Revista Electrónica:
Depósito Legal: ppi 201502ZU4665 / / ISSN electrónico: 2477-944X
Revista Impresa:
Depósito Legal: pp 199102ZU46 / ISSN 0798-2259

UNIVERSIDAD DEL ZULIA

REVISTA CIENTÍFICA

FACULTAD DE CIENCIAS VETERINARIAS
DIVISIÓN DE INVESTIGACIÓN

MARACAIBO, ESTADO ZULIA, VENEZUELA

Vol. XXX (1) 2020

Revista Científica, FVC-LUZ / Vol. XXX, N° 1, 7 - 18, 2020

TECHNICAL EFFICIENCY IN DIFFERENT PRODUCTION SYSTEMS WITH RUMINANTS: A SYSTEMATIC REVIEW AND META-ANALYSIS APPROACH

EFICIENCIA TÉCNICA EN DIFERENTES SISTEMAS DE PRODUCCIÓN CON RUMIANTES: UNA REVISIÓN SISTEMÁTICA Y UN ENFOQUE DE META-ANÁLISIS.

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ABSTRACT

This paper provides the results of a systematic research and a meta-analysis performed with studies published around the world about technical efficiency in production systems (PS) with ruminants, covering the period of years 1993–2015 and all the geographical areas in the world. From the total of studies collected, 58 were extracted. The overall estimate found was 81.85 %, lying into a 95 % confidence interval defined by the limits 79.23 and 84.48 %. The meta-regression analysis conducted supports as heterogeneity factors in the efficiency studies the following variables: sample size, approach, methodology, orientation, continent, and PS. Dairy cattle and beef cattle showed the highest levels of efficiency. The results obtained indicate that this economic sector could improve its efficiency reducing the consumption of resources around 15 % in overexploited systems, or by increasing the production about 23.6 % in PS with limited resources.

Key words: Ruminant production system; meta-analysis; meta- regression; technical efficiency; sources of heterogeneity

RESUMEN

Este trabajo proporciona los resultados de una investigación sistemática y un meta-análisis realizado con estudios publicados en todo el mundo sobre eficiencia técnica en sistemas de producción (SP) con rumiantes, cubriendo el período de años 1993–2015 y todas las áreas geográficas del mundo. Del total de estudios considerados, 58 fueron seleccionados. La estimación encontrada fue 81,85 %, incluida en un intervalo de confianza al 95 % definido por los límites 79,23 y 84,48 %. La meta-regresión realizada señala como factores de heterogeneidad en los estudios de eficiencia a las siguientes variables: tamaño muestral, enfoque, metodología, orientación, continente, y SP. Los SP de leche y carne mostraron los mayores niveles de eficiencia. Los resultados obtenidos indican que este sector económico podría mejorar su eficiencia reduciendo el consumo de recursos en torno a un 15 % en sistemas sobreexplotados, o incrementando la producción en un 23,6 % en SP con recursos limitados.

Palabras clave: Sistemas de producción con rumiantes; meta-análisis; meta-regresión; eficiencia técnica; fuentes de heterogeneidad

Recibido: 16/08/2019 Aceptado: 15/01/2020

INTRODUCTION

This paper deals with the assessment of technical efficiency (TE) in production systems (PS) with ruminants *Ovis aries*, *Capra hircus*, *Bos indicus*, *Bos taurus* around the world. This issue has been extensively researched until today and a large amount of specific and scientific literature has been published. A meta-analysis (MA) is also performed to condense the published results.

During the last decades, the livestock economic sector has been deeply transformed and it is today still in evolution. The world areas with faster growing economies have experienced an increasing demand of all types of food derived from the animals.

Technology innovations and structural changes in this economic sector have contributed to a substantial increasing of the production of the livestock systems (LS). In the years (y) 1961–2014, the Food and Agriculture Organization of the United State [30] data showed that the world mean number of heads of livestock integrated in PS was 1,370.59 million.

Livestock PS provide the 40% of the value of the total agricultural-world production, and support the living means and food safety of almost 1,300 million people. The world production of meat coming from cattle (*Bos indicus*), sheep (*Ovis aries*), and goat (*Capra hircus*), has grown from 33.71 million metric tonnes (MMT) in 1961 to 77.94 MMT in 2013. The milk production has been increased from 325.69 MMT in 1961 to 663.68 MMT in 2013 [30].

The growing and transformation of this crucial economic sector make easier the agricultural development, the food safety and the poverty reduction. In many developing countries, LS are a multifunctional activity. However, million people in rural areas still continue to grow up livestock with traditional PS, which support their way of living and the food safety of their families. Therefore, all the efforts, directed towards improving efficiency and productivity, are welcome.

These systems produce milk and/or meat and require resource consumption. These resources are labour, equipment, ground, infrastructure, livestock and capital. TE analyses compare the firms of this economic sector. TE level of each firm was obtained, useful information about which inputs could be reduced and their reduction percentages was also found, this implies a reduction of the resource consumption and an increase in production. Relevant factors involved in the efficiency were also detected.

The survey provided by the present paper becomes interesting because it offers an opportunity to draw, from the large amount of studies considered, a general conclusion regarding the efficiency levels of the PS with ruminants around the world, it also provides relevant information to detect the inefficiency reasons. Moreover, the application of the MA methodology to the estimations reported by the different studies lends support for estimating the overall efficiency considering the variance of each one of such estimations.

The studies published examine PS with different characteristics. Therefore, production technology (PT) was not homogeneous. In the present systematic bibliographical review a large dispersion of the efficiency estimates, varying from 50 to 99 % was found. As regards the temporal aspects of the studies, two options have been considered; Cross Sectional (CS) refers to a sample of *n* enterprises in a given season, for example, in one y. On the other hand, Panel Data (PD) analyses refer to studies of *n* enterprises during *T* periods of time. Sample size could also influence the assessed efficiency levels.

The PT available, weather conditions, and the cultural characteristics of the diverse world areas were different, and they could influence the efficiency level of the decision making units (DMUs). The studies surveyed cover a wide geographical region, in the five continents.

The applied efficiency analysis methods, stochastic frontier methods [11] or non-parametric [9, 22], and the orientation approach, can also incorporate heterogeneity.

Nevertheless, the comparison of the efficiency among the PS (dairy cattle, beef cattle, dual purpose (DP) cattle, small ruminant, or mixed) stimulates this research. As different technologies are applied to the contrasting PS, overall estimates of the efficiency and the reasons of the efficiency levels achieved must be studied separately.

Therefore, it is very compelling to determine whether there is heterogeneity among the varied efficiency studies separately conducted on these PS. On this basis, overall efficiency was assessed for each homogeneous group to get conclusions and make decisions for correcting the inefficiency.

MA methodology allows the analysis of a set of previously published studies and assesses a measure to condense them [14]. This methodology has been mainly applied to medical research.

There are MA studies about the prevalence of diseases [8], where a measure to summarize all the previously published studies of the same disease is estimated. In addition, meta-regression (MR) was applied to better analyze the influence on the objective variable, i.e., the prevalence, of the different heterogeneity sources [7]. This method applies a non-conventional regression model that considers the precision of each observation [14, 67] provide a solid methodological basis on this matter, and Veroniki *et al.* [74] present a very interesting survey of the available methods and software developed concerning these issues.

Regarding the applications to economic matters, Knell and Stix [48] used meta-analytic (MA) methods to investigate possible sources for the large variation in empirical findings about the income elasticity of money demand. Longhi *et al.* [51] performed a MA assessment of the effect of immigration on wages. Bom and Ligthart [13] also used MR analysis in their research on the private output elasticity of public capital.

As far as it known, in the analysis of TE there are no studies where MA has been applied. In the papers of Bravo-Ureta *et al.* [15], Moreira and Bravo-Ureta [58], and Thiam *et al.* [71], a regression model is used to determine factors of influence on the TE of the agricultural sector based on the results of previous studies.

The aim of this study was to carry out a systematic and quantitative review of TE in PS ruminants, to provide the joint estimate of TE and to examine the consistency of these estimates between published studies, which will provide useful information for making appropriate decisions to improve efficiency.

MATERIALS AND METHODS

This paper is based on previous papers, where the TE of livestock PS was estimated. A systematic literature search was performed and different sources of variation are pointed out. After the literature search, a MA using the method of DerSimonian and Laird [26] was conducted to estimate the overall efficiency. Heterogeneity was also tested by MR.

Literature search

MA of already published studies requires an effort of searching and organizing the existing literature. This paper provides a systematic literature search using the Internet, the University Library services, and the data bases of the JCR (Journal Citation Report index) and other prestigious indexes. The search performed includes the studies collected in papers published in the important scientific journals covering the period of 1993–2015.

Variables

The sources of variation related to the efficiency analysis pointed out by this paper were the following: sample size, PS, continent, approach, methodology and orientation. In the MA conducted in this paper, it was needed to know the mean efficiency and the standard deviation. Therefore, from the total of 99 papers containing 223 studies collected, eventually 58 studies were extracted for the MA and MR studies. These 58 studies were classified into several categories according to the different values of the sources of variation. The values of the PS considered were dairy cattle, beef cattle, small ruminants, DP cattle and mix. Regarding the continent the values were Europe, America and rest of the world. The categories of the approach were cross sectional and panel data. Finally, the categories for the methodology were no parametric and stochastic studies, while the analyses were classified according to the orientation into input oriented and output oriented studies.

TABLE I condenses the different sources of variation considered and their categories. Frequencies and percentages over the 58 studies finally selected were also included in TABLE I.

TABLE I
CHARACTERISTIC VARIABLES FOR THE META-ANALYSIS AND META-REGRESSION ANALYSES

Variable	Categories	Frequency	Percentage
Approach	Panel Data	19	32.8
	Cross Sectional	39	67.2
Methodology	Stochastic	23	39.7
	No parametric	35	60.3
Orientation	Output	36	62.1
	Input	22	37.9
Continent	Europe	21	36.2
	America	21	36.2
	Rest of the world: Africa, Asia and Oceania	16	27.6
Production System	Dairy cattle	37	63.79
	Beef cattle	7	12.07
	Small ruminants, dual purpose cattle and mix	14	24.14

Meta-analysis

The present work develops a MA under the random-effects model. The random-effects model proposed by DerSimonian and Laird [26] has been applied.

As a result of the MA conducted, for each group of studies it was assessed:

1. Overall efficiency of the whole set of firms included into the group.
2. Measures for heterogeneity detection.
3. Pictures called “Forest Plot”, which show the variance of each single study and the global variance.

Let Y be the value of the estimated mean efficiency for each study, and let se (Y) be the value of its standard deviation. Then, regarding the random-effects model, and for the sake of estimate the overall efficiency, the weights were given by

$w_i^* = \frac{1}{se(Y_i)^2 + \hat{\tau}^2}$, being the between-study variance, τ^2.

Thus, the pooled efficiency was given by $Y_{DL} = \frac{\sum w_i^* Y_i}{\sum w_i^*}$, and

$$se(Y_{DL}) = \frac{1}{\sqrt{\sum w_i^*}}$$

Therefore, firstly, it was necessary to estimate τ^2, which was based on the value of the Cochran’s *Q* statistics. And then the heterogeneity measures were initially calculated.

Heterogeneity was analyzed with the Cochran’s *Q* statistics and the value I^2 of Higgins [43, 44].

For the computation of Q, it was assigned a weight for each value of Y. This weight was $w_i = \frac{1}{se(Y_i)^2}$. And then the value of

Q was given by $Q = \sum_{i=1}^{n} w_i Y_i^2 - \frac{\left(\sum_{i=1}^{n} w_i Y_i\right)^2}{\sum_{i=1}^{n} w_i}$.

The value I^2 of Higgins was then estimated with $I^2 = \frac{Q - df}{Q} \times 100\%$, being Q the Cochran's Q, and $df = n - 1$ the degrees of freedom, where n was the number of studies. The estimate of the between-study variance, τ^2, was given by $\hat{\tau}^2 = \max\left\{\frac{Q-(n-1)}{\sum w_i - \frac{\sum w_i^2}{\sum w_i}},\ 0\right\}$. In addition to the heterogeneity test, a meta-regression was needed for an accurate identification of the sources of heterogeneity.

Forest plot

In each Forest Plot (FIGS. 1, 2 and 3), each horizontal entry describes the results from a single study. The study number, the efficiency estimate ("te" column), the standard deviation ("sd" column) and the weight assigned to the study were also reported. The length of the horizontal line represents the 95 % confidence interval (CI) for the efficiency for the individual study.

In the plots, the center of the circle marks the efficiency estimate for the study, and the area of such circle was proportional to the weight assigned to such study. The vertical dashed line in these pictures indicates the overall efficiency for the studies included in each specific group.

Meta-regression

Meta-regression aims to investigate whether heterogeneity among results of multiple studies was related to specific characteristics of the studies. With this purpose, a regression model was estimated where the variable of interest was the TE of each study Y_i, and the explanatory variables were the factors which could influence the lack of homogeneity of the studies.

These are: sample size, temporal aspects, applied method, orientation approach, zone, and PS. All these explanatory variables were categorical except sample size. Temporal Aspect factor includes a coded variable which considers Cross Sectional Approach and omits Panel Data.

About Orientation Approach, Output orientation was omitted; about Zone the omitted value was Europe group; and, finally, regarding PS, the omitted value was Dairy System.

Meta-regression model differs from general lineal models usually applied, mainly because it estimates with methods which utilize not only the value of the variable of interest (Y_i), but also its standard deviation (Y_i).

The proportion of the between-study variance explained by the covariates (adjusted R-squared) was $R_a^2 = \frac{\hat{\tau}_0^2 - \hat{\tau}^2}{\hat{\tau}_0^2}$, where $\hat{\tau}^2$ and $\hat{\tau}_0^2$ were the estimates of the between-study variance in models with and without the covariates, respectively.

Once τ^2 has been estimated, the estimated coefficients, $\hat{\beta}_j$, j = 1, …, k, were obtained by a weighted least-squares regression of Y on X with the weights $w_i^* = \frac{1}{se(Y_i)^2 + \hat{\tau}^2}$. The estimate of the variance-covariance matrix of coefficients is $\left(X'\hat{V}^{-1}X\right)^{-1}$, where $\hat{V} = diag(\sigma_1^2 + \hat{\tau}^2, \sigma_2^2 + \hat{\tau}^2, ..., \sigma_n^2 + \hat{\tau}^2)$. A statistical test for evidence of effect of a particular covariate was available via a Wald test using the statistic $t_j = \frac{\hat{\beta}_j}{se(\hat{\beta}_j)}$, j = 1, …, k. If the value of this statistic was not significantly different from 0, then the corresponding variable does not generate heterogeneity in the MA. After the identification of the heterogeneity sources with the MR, a MA was carried out for each homogeneous group.

Therefore, separate MA was developed for the orientation groups: output and input oriented. And also for the three diverse groups regarding the PS: dairy cattle, beef cattle, and the rest. The specific software for MA included in the Stata package [68] has been used for applying the methodology [62].

RESULTS AND DISCUSSION

Efficiency and its characteristic parameters on the basis of the published studies

The efficiency levels of the PS with ruminants have been obtained firstly from the results and conclusions reported by the 58 published studies and this paper was also a survey of them.

TABLE II shows the main characteristics of the 58 studies included in the MA, with the corresponding Forest Plot shown in FIGS. 1, 2 and 3.

The mean value of the efficiency indexes estimated was 77.24 % with standard deviation of 11.48, and all the estimates lie between the values 50.10 and 99.23.

On the other hand, it was also observed a great variability of the sample size of the different studies selected.

This variability lies from studies with a sample size of 21 decision making units to studies with a sample size of 3,351 units. The mean of decision making units considered in the studies selected was 285.69 units with a standard deviation of 512.59 units.

TABLE II
MAIN CHARACTERISTICS OF THE CONSIDERED STUDIES

Author	PS	Zone	Sample	Approach	Method	Orientation	Efficiency	Standard Deviation
[1]	Dairy	Asia	66	CD	Stochastic	Output	78	14
[2]	Dairy	Europe	74	PD	Stochastic	Output	86.5	5.2
[2]	Dairy	Europe	86	PD	Stochastic	Output	93.1	3.1
[4]	Dairy	C-S America	35	CD	N-Param	Output	78.2	13
[5]	Dairy	C-S America	21	PD	N-Param	Input	93.2	10
[6]	SR	C-S America	40	CD	N-Param	Input	77	19
[6]	SR	C-S America	40	CD	N-Param	Output	74	21
[10]	Dairy	Europe	38	CD	N-Param	Input	67	19
[12]	Mix	Africa	252	CD	Stochastic	Output	61.61	23.28
[16]	Dairy	C-S America	147	PD	Stochastic	Output	81.1	10.9
[17]	Dairy	N-America	3351	PD	Stochastic	Output	92	12
[18]	Dairy	N-America	273	CD	Stochastic	Output	88	8
[19]	Dairy	C-S America	875	CD	Stochastic	Output	82.58	8.03
[20]	Beef	Europe	50	CD	N-Param	Output	73.5	21.67
[21]	Dairy	N-America	1593	CD	N-Param	Input	57.7	18
[23]	Dairy	N-America	1151	PD	Stochastic	Output	90	5.6
[24]	Dairy	Africa	34	CD	N-Param	Input	95.1	35.1
[25]	Dairy	Asia	100	CD	N-Param	Input	59	24
[27]	Mix	Europe	112	CD	N-Param	Output	74.17	17.6
[29]	Mix	C-S America	53	CD	N-Param	Output	68.8	26.2
[31]	Dairy	Oceania	50	PD	N-Param	Input	85.5	11.9
[31]	Dairy	Oceania	50	PD	N-Param	Output	89	11
[32]	DP	C-S America	71	CD	N-Param	Input	59.76	23.25
[32]	DP	C-S America	71	CD	N-Param	Output	72.23	23.9
[33]	Mix	Europe	69	CD	N-Param	Input	70	21.1
[35]	Beef	C-S America	648	CD	Stochastic	Output	53.44	20.4
[35]	Beef	C-S America	305	CD	Stochastic	Output	99.23	1.0
[36]	Beef	Asia	70	CD	N-Param	Input	67.66	24.34
[37]	Dairy	Europe	507	PD	N-Param	Output	85.4	16.4
[38]	Dairy	Europe	209	PD	N-Param	Input	87.7	12.3
[39]	Dairy	Europe	507	PD	N-Param	Input	86.5	14.8
[40]	Dairy	Europe	361	PD	N-Param	Input	71	14.7
[41]	Dairy	Asia	58	CD	Stochastic	Output	76	12.3
[41]	Dairy	Asia	58	CD	Stochastic	Output	86	14.7
[42]	Dairy	C-S America	30	PD	N-Param	Output	69	13
[45]	Mix	Africa	252	CD	N-Param	Input	50.1	21.2
[46]	Dairy	Oceania	264	CD	N-Param	Input	83	14
[47]	Dairy	Europe	190	CD	N-Param	Input	78.51	17.82
[49]	Dairy	Europe	187	PD	Stochastic	Input	68	3
[50]	Dairy	Europe	230	PD	Stochastic	Output	79.6	6.2
[52]	Beef	Europe	381	PD	N-Param	Input	75	10

[53]	Dairy	Europe	1212	PD	Stochastic	Output	86	5
[54]	SR	Europe	61	CD	N-Param	Input	64.2	22.6
[55]	Beef	Africa	90	CD	Stochastic	Output	91	8
[56]	SR	Europe	137	CD	N-Param	Output	83	13
[58]	Dairy	C-S America	92	PD	Stochastic	Output	81.1	10.9
[59]	Dairy	Africa	39	CD	Stochastic	Output	79.3	15.4
[60]	Dairy	N-America	103	PD	Stochastic	Output	68.2	11.4
[61]	Beef	Africa	66	CD	Stochastic	Output	76.3	9.9
[63]	DP	C-S America	83	CD	N-Param	Output	79.01	17.59
[65]	Dairy	Europe	200	CD	N-Param	Input	82.9	2.3
[65]	Dairy	Europe	200	CD	N-Param	Output	82.9	2.2
[66]	Dairy	Europe	122	CD	N-Param	Input	66.4	15.4
[69]	Dairy	N-America	395	CD	N-Param	Input	74	15
[72]	SR	Europe	31	CD	Stochastic	Output	66.7	17.9
[73]	DP	C-S America	144	CD	N-Param	Output	54	20
[75]	Dairy	Oceania	315	CD	N-Param	Output	85.98	10.96
[75]	Dairy	Oceania	315	CD	Stochastic	Output	96	11.83

PS: Production systems, SR: Small ruminant, DP: Dual purpose cattle, C-S: Centro-South, N: North, CD: Cross Sectional, PD: Panel Data, N-Param: Non parametric

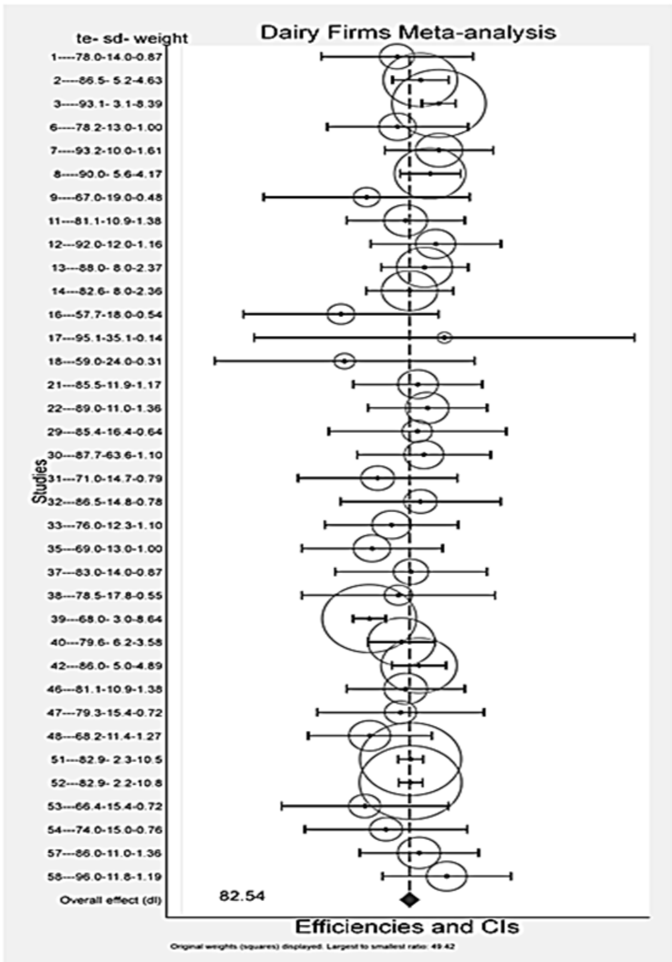

FIGURE 1. FOREST PLOT OF THE DAIRY CATTLE PRODUCTION SYSTEM, EFFICIENCIES, WEIGHTS AND OVERALL EFFICIENCY

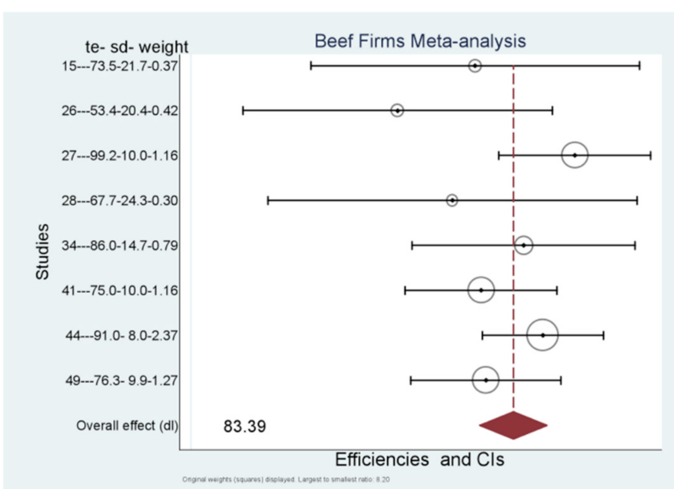

FIGURE 2. FOREST PLOT OF THE BEEF CATTLE PRODUCTION SYSTEMS, EFFICIENCIES, WEIGHTS AND OVERALL EFFICIENCY

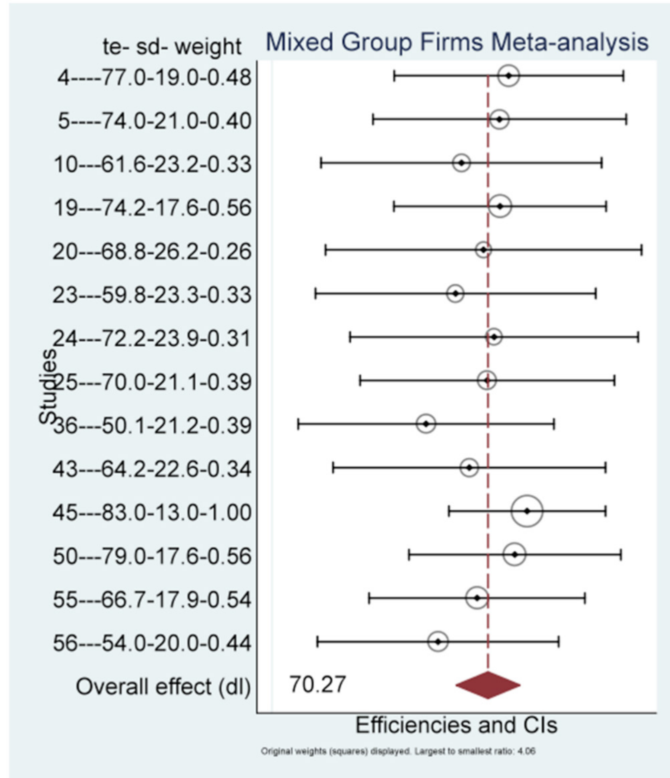

FIGURE 3. FOREST PLOT OF THE SMALL RUMINANTS, DUAL PURPOSE CATTLE AND MIX PRODUCTION SYSTEMS, EFFICIENCIES, WEIGHTS AND OVERALL EFFICIENCY

Efficiency in dairy production systems

The mean value of the efficiency reported by the considered studies dealing with milk (dairy cattle) is 80.8 % with a minimum of 57.7 % and a maximum of 96 %. The management strategies and best-practices concerning health, feed and animal reproduction show positive influence on efficiency [23, 25, 31, 59, 75]. Farmer's decisions of analyzing forage and cereal fodder, in feeding portions for milk cows were relevant for the efficiency [4, 5, 39]. In milk farms of Wisconsin, the intensification of the systems improves the TE [18], and the farmers on the efficiency frontier had a relatively higher milk production, milk production per cow, and land surface [24, 66]. In addition, Álvarez-Pinilla and del Corral [2] have found that the intensive livestock farms were more efficient and productive than the extensive ones, in South America the least efficient farms were operating at a sub-optimal size [16]. Others studied the effect of the quota system and subsidy [49, 50].

Other papers considered the environmental impact. They concluded that the firms, with a more efficient use of the inputs, reduce their greenhouse gas emissions for each liter of milk [3, 65]. On the other hand, Mukherjee *et al.* [60] deduced that the global warming could increase the heat stress of the animals, and the milk production was affected.

Hansson *et al.* [40] analyzed with logistic regression the effects of mastitis prevention measures. Their results show that taking actions, as contact a vet and perform hygiene general test routines, led every firm to increase significantly its probability to be totally efficient. In addition, Barnes *et al*. [10] concluded that the farmers must try to reduce the laminitis below the 10% level for an efficient use of the resources. Studies showed that several farmers characteristics as agriculture training, household labor, farm management experience, study group participation, the help of advisers as important information sources, and accounting control, aid considerably for improving the farm TE [17, 19, 21, 37, 69]. Hazneci and Ceyhan [41] proposed new strategies such as providing better agricultural extension services and farmer training programs to increase the educational level of farmers, and providing farmers with the opportunity of accessing loan to enhance their technical efficiency.

The research of Hansson [38] in dairy cattle systems in Sweden deduced that greater farms were technically better regarding the use of their inputs. The management of the herd influences the quality of the produced milk, and quality improvements lead to quantity reduction. In Turkey, the results illustrate that animals with high genetic quality must be numbered in the herds [1, 42, 47].

Efficiency in beef production systems

The mean value of the reported efficiency of the beef cattle studies was 76.59 %, the minimum value was 53.44 % and the maximum 99.23 %.

Under the approach of input saving, several farms in Sweden and Brazil were analysed. As a result, the most efficient farms were farms which involve all the actions of breeding, rearing and fattening livestock [52]. Castillo-Quero [20] deals with the farms in Spanish pasture. It concludes that intensification, measured by stocking density and mechanization index, influences the efficiency. Similar results were proposed in feedlot systems, where in a smaller area of the field could lead to a better TE [36].

Gatti *et al*. [35], in beef systems cattle in Argentina, compared different areas of La Pampa, grouping them on the basis of partial productivity indexes. They pointed out significantly differences in efficiency among these areas, mainly due to several characteristics as the existence of electric lighting, artificial insemination, contribution of technical advisers, and supplementary food. A similar approach was applied in Kenya by Otieno *et al*. [61], regarding pastoralism systems, agrarian grazing and ranches. They found out differences of efficiency due to native breeds, mating control, specialization, age, and presence farmer. Mlote [55] in Tanzania pointed out the socio-economic determinants of the respondents' technical efficiency were age, education, experience, extension services and ethnicity.

Efficiency in small ruminant, DP cattle, and mixed production systems

The mean value of efficiency reported in the studies of these livestock PS is 68.18 %. The minimum value was 50.10 % and the maximum is 83 %.

Most of these small-ruminant systems were characterized by a high dependency from the pastureland, and from the restricted access to suitable resources and production methods. These were significant structural limitations, nevertheless, the ovine and goat production was still a matter of the greatest importance to economic, environmental and social issues in Mediterranean Countries [28].

In several Countries, as Syria and Greece, the traditional systems have been studied by Shomo *et al.* [64]. These systems have been classified on the basis of livestock and people movements, and regarding the use of natural resources. The sedentary PS was the most efficient, and the migratory one the less efficient. The main reasons of inefficiency were a high abortion rate, low fertility, high lamb mortality, and the long distances to water sources and markets. Other results indicated that the European Union subsidies have a significant impact in the technical efficiency of farms with low levels of efficiency and small size. In ovine farms in Chios, Greece, it has been observed that big size farms are positively correlated with technical efficiency. These results showed that the farms could be associated in order to achieve an optimal size and increase their production. The estimation of the scale efficiency shows that scale economies could be profitable for productivity [46, 53, 70]. Arzubi *et al*. [6] concludes that the specialized systems in ovine-wool and ovine-meat production have more technical and economic efficiency than the mixed systems.

The efficient and sustainable managements were compared in the region of Villuercas-Ibores (Spain). It was observed that the big farms devoted to both sheep and goat flocks, and which were not in the Protected Designation of Origin, were the most sustainable and, in several issues, the most efficient [54]. In addition, they deduce that, for improving the competitiveness of the less efficient farms, supplementary food and an increasing of the production capacity of the sheep were required. This conclusion coincides with the results of the research of Morantes [56], Morantes *et al.* [57] and Toro-Mujica *et al*. [72] where the ovine production in Castilla-La Mancha (Spain) was studied, and the management and productivity levels were related. As a result, if the functions of organization, planning, direction and control were well performed in the farm, the farm was more efficient. Regarding this result, it is also possible to mention the paper of Gaspar *et al.* [34], who pointed out that the economic results in the ovine farms in the Spanish pastureland were connected with the labour management of the owners of the farms.

Urdaneta *et al*. [73] deal with DP cattle in Venezuela. Their results showed different efficiencies among agro-economic zones, and that the supplementary food has a determinate effect in these livestock, and Peña [63] pointed out the managerial performance of farmers. Gamarra [32] studied DP cattle in Colombia. The use of organic fertilizers and insecticides (ha), and the livestock density (animals/ha) were factors which affect efficiency.

A crucial aspect in mixed systems was the definition of the outputs. The high heterogeneity of the produced outputs helps the different authors to unify the measure units with monetary or weight units [27, 29]. The papers of Hussein [45] and Beshir *et al*. [12] coincide with the conclusion that the implementation of new technologies was a determinate factor in the efficiency of these

TABLE III
META-REGRESSION RESULTS

Explanatory variable	Coefficient	Standard error	T (statistic)	*p*-value (P>|t|)
Sample size	-0.004	0.009	-0.43	0.673
Approach Cross Sectional	0.978	3.928	0.25	0.804
Methodology N-Parametric	-2.432	3.914	-0.62	0.537
Orientation Input	8.854	3.730	2.37	0.022
America	-0.250	3.633	-0.07	0.945
Rest	-0.278	4.675	-0.06	0.953
Beef cattle	0.575	5.369	0.11	0.915
Mix	-13.389	6.189	-2.16	0.035
Constant	70.885	8.596	8.25	0.000

systems.

Gaspar *et al*. [33], in their research of the farms of the Spanish pasture, study the effect of the funding coming from the Common Agricultural Policy (CAP) of the European Union. The farms with pigs (*Sus scrofa domesticus*) were the most efficient. It has been suggested that several modification in the livestock density should be performed, in order to use suitably the natural resources to achieve better efficiency levels in the farms of the pasture.

Efficiency with meta-analysis

The total efficiency mean was 77.24, which does not take into account the accuracy of the computation of the different estimates.

The overall efficiency, found out by the MA of all the 58 studies, is 81.85 with a 95 % CI defined by the extremes 79.23 and 84.48. The Forest Plot of the whole sample was not presented due to space reasons and because it would provide redundant information (FIGS. 1, 2 and 3). These three pictures, respectively, illustrate the Forest Plots of the separate MA for the three groups of PS considered: dairy cattle, beef cattle, and mixed group. The information of each study does not changed and it keeps invariant when the study was taken into an overall sample or into a specific group of studies MA. For instance, the information of the study number 1 shown in FIG. 1 (dairy firms MA) was just the same of the information of such study number 1 in an overall sample MA.

Heterogeneity was also analyzed with the *Q*-Cochran test. The Cochran's Q was 67.74 with $P = 0.156$. Another heterogeneity measures were given by I^2, with a value of 15.86, and τ^2, which is equal to 11.83. Therefore, for better understanding the heterogeneity reasons, a MR analysis was applied. To perform the MR, the variable to be explained was the efficiency (with its standard deviation S.D.), and the explanatory variables were the sources of heterogeneity.

The MR results were condensed in TABLE III with τ^2 equal to 20.01. These results show that two explanatory *orientation (O)* and PS variables were significant, in addition to the constant, with a significance level of $\alpha < 0.05$. As regards O, the value of the coefficient of the explanatory variable was 8.85 with positive sign. It suggests that the efficiency of the input oriented studies was around 8.85 % larger than the output oriented studies (default category).

Regarding PA, it was significant the coefficient of the set of mix PS. This mix PS group comprises small ruminants, DP and mix. These PS showed an efficiency level around 13.38 % lower than the efficiency levels of dairy cattle PS (default category). The MR results proved that O and PS were sources of heterogeneity, additional separate MA of the different groups were performed.

Firstly, the overall efficiency of the groups studied separately by their PS (i.e., dairy firms, beef firms and mixed group firms) was estimated with the corresponding MA. The results of these additional MA were depicted by the Forest Plots (FIGS. 1, 2 and 3).

The overall efficiency for the dairy cattle PS was 82.54 (FIG. 1), in the beef PS 83.39 (FIG. 2) and in the mixed group was 70.27 (FIG. 3). These values lie, respectively, in the 95 % CI defined by the limits 79.34 and 85.73 (dairy cattle, FIG. 1), 74.77 and 92.00 (beef cattle, FIG. 2), and 59.99 and 80.55 (mix group, FIG. 3).

Finally, the overall efficiency of the groups studied separately by their orientation was also estimated with their corresponding additional MA. These two additional MA performed separately by O confirm the previous results provided by the MR. The overall estimated efficiency in *output oriented* studies (76.39, lying in a 95 % CI with limits 71.35 and 81.44) was lower than the overall efficiency of *input oriented* studies (84.9, lying in a 95 % CI with limits 82.52 and 87.44).

As a result of the performed MA of the whole sample, the overall efficiency of the sector was estimated to be 81.85 % with a 95 per cent CI with limits 79.23 and 84.48. This overall efficiency level was large, but it also means that improvement strategies could be implemented to enhance efficiency between 15.5 and 21 % in some of the two directions: increasing production or decreasing resource consumption. Besides, by comparing the overall efficiency estimated by the MA (81.85), with the sample arithmetic mean (77.24), it could be concluded that this methodology was quite suitable. In fact, the consideration of the accuracy of the efficiency estimates of the different studies leads to modify the overall efficiency estimate, avoiding incorrect and misleading conclusions. The output O studies had lower efficiency than input orientation studies. These results agree with the results obtained by Bravo-Ureta *et al.* [73].

Improving measures could be taken to achieve better efficiency levels, and these actions must be based on the factors which influence efficiency. These relevant factors pointed out by the varied published papers regarding the different PS are similar.

CONCLUSIONS

The systematic survey conducted has been useful for identifying the determinant factors of the efficiency of the PS analyzed. In addition, it has been the basis for performing a MA. MA and MR provide a well-founded and supported comparison among PS. As a result of this comparison, it was concluded that small ruminant PS were less efficient than dairy or cattle PS.

In summary, the most relevant and crucial aspects to be considered in order to improve efficiency levels in PS with ruminants were the following: management training and more attention must be paid to livestock, particularly looking after their management, health and well-being. It also entails intensifying new technologies usage to achieve the required levels of sustainability.

ACKNOWLEDGEMENTS

Corresponding author research is partially supported by Spanish Government Research Project MTM 2017-84150-P.

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REVISTA CIENTÍFICA

Vol, XXX, Nº 1

Esta revista fue editada en formato digital y publicada en Diciembre 2020, por ***La Facultad de Ciencias Veterinarias, Universidad del Zulia. Maracaibo-Venezuela.***

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