. Efficiency evaluation using data envelopment analysis. Introduction to basic models. [Spanish]. In: Martínez-Coll, J.C. (Ed.), Valencia: B-EUMED 2000. Universidad Politécnica de Valencia.

Conradie, B., Piesse, J., 2015. Productivity benchmarking of free-range sheep operations for Laingsburg, South Africa. Agrekon 54 (2), 1–17. https://doi.org/10.1080/03031853.2015.1065186.

Cooper, W.W., Seiford, L.M., Tone, K., 2006. *Introduction to Data Envelopment Analysis and Its Uses* (I). Springer, Boston, MA. https://doi.org/10.1007/0-387-29122-9.

Cooper, W.W., Tone, K., Seiford, L.M., 2007. Data Envelopment analysis : a Comprehensive Text With models, applications, References and DEA-solver Software. Springer US.

Dalgic, A., Demircan, V., Ormeci Kart, M.C., 2018. Technical efficiency of sheep farming in Turkey: a case study of Isparta Province. Sci. Pap.-Ser. Manag. Econ. Eng. Agric. Rural Dev. 18 (3), 65–72.

Deng, Y., Mao, J., Choi, J., Lê Cao, K.-A., 2024. StableMate: a statistical method to select stable predictors in omics data. NAR Genom. Bioinform. 6 (4), 130. https://doi.org/10.1093/NARGAB/LQAE130.

Dyson, R.G., Allen, R., Camanho, A.S., Podinovski, V.V., Sarrico, C.S., Shale, E.A., 2001. Pitfalls and protocols in DEA. Eur. J. Oper. Res. https://doi.org/10.1016/S0377-2217(00)00149-1.

El-Mahgary, S., 1995. Data envelopment analysis. OR Insight 8 (4), 15–22. https://doi.org/10.1057/ori.1995.21.

Elhadi, A., Caja, G., Salama, A., Mendivil, M., Durán, E., Albanell, E., 2017. Effects of forage to concentrate ratio in dairy ewes [Spanish]. AIDA XVII Jorn. Sobre Prod. Anim. 126–128.

Färe, R., Grabowski, R., Grosskopf, S., 1985. Technical efficiency of Philippine agriculture. Appl. Econ. 17 (2), 205–214. https://doi.org/10.1080/00036848500000018.

Farrell, M.J., 1957. The measurement of productive efficiency. J. R. Stat Soc. A. 120 (3), 253. https://doi.org/10.2307/2343100.

Gang, C., 2014. Data Envelopment Analysis Method and MaxDEA Software [M]. Intellectual Property Publishing House, Beijing.

Golany, B., Roll, Y., 1989. An application procedure for DEA. Omega (Westport) 17 (3), 237–250. https://econpapers.repec.org/RePEc:eee:jomega:v:17:y:1989:i:3:p:237-250.

Hernández-Díaz, F., 2016. Influence of Reproductive Management On the Productive Indices of an Intensive Dairy Sheep Farm of Lacaune breed in Spain. Bases for the Improvement of productivity. [Spanish]. Universidad Complutense de Madrid. *Universidad Complutense de Madrid*.

ICAR. (2023). *Procedure 5 of Section 11 of ICAR Guidelines - Procedure for Testing of Automatic Milk Recording and Sampling Systems* (ICAR. The Global Standard for Livestock Data, Ed.). ICAR.

Iráizoz, B., Rapún, M., Zabaleta, I., 2003. Assessing the technical efficiency of horticultural production in Navarra, Spain. Agric. Syst. 78 (3), 387–403. https://doi.org/10.1016/S0308-521X(03)00039-8.

Jurado, J., Jiménez, M., 2013. Relationship between productive life and age at first lambing in dairy and beef ewes. [Spanish]. AIDA XV Jorn. Sobre Prod. Anim. II 454–456.

Lamanna, M., Muca, E., Buonaiuto, G., Formigoni, A., Cavallini, D., 2025. From posts to practice: instagram's role in veterinary dairy cow nutrition education—How does the audience interact and apply knowledge? A survey study. J. Dairy Sci. 108 (2), 1659–1671. https://doi.org/10.3168/jds.2024-25347.

Latruffe, L., Bravo-Ureta, B.E., Carpentier, A., Desjeux, Y., Moreira, V.H., 2017. Subsidies and technical efficiency in agriculture: evidence from European dairy farms. Am. J. Agric. Econ. 99 (3), 783–799. https://doi.org/10.1093/ajae/aaw077.

Laurinavičius, E., Rimkuvienė, D., 2017. The comparative efficiency analysis of EU members agriculture sectors. Rural Sustain. Res. 37 (332), 10–19. https://doi.org/10.1515/plua-2017-0002.

Liu, J.S., Lu, L.Y.Y., Lu, W.-M., Lin, B.J.Y., 2013. A survey of DEA applications. Omega (Westport) 41 (5), 893–902. https://doi.org/10.1016/j.omega.2012.11.004.

Mantecón, A., Lavín, P., 2000. Sheep milk production: the region of Castilla y León (Spain) as a model. [Spanish]. Cuad. Ceagro 2, 139–152.

Mantecón, A.R., 2021. Techno-economic analysis of the impact of artificial insemination (AI) on farm profitability. [Spanish]. In: *Agricultura. Seminario 4: 'Nuevo Modelo Sanitario En El Ovino Español (II): Reproducción Sostenible y Eficiente'*.

Mantecón, A.R., Díez, P., Villadangos, B., Martínez, Y., Lavín, P., 2007. Flock size and importance of production factors in sheep milk production systems in León (Spain). [Spanish]. Econ. Gest. 125–128.

Mantecón, Á.R., Lavín, P., 2001. Sheep, present and future: the Assaf breed. [Spanish]. Mundo Ganad. XII (136), 68–72.

MAPA, 2023. The Sheep and Goat Sector in figures. Main economic indicators. Data 2023. [Spanish]. Ministerio de Agricultura, Pesca y Alimentación.

MAPA. (2024a). *Assaf breed [Spanish].*

MAPA. (2024b). *Lacaune breed [Spanish].*

Milán, M.J., Caja, G., González-González, R., Fernández-Pérez, A.M., Such, X., 2011. Structure and performance of Awassi and Assaf dairy sheep farms in northwestern Spain. J. Dairy Sci. 94 (2), 771–784. https://doi.org/10.3168/JDS.2010-3520.

Murias, M.P., 2003. Methodology for the application of Data Envelopment Analysis: evaluation of technical efficiency at the University of Santiago de Compostela. [Spanish]. In: Eduga: Revista Galega Do Ensino, 46. Universidade de Santiago de Compostela.

Nathanson, B.H., Higgins, T.L., Giglio, R.J., Munshi, I.A., Steingrub, J.S., 2003. An exploratory study using data envelopment analysis to assess neurotrauma patients in the intensive care unit. Health Care Manag Sci. https://doi.org/10.1023/A:1021912320922.

Nunamaker, T.R., 1985. Using data envelopment analysis to measure the efficiency of non-profit organizations: a critical evaluation. Manag. Decis. Econ. 6 (1), 50–58. https://doi.org/10.1002/mde.4090060109.

Palacios, C., 2008. Mating of ewes during milking. [Spanish]. Albéitar 120, 54–55.

Pereira, J.S., David, J.S., David, T.S., Caldeira, M.C., Chaves, M.M., 2004. Carbon and water fluxes in Mediterranean-type ecosystems— Constraints and adaptations. Prog. Bot. 65, 467–498. https://doi.org/10.1007/978-3-642-18819-0_19.

Pérez, J.P., Gil, J.M., Sierra, I., 2007. Technical efficiency of meat sheep production systems in Spain. Small Rumin. Res. 69 (1–3), 237–241. https://doi.org/10.1016/J.SMALLRUMRES.2006.02.003.

Plaza, Isabel, Nieto, Jaime, Hidalgo, Cristina, Sánchez-García, Mario, Palacios, C.J.R., 2021. Milk quality and carbon footprint indicators of dairy sheep farms depend on grazing level and identify the different management systems. Anim. 11 (5). https://doi.org/10.3390/ani11051426, 1426-NA.

Ray, S., 1985. Measurement and test of efficiency of farms in linear programming models: a study of West Bengal farms. Oxf. Bull. Econ. Stat. 47 (4), 371–386.

Requejo, J.A., Martín, S., Mantecón, Á.R., 2010. Dairy sheep farm plan: improving the efficiency of labor and facilities. [Spanish]. Mundo Ganad. 234, 30–34.

Riveiro, J.A., Mantecón, A.R., Álvarez, C.J., Lavín, P., 2013. A typological characterization of dairy Assaf breed sheep farms at NW of Spain based on structural factor. Agric. Syst. 120, 27–37. https://doi.org/10.1016/J.AGSY.2013.05.004.

Sharma, K.R., Leung, P., Zaleski, H.M., 1997. Productive efficiency of the swine industry in Hawaii: stochastic frontier vs. Data envelopment analysis. J. Product. Anal. 8 (4), 447–459. https://doi.org/10.1023/A:1007744327504.

Simões, J., Abecia, J.A., Cannas, A., Delgadillo, J.A., Lacasta, D., Voigt, K., Chemineau, P., 2021. Review: managing sheep and goats for sustainable high yield production. Animal 15, 100293. https://doi.org/10.1016/j.animal.2021.100293.

Srivastava, A., Kumaresan, A., Manimaran, A., Prasad, S., 2015. Mastitis in Dairy animals: An update. Satish Serial Publishing house.

Tauer, L., Stefanides, Z., 1998. Success in maximizing profits and reasons for profit deviation on dairy farms. Appl. Econ. 30 (2), 151–156. https://doi.org/10.1080/000368498325958.

Thanassoulis, E., 1993. A comparison of regression analysis and data envelopment analysis as alternative methods for performance assessments. J. Oper. Res. Soc. https://doi.org/10.1057/jors.1993.185.

Zervas, G., Tsiplakou, E., 2011. The effect of feeding systems on the characteristics of products from small ruminants. Small Rumin. Res. 101 (1–3), 140–149. https://doi.org/10.1016/j.smallrumres.2011.09.034.