Analysis of Sustainability In Livestock Production Systems In Cordoba, Colombia.

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Abstract

The concept of sustainability is usually broad; it refers to the ability of the system to meet the current demand for livestock products without compromising the use of resources by future generations. Therefore, this study has been conducted to provide an overview of rotational, intensive, and regenerative livestock models to evaluate and measure their level of sustainability in the environmental, social, and economic dimensions to guide livestock guilds, professionals and stakeholders to transform their agricultural systems by adopting the concept of sustainability. The results show that the regenerative livestock system has a high association with the economic dimension in the Almost Good category, in the environmental dimension in the Moderate category, and in the social dimension in the Almost Good and Very Good categories. On the other hand, the rotational livestock system and the intensive livestock system have an association with the environmental dimension categorized as good; however, the association of the intensive livestock system is not as strong as that of the rotational livestock system.

Introduction

Throughout the centuries, the livestock sector has been linked to a model of land colonization (1). The livestock herd in Latin America has multiplied in such a way that it has exerted high pressure on natural resources, especially the loss of forest cover, soil degradation and water consumption, to produce grazing livestock. This global problem has induced countries to improve their capacity to analyze and manage risks in the livestock sector to develop viable production strategies from a technical, economic, social, and environmental point of view (3). The sector must therefore move toward more efficient models, making more sustainable use of natural, social, and economic resources. For this, it is important to apply methods that allow us to evaluate the sustainability of the sector to obtain practical, operative, and systemic information in which opportunities for improvements in sustainability issues are indicated. The concept of sustainability is often broad, referring to the ability of the system to meet the current demand for livestock products without compromising the use of resources by future generations (4). Applying this concept to the livestock production sector is based on three dimensions: social sustainability (working conditions, animal welfare, landscape quality, etc.), economic sustainability (profitability) and environmental sustainability (GHG emissions, pollution of natural resources, etc.).

Situation context

Several studies have developed a variety of tools to assess sustainability performance on farms dedicated to livestock expansion. The assessment of sustainability performance at the farm level has been studied using a model called SOSTARE and the hierarchical analysis process (AHP) methodology, which assessed the level of sustainability at the farm level in Greece, enabling decision making based on sustainability indicators (5, 6). Likewise, the IDEA, RISE and SAFA methods have been used as tools for sustainability assessment on dairy system farms. The measurement of sustainability encompasses social, environmental, and economic aspects to support decision making. For this purpose, Van-Heurck and other authors considered a multicriteria model based on indicators to evaluate sustainability in Peruvian Amazonian livestock farming. The results showed that the most critical aspects that affect the sustainability of livestock farming are the scarce implementation of silvo-pastoral systems, the low level of associativity and soil degradation (8).

In Sicily, sustainability performance was studied under dimensions of good governance: environmental integrity, economic resilience and social well-being under the framework of the Sustainability Assessment of Food and Agricultural Systems" (SAFA) developed by FAO. It was implemented in ten agricultural systems, providing farmers with a tool that allows them to know the critical points on which they must intervene in search of sustainable development (9).

The analysis of relationships or the use of the K-Means technique to analyze the performance of sustainability has been implemented in several works (10–13), where relationships between agro-environmental, economic, and social dimensions in farms are evaluated. Likewise, they have performed cluster analysis of the composite farm assessment and have

implemented the K-Means and multicriteria applied to the evaluation of sustainability for decision making. In this context, the objective of this study is to provide an overview of the rotational, intensive and regenerative livestock models to assess and measure their level of sustainability in the dimensions listed above to guide livestock guilds, professionals and stakeholders to transform their agricultural systems, placing the concept of sustainability in a framework in which both public and private efforts are articulated around an intersectoral vision to carry out planning, management and evaluation of agro-sustainable transitions.

Materials And Methods

Study area. The department of Cordoba is located in the northwest of the Republic of Colombia with a surface area of 25,020 km², representing 2.1% of the national territory. It stands out for its agricultural, livestock and mining activities(14).

Cordoba has one of the greatest edaphoclimatic offers in Colombia, which allows it to increase its agricultural frontier. Its productive vocation is mainly associated with agricultural, forestry and fishing activities (15).

The study focused on the subregions of La Sabana, Coastal Zone and Sinu Medio of the Department of Cordoba, Colombia, characterized by their large contribution to the regional livestock herd, despite their disparate environmental conditions. La Sabana is characterized as a tropical dry forest; it has 100 ha of secondary natural forest, and its soils are mostly used for livestock activities (14). Within this subregion, there is a farm with a rotational livestock system and a farm with an intensive livestock system.

The coastal zone is classified as a tropical dry forest and is characterized as an area that presents homogeneous agroecological conditions suitable for agricultural and livestock activities and other rural activities (15). Within this subregion, there are three farms with regenerative livestock systems and one farm with rotational livestock systems. Sinu Medio is classified within the tropical dry forest, with a forest cover of 0.05% of the total forest in the department. Its main economic activity is based on livestock, a major contributor to the production of meat and milk (14). Within this subregion, there are two farms with intensive livestock systems and two farms with regenerative systems.

Table 1 shows the consolidated number of farms for each livestock system evaluated.

Table 1. Prioritized livestock systems

Type of system	Number
Rotative	5
Regenerative	5
Intensive	4
Total	14

Figure 1 below shows a map showing the location of livestock production systems and their distribution in the subregions.

Type and focus of research. The study, given the nature of the research objective, is of the cross-sectional descriptive type because it investigates the incidence of the modalities or levels of one or more variables in a population (16). According to the nature of the information to be collected, it corresponds to quali-quantitative research due to the systematic collection, analysis, and integration of data. For this, the information obtained by means of instruments of information collection was considered, taking into account a set of indicators to represent livestock productive systems in an integral and reliable way, according to the revision of contextualized models.

Analytical Hierarchy Process. To evaluate sustainability at the livestock farm level, the analytical hierarchy process (AHP) method, developed by Thomas L. Saaty (17), is designed to resolve decision making through multicriteria analysis (MCDA).

The AHP provides the possibility of including quantitative and qualitative data (18). This methodological tool has been applied in several studies to incorporate the particularities of actors involved in a conflict and/or participatory process in decision-making (19).

For this case, the AHP has been implemented to evaluate the most sustainable livestock production system in the region.

Selection of sustainability indicators. Considering the versatility of livestock farming, a set of indicators was selected to comprehensively represent each livestock production system. The three dimensions of sustainable development (environmental, social, and economic) are addressed (6) based on prioritization analysis using the following criteria: ease of data collection, scalability, reliability, data accessibility and cost. Table 2 shows the indicators that were evaluated for the study.

Table 2
Environmental indicators at farm level

Sustainability Dimension	Indicator	Unit
Environmental	Water consumption per kg of product	Lt/kg
	Pesticide Use	Lt/ha/año
	The use of direct energy	kw/ha/año
	Greening: Permanent pasture	%
	Green fodder production per hectare	kg/ha
	Percentage of paddock areas managed with trees ((more than 20 trees/ha)	ha
	Soil health - biological indicator	# detritiburous individuals/ # non detritiburos* ha
	Solid waste generation	kg/ha
	Seminatural cultivation areas	%
Social	Distribution of roles by gender	No. of men and women per total number of workers
	Level of technical training of workers	-
	Dedication to livestock activity	No. of working days per year/No. of working days per year
	Working day	No. of hours worked*day
	Educational level (training)	-
Economic	Total output/total input	COP
	Total subsidies/family farm income	COP
	(Family farm income/family work unit)/reference income	COP
	Rate of return	%
	Cost of kg per calf produced	COP/Calf
	Cost per Lt of milk produced	COP
	Net profit margin	Net income year - production costs year
	Lt of milk sold per month	Lt/ha/year
	Intervals between births	# hatchlings/ha/year

Source: Authors, based on FLINT and FADS data sources

K-means model. The K-means method (20) is an iterative algorithm that seeks to divide the data set into K subgroups (e.g., clusters) that are unique and nonoverlapping where each data point belongs to a single group. The essence of cluster analysis is to sort the data into several clusters according to distance until the difference between data in the same cluster is as small as possible and the difference between data in different clusters is as large as possible. The key to clustering is to group similar things together in the same group This learning algorithm is simple without supervision.

Development of the K-means method. K-means is an unsupervised classification (clustering) algorithm that groups objects into k groups based on their characteristics (22). Clustering is performed by minimizing the sum of distances between each object and the centroid of its group or cluster. The quadratic distance is usually used.

The algorithm consists of three steps:

- 1. Initialization:** once the number of groups k has been chosen, k centroids are established in the data space, for example, by choosing them randomly.
- 2. Assignment of objects to centroids:** each object in the data are assigned to its nearest centroid.
- 3. Centroid update:** The position of the centroid of each group is updated, taking as new a centroid the position of the average of the objects belonging to that group.

Steps 2 and 3 are repeated until the centroids do not move or move below a threshold distance at each step. In this context, a k-means cluster analysis was carried out to categorize sustainability for each of the dimensions, followed by a correspondence analysis that allows us to see the associations generated by each of the dimensions, in addition to analyzing their relationship with the type of livestock system generated by each of the dimensions (Table 3).

Table 3. Description of Algorithm I: K-means

Algorithm I: K-means

1. For a given cluster assignment C, the total variance of the cluster (3) is minimized with respect to $\{m_1, \dots, m_K\}$ by producing the cluster means of the currently assigned clusters (2)

Given a current set of means $\{m_1, \dots, m_K\}$ (3) is minimized by assigning each observation to the nearest (current) cluster mean. That is,

$$C(i) = \operatorname{argmin}_{1 \leq k \leq K} \|x_i - m_k\|^2 \quad (3)$$

2. Steps 1 and 2 are repeated until the assignments do not change
-

$$C^* = \min_C \sum_{k=1}^K N_k \sum_{C(i)=k} \|x_i - \bar{x}_k\|^2$$

It can be obtained by observing that for any set of observations S

$$\bar{x}_s = \operatorname{argmin}_m \sum_{i \in S} \|x_i - m\|^2 \quad (2)$$

Therefore, we can obtain C^* solving the extended optimization problem

$$\min_{C, \{m_k\}_{k=1}^K} \sum_{k=1}^K N_k \sum_{C(i)=k} \|x_i - m_k\|^2 \quad (3)$$

Note that each of steps 1 and 2 reduces the value of criterion (3), so that convergence is ensured.

Multiple Correspondence Analysis Methodology. Once the clusters of each of the categories under analysis have been obtained, we proceed to analyze the relationship between each of them using the multiple correspondence analysis technique developed by Hansen and Jaumard (23). It is a statistical technique used to analyze, from a graphic point of view, the relationships of dependence and independence of a set of categorical variables from the data of a contingency table. With this, it is based on the interest in the relationships within a set of variables to observe the associations between categories of variables.

In summary, the proposed methodology for the implementation of the algorithm is as follows:

Table 4
Description of Algorithm II: K-means

Algorithm II: Clustering for each category using K-means
<p>Step 1: For each of the farms, the environmental, economic, and social variables will be evaluated, taking into account the variables described in the methodology. (24)</p> <p>Step 2: For each of the categories, the variability of the variables is analyzed and those that have constant values or do not have information on at least 50% of said variable in the farms are not considered in the study (25)(26) of NA.</p> <p>Step 3: For variables with a percentage less than 50%, the media as a data imputation technique will be considered (27)</p> <p>Step 4: The variables will be standardized, so that they are all on the same measurement scale.</p> <p>Step 5: The K-means algorithm is applied to group the associated dimension of the different farms in which they are generated.</p> <p>Step 6: For each of the dimensions depending on the number of groups generated in step 5 the sustainability of the farm will be categorized in relation to the sustainability of the farm as Almost good, moderate, good and very good Sustainability</p>

Once Algorithm II described in each dimension was implemented, a multiple correspondence analysis was carried out to observe the associations or relationships generated by each of the dimensions, whether environmental, economic or social. The type of livestock system was also considered to observe the relationship with sustainability.

ACM software. The multiple correspondence analysis methodology was carried out through the implementation of the statistical software R-Studio <https://cran.r-project.org/> imputeTS library (28), performing steps 3 and 4 of the methodology proposed in Algorithm II. Subsequently, we used the cluster library (29) and factoextra library to perform step 5. Finally, the FactoMineR (31) library was used for the multiple correspondence analysis in step 6.

Results

Descriptive analysis by dimension evaluated

Economic dimension. As shown in Table 5, the results obtained for each variable of the economic dimension are available. Among the most profitable systems, rotary and regenerative systems are found, with the rotary system being the most profitable in terms of income and subsidies in agricultural income. For this, the cost of kg of meat and L of milk sold monthly was considered, with greater sales and production of milk. In the same way, the regenerative system is the second most profitable, focused on meat sales. The intensive system presents a greater money invested in terms of products of tick control, mosquito control and food purchases per drought on an annual

Table 5
Identification of variables of the economic dimension

Variable	Type of livestock system			
	Intensive	Regenerative	Rotacional	Average
Monthly income generated by the farm	\$3.000.000	\$5.500.000	\$11.300.000	\$7.909.091
Monthly expenses generated on the farm	\$2.000.000	\$2.452.500	\$3.340.000	\$2.784.583
Number of total subsidies among farm income	N.A	\$425.000	\$1.166.667	\$795.833
Family farm income among the family work unit family	\$ -	\$3.275.000	\$1.266.667	\$1.725.000
Cost per kg of meat produced	\$3.750	\$3.330	\$4.800	\$3.977
Cost per liter of milk produced	\$900	\$900	\$816	\$840
Liters of milk sold monthly (L/month))	192	420	816,67	599,33
kg of meat sold annually (kg/year)	0	28716,67	8633,33	17238,46
Average Interval Between Births (Days)	365	431,17	450	434,77
Money invested in the purchase of herbicides in the year	\$1.252.500	\$258.333	\$2.866.667	\$1.518.214
Money spent on feed purchase in drought per animal/year	\$1.800.000	\$859.542	\$1.250.000	\$1.161.232
Money spent on tick killer and mosquito killer in the year	\$2.750.000	\$98.333	\$408.333	\$610.000

Environmental dimension. According to the analysis of the variables observed in Table 6. According to the analysis of the variables, given the nature of the intensive livestock system, this has a greater participation in terms of water consumption, since it is an arrangement in which the number of head of cattle per hectare is greater. For the type of production, animal consumption is considered, which is categorized depending on the destination if it is meat, dairy or dual purpose. Based on the literature, a meat animal consumes between 10% and 15% of its weight in water (32), and animals destined for dairy production consume between 100 and 115 L/day (33). In general, the intensive system consumes 281,000 L/month, 40% of the total. Additionally, burning and the use of agrochemicals for weed control are carried out.

Additionally, the energy expenditure and bromatological content are higher given the demand and animal load. On the other hand, the regenerative system, having purely meat production and high animal load, consumes 220,400 L/month, 38% of the total; by its nature, this system has higher forage production, larger silvo-pastoral areas, shorter period of occupation of areas and lower energy consumption. There is no burning or no use of agrochemicals. These systems have conservation areas. On the other hand, the rotational system has a longer resting time between paddocks, higher occupation per area, and a lower average production of green forage per hectare and number of dead animals per year. There is burning and use of agrochemicals. It has conservation areas. Considering the variable of solid residues, the intensive system is lower since for the evaluation, this arrangement is presented in smaller quantity.

Table 6
Identification of environmental dimension variables

Type of livestock system				
Variable	Intensive	Regenerative	Rotational	Average
Water consumption (L/month)	281.000	220.400	197.167	219000
Paddock Resting Time (Days)	20	40	41,33	37,71
Green fodder production per Ha (kg/ha/month)	21.500	21.900	3.326	15109,32
Bromatological content of pasture (%)	12	5	7,8	7,45
Areas of pasture managed with trees (%)	15	50,17	25,92	34,75
Seminatural crop areas (Ha)	0	6,67	1,67	3,57
Number of dead animals per year	4	1,92	1,5	2,04
Electricity consumption (kw/month)	315	21,67	237,5	156,071
Occupancy period per area (Days)	7,5	3,67	10	6,93
Solid waste generated (kg/month)	1,5	11,9	5,75	7,77

In relation to the variables analyzed in Figure 2, it is observed that the intensive and rotational systems present burning activities in all the farms analyzed, contrary to the regenerative system that does not perform this type of activity. On the other hand, the intensive and rotational systems present weed control in all the farms, while for the farms that apply the regenerative system, only 33.3% of them perform weed control (e.g., specific cases). Finally, it is observed that the rotational and regenerative systems in their totality have conservation areas while the Intensive system does not have, and according to the physical chemical analysis of the soil, 50% of the farms with intensive livestock system apply it and only 33.33% apply it in the regenerative livestock system.

Social dimension. With respect to the categorical variables of the social dimension, Table 7 shows that only 17% of the farms with a regenerative system have a level of professional training, and the rest of the farms have no level of training. Regarding social security coverage, in intensive farms, 50% have social benefits, health, pension and labor risks; for the case of regenerative and rotational farms, only 33% have social benefits, and the rest of the farms have a subsidized regime. In relation to educational level, 50% of the farms have people with at most basic secondary education (high school), and the other 50% have secondary education. At the regenerative level, 67% have at most basic elementary education, and at the rotational level, 83% have at most basic elementary education.

For the periodicity of technical training, 100% of the intensive systems do not receive training; in the regenerative system, 33% receive daily training, another 33% receive weekly training, 17% receive monthly training and only 17% have never received training. Finally, in the rotational system, 33% receive monthly training, 17% receive quarterly training, 17% receive annual training, and the remaining 33% do not receive training.

Table 7
Identification of variables of the social dimension

Variables	Categories	Type of Livestock System		
		Intensive	Regenerative	Rotational
Technical training	None	100%	83%	100%
	Technologist	0%	0%	0%
	Technician	0%	0%	0%
	Professional	0%	17%	0%
Social security coverage	Belong to the subsidized regime	50%	67%	67%
	Not covered	0%	0%	0%
	Social benefits, health, pension, and occupational hazards	50%	33%	33%
Educational level of workers	Preschool	0%	0%	0%
	Elementary	0%	67%	83%
	Basic Secondary	50%	17%	0%
	Media	50%	17%	17%
Periodicity of technical training	Daily	0%	33%	0%
	Weekly	0%	33%	0%
	Monthly	0%	17%	33%
	Quarterly	0%	0%	17%
	Semiannual	0%	0%	0%
	Annual	0%	0%	17%
	Never	100%	17%	33%

Similarly, Table 8 shows that the average number of permanent workers is 1.5 in the intensive and rotational systems and 1 in the regenerative system; the number of daily wages is 2 for the intensive system, 1.67 for the regenerative system and 2.17 for the rotational system.

On the other hand, the number of days that workers work per year in the intensive system is 332.5, and the regenerative system is 327.5 and 337 in the rotational system. In the same way, it is observed that the one that has a lower average number of daily wages per hectare generated is the intensive system, as for the regenerative and rotational system there is an average of 1.5; the workers who work more daily hours are those of the regenerative system with 7.3 hours, followed by the intensive system with 7 hours daily and finally in the regenerative system they work 6.33 hours daily.

Table 8
Average number of workers per livestock system

Type Of Livestock System	Intensive	Regenerative	Rotational
Number of permanent employees	1,5	1,0	1,5
Number of day laborers	2,0	1,7	2,2
Number of days worked per year	332,5	327,5	337,8
Average number of daily wages generated per hectare	1,0	1,5	1,5
Number of hours worked per day	7,0	6,3	7,3

K-means Analysis By Dimension

Economic dimension. Due to the lack of complementary information for the economic dimension, the technique of imputation of missing data is used, using the media, where the variables are standardized to balance the data, and these remain on the same measurement scale. The K-means algorithm is applied to group the economic dimension of the different farms into three clusters, resulting in Figure 3, where the groups were categorized as Almost good, Good and Moderate.

From the economic dimension, we obtain the formation of three clusters, where the averages of each cluster for each of the variables that belong to this category are shown in Table 9.

Table 9
Average number of clusters of the economic dimension

Variable	Clúster		
	Good	Moderate	Almost good
Monthly income generated by the farm (\$)	25000000	3318182	6803030
Monthly expenses generated on the farm (\$)	5750000	1469167	3111528
Number of total subsidies among farm income (\$)	1147916.7	810416.7	663888.9
Family farm income among the work unit family (\$)	1725000	1300000	2150000
Cost per kg of meat produced (\$)	3250.0	5162.9	3034.4
Cost per liter of milk produced (\$)	666	898.38	840.29
Liters of milk sold monthly (L/month)	400	1065,33	199,78
kg of meat sold annually (kg/year)	18900	2716.67	31206.41
Average Interval Between Births (Days)	475	440,83	415.29
Money invested in the purchase of herbicides in the year (\$)	7000000	1008333.3	200833.3
Money spent on feed purchases in drought per animal/year (\$)	0	2709542	0
Money spent on tick killer and mosquito killer in the year (\$)	500000	1098333.3	158333.3

In this dimension, three clusters were generated, where they were categorized taking into account the results presented in Table 9, as shown in Figure 3. The following results are observed:

Cluster 1 is designated Good, where the farms that are categorized as having the highest profit in monthly income generated are grouped, with this of \$25.000.000 COP for this cluster. The main source of income for these farms is in the sale of meat, with a total of 18,900 kilos sold annually; however, they also have a monthly milk production of 400 liters, as observed in Table 4. They have the lowest cost per liter of milk produced, and the meat is the second lowest at 3250 per kg of meat produced. In this sense, it is observed that there is no investment of money in the purchase of food in time of drought, and the investment tick control and mosquito control is not the highest; however, it is the one that has the highest average number of total subsidies among the agricultural incomes.

The almost good cluster is considered to be the farms belonging to cluster 3. These farms are categorized as having a moderate profit of \$3,691,502 COP. Additionally, it is observed that these farms are the ones with the highest amount of kg of meat sold annually, and with the lowest average of average interval between calving, they do not invest in money for the purchase of feed during the dry season and they are the ones that invest the least amount of money in tick control and mosquito control during the year. Finally, it is considered a moderate cluster of farms grouped in cluster 2. These farms are characterized by having lower profits since their expenses represent 45.76% of the total income because these farms have intermediate prices of cost per liter of milk produced and meat, with costs of \$898 and \$5162, respectively. In addition, they have as main source of income the sale of milk and the sale of kg of meat annually, being the smallest of the 3 clusters, which generates expenses when investing money in the purchase of food in the droughts of the year with an average of \$2.709.542,00 COP. Additionally, they are the ones that invest the most in tick control and mosquito control during the year.

Environmental dimension. In this case, for the grouping of data, the variables of fauna associated with the soil and bromatological content of the pastures are not considered, since the fauna associated with the soil does not present variability because it has the same results and the bromatological content does not contain most of its values. Therefore, the technique of imputation of missing data is used, using the media, where the variables are standardized so that all are in the same measurement scale and the K-means algorithm is applied, to group the environmental dimension of the different farms into two groups, resulting in Figure 4 and Table 10.

Table 10
Average of Clusters of the environmental dimension

Variable	Cluster	
	Moderate	Good
Water consumption (L/month)	203889	246200
Burning activities	1,11	2
Weed Control (L/month)	1.0	1.8
Electricity consumption (kW/month)	209,44	20
Occupancy period per area (Days)	10	1,4
Paddock rest time (Days)	34,22	44
Green fodder production per Ha (kg/ha/month)	9125.61	25880
Areas of pasture managed with trees (%)	21,72	58,2
Solid waste generated (kg/month)	5.17	12.45
Bromatological content of pasture (%)	7.99	6.47
Conservation areas	1.22	1
Seminatural crop areas (ha)	1.11	8
Number of dead animals per year	2.44	1,3
Soil-associated fauna register	2	2
Physical-chemical analysis of the soil	1.78	1,6

Following the methodology, 2 clusters were obtained for this dimension, which were categorized as good and moderate according to the results obtained in Table 10.

In Figure 4, cluster 1 has been designated Good, where farms that are categorized by lower water and energy consumption, lower burning activity, lower average generation of solid residues, larger conservation areas and, in general, have performed physical-chemical analysis of the soil and higher production of green forage per hectare are grouped.

Cluster 2 has been designated moderate farms with higher water consumption and burning activities and higher weed control. These farms are characterized by higher energy consumption, and the number of dead animals per year is approximately 2.

Social dimension. The social dimension has certain gaps in terms of information; therefore, the missing data imputation technique continues to be used to implement the proposed methodology.

For this dimension, four clusters were obtained, according to the results shown in Table 11.

Table 11
Average number of clusters of the social dimension

Variable	Cluster			
	Moderate	Very Good	Almost good	Good
Number of permanent employees	1.2	1	1	2.5
Number of day laborers	0.80	2.00	2.33	3.50
Number of days worked per year (Days)	331.00	300	335.33	345
Level of technical training of workers	0	3	0	0
Periodicity of technical training (\$)	6.8	2	3	3
Number of hours worked per day (Hour)	7.60	8	5,67	8
Average number of daily wages generated per hectare	1.80	0.01	1.29	2.00
Social security coverage	1.2	2	1,5	1
Educational level of workers	2.4	2	3	2

Next, four clusters were generated, categorized as Almost Good, Good, Moderate, and Very Good. Figure 5 shows the following results.

Next, four clusters were generated, categorized as Almost Good, Good, Moderate, and Very Good. Figure 5 shows the following results.

The almost good cluster is designated farms that are characterized by having the lowest average number of daily working hours. In addition, half of the farms do not have social security coverage, social benefits, health, pension, and labor risks; however, it is considered almost good for having the majority of its workers with a basic secondary education.

The good cluster is designated to those farms where the results are considered good. According to Table 10, these farms on average are characterized by having a greater number of permanent workers and day laborers on their farms, in addition to working full time; however, their educational level is primary or lower. In addition, they have as social security coverage affiliation with the subsidized regime. It is noted that this cluster is not categorized as excellent since it has a subsidized health regime, being ideal an affiliation to social benefits, health, pension, and labor risks. On the other hand, the Very Good cluster is considered the farm with the highest level of technical training and professional level of workers, their technical training is weekly, and they work a full working day. In addition, they have social coverage of social benefits, health, pension, and labor risks, which is ideal in this dimension.

Finally, there is the moderate cluster, where the farms belonging to this group in general have an average of no or only annual training for their employees. Similarly, most of their employees belong to the subsidized regime, and they have the lowest average number of day laborers.

Multiple Correspondence Analysis. Considering the groupings and categorizations of the farms for each of the evaluated dimensions, we proceeded to analyze the association that exists between each of them. In addition, the behavior and articulation of these categories are analyzed with respect to the type of livestock system. For this, the multiple correspondence analysis (MCA) methodology is implemented. Figure 6 shows how this method allows the analysis of these associations.

As shown in Figure 6, the regenerative livestock system has a high association with the economic dimension in the Almost *Good* category, in the environmental dimension in the Moderate category and in the social dimension in the Almost *Good*

and Very *Good* categories.

On the other hand, the rotational livestock system and the intensive livestock system include an association with the environmental dimension categorized as *good*; however, the association of the intensive livestock system is not as strong as that of the rotational livestock system. Similarly, it is observed that the intensive system presents an intermediate association with the social dimension in the moderate category and the economic dimension in the *moderate* category. In relation to this analysis, it can be observed that the social dimension in the *good* category and the economic dimension in the good category have no association with the livestock systems in the region.

Discussion

Regarding the economic dimension, Mariella Van-Heurck, Julio Alegre, Reynaldo Solis, Dennis Del Castillo, Lisset Pérez, Patrick Lavelle and Marcela Quintero affirm that livestock farming in Yurimaguas is just above the minimum threshold of sustainability, cataloging itself as low in terms of the economic dimension, whose results are based on income and type of production (8). On the other hand, given the sustainability scale, the regenerative and rotational livestock system has a high 3/3 sustainability since it was associated with the ALMOST GOOD category, being the highest ranking. The intensive livestock system has intermediate sustainability. These results respond in scale to the low costs incurred in developing regenerative systems, represented in lower energy costs, the nonuse of nitrogen compounds for soil treatment, and chemicals for phytosanitary control, among other aspects.

On the other hand, Mariarita Cammarata, Giuseppe Timpanaro and Alessandro Scuderl affirm that in Silicia, high sustainability was obtained in ecological livestock systems considering the FAO SAFA methodology (7), similar to the results found in the regenerative system. Regarding the environmental dimension, the analyses of livestock systems in Yurimaguas show very low thresholds in terms of sustainability, mainly attributed to soil degradation, bad livestock practices, increases in agricultural frontiers and deforestation (8). In contrast, the rotational system includes a high sustainability categorized as GOOD because the rest of the paddocks allow more recovery time and less pressure on soils. The regenerative livestock system is associated with intermediate sustainability in the MODERATE category. The results are based on water and energy consumption, burning activities, use of agrochemicals and forage production. Agroecological livestock systems in Silicia show high sustainability due to their agroecological approach. The results were based on GHG emissions, water and energy consumption, soil use and biodiversity (7).

Regarding the social dimension, regenerative livestock systems have very high sustainability due to the higher social benefits identified, such as social security coverage and the educational level of workers. Intensive systems have intermediate sustainability categorized as moderate, and rotational systems have high sustainability associated with the good category. In comparison, Mariella Van-Heurck, Julio Alegre, Reynaldo Solis, Dennis Del Castillo, Lisset Perez, Patrick Lavelle and Marcela Quintero found in the analysis developed in Yurimaguas that the social dimension presents good sustainability in terms of education, housing, and participation in social organizations (8). Mariarita Cammarata found that the level of sustainability in the social dimension is high in organic livestock farming.

The results are based on the standard of living of workers, education, health, and income. However, there are medium levels of sustainability in some agroecological farms due to the working hours (7)

Conclusion

The livestock systems analyzed present significant differences in terms of the level of pressure they exert on the natural system, specifically on soils, associated with the possibility of these systems enhancing the availability of biomass of major and minor structures. In this case, the regenerative and rotational systems represent to a greater extent the tendency to maintain ecological synergy and the sustainable use of soil resources. For the case of the regenerative system, in conglomerates, it is the system that mostly marks an orientation toward a livestock production model toward sustainability,

given its integral behavior in the analyzed dimensions, in second place, the intensive system, and finally the rotational system. The indicators analyzed for the environmental, social, and economic dimensions present similarities with those identified in the literature; therefore, the development of comparisons is possible to determine the best behavior of the system as an integral model.

On the other hand, this study did not consider the production purpose; that is, if it refers to a dairy, meat, or dual purpose, it is pertinent to incorporate indicators oriented to determine the profitability of the system from different arrangements. Henceforth, to continue advancing the study of livestock systems toward models with a high degree of sustainability, it is considered relevant to design protocols for the capture, processing and simulation of data in real time or real causality to determine with greater precision the dynamics and opportunities for improvement of the systems. Understanding from a holistic approach the synergy between the variables analyzed would allow distinguishing, for example, the driving forces that generate greater sustainability in rotational and intensive systems, proposing models to simulate the arrangements that could be developed against a proposed objective

Declarations

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Figures

Figure 1

Location of livestock systems in the Department of Cordoba.

Figure 2

Percentages of the variables for the environmental dimension

Figure 3

Economic dimension cluster plot

Figure 4

Cluster plot of the environmental dimension

Figure 5

Cluster plot of the social dimension

Figure 6

MCA (Environmental, Economic, Social) dimensions and the type of livestock system.