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Characterization of the Cattle Production Systems in the Department of Cundinamarca (Colombia), Proposals for Sustainability

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Abstract: The aim of this document is to analyze the bovine production systems in the Department of Cundinamarca (Colombia) as an initial part of the strategic plan to implement sustainable and efficient technological proposals in this region of the Andes. Descriptive and productive agricultural data related to bovine production of the 116 municipalities were analyzed using a multivariate analysis method (principal component, cluster and variance analysis). The information contained quantitative variables regarding three topics: general information (geographical, cadastral and productive), a municipal bovine inventory, and productive information about the cattle farms. The analysis enabled us to generate three clusters of bovine production systems as follows: Cluster 1, representative of the dual-purpose activity, made up of 48 medium-climate municipalities, of which 64.6% of the municipal farms correspond to dual-purpose production with an average farm size of 5.2 ha, a carrying capacity of 1.2 UGM/ha and milk production per cow of 7.75 L/d; Cluster 2, made up of 36 cold-climate municipalities dedicated mainly to dairy production on farms (65.9%) of approximately 3.8 ha, with a carrying capacity of 2.3 UGM/ha and milk production per cow of 14.34 L/d.; and Cluster 3, made up of 32 warm-climate municipalities dedicated mainly to beef production on farms. In this cluster, 66.6% of the farms correspond to beef production of approximately 8.5 ha, with a carrying capacity of 1.2 UGM/ha and milk production of 6.35 L/d. Colombia's climatic diversity and the wide range of bovine livestock activities are among the main strengths that make up the system's advantages. However, the low technological development in the majority of the bovine livestock farms, which is related to variables such as low carrying capacity, as in Clusters 1 and 3 and with the low employment generated by bovine production in Colombia, are opportunities to improve the livestock industry. It is advisable to continue working to obtain data on important aspects of the system such as technology, nutrition, reproductive management (including artificial insemination), the economy and environmental and social aspects, in order to delve deeper into the sustainability of productive systems.

Keywords: bovine livestock systems; Andean region; dairy production; meat production; dual-purpose production

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1. Introduction

The information on the different animal production systems in Latin America is generally scarce and not up to date [1]. However, interesting studies on specific sectors have been carried out in relation to bovine production systems. For example, Toro et al. [2] studied the pastoral beef systems in Chile using a multivariate analysis, Nahed et al. [3] studied the sustainability of conventional and organic dairy cattle production units in Mexico, Vilaboa et al. [4] studied dual-purpose cattle also in Mexico, and Ruviaro et al. [5]

studied different feed management in the beef production in Brazil. Studies of this nature can affect decision-making for the livestock sector, the generation of public investment policies or strategic aspects such as research, technology transfer and the orientation of education towards the agricultural sector. To a large extent, the disconnect between government entities and communities of food producers of animal origin contributes to this and ends up affecting the productive performance of livestock farms [6,7]. This is particularly evident in the practices of cattle producers of the Department of Cundinamarca (Colombia), in which the production of animals for slaughter is highly heterogeneous and there is a lack of information on their productive systems.

In Colombia, livestock activity using different species is a valuable part of the economy and accounts for 1.4% of the national Gross Domestic Product (GDP) [8]. Among all the livestock activities carried out, cattle farming is present throughout the national territory and generates considerable income locally, contributing 21.8% of the agricultural GDP and 48.7% of the country's livestock GDP and generating 810×10^3 direct jobs, which represent 6% of national employment and 19% of agricultural employment, respectively [8]. However, the profitability of the livestock system in this area is low, due to its poor technological level and its products having little added value [9]. Unplanned development and traditional production models based on deforestation to establish grasslands in large regions of Colombia have meant that cattle production is responsible for many environmental problems associated with the use of land, water, forests and their services and ecosystems, as well as greenhouse gas emissions [10]. In addition, according to the Rural Agricultural Planning Unit (in Spanish, UPRA) [11], Colombia has dedicated 33% of its territory to pasture for livestock when it barely has 7% of the soils suitable for this purpose, which means that just over three-quarters of these areas have undergone some degree of degradation [12]. According to Garcia et al. [13], close to 60% of the deforestation in the country is associated with the establishment of grasslands for extensive cattle ranching, mainly in territories such as the Amazon region.

The worrying environmental impact of the current livestock development model in Colombia has therefore generated the need to investigate how to assess and measure the current sustainability of production at different scales in the different departments of the country, with the ultimate purpose of implementing measures to minimize the impact and generate operational strategies that can be used in the different livestock systems [14,15].

The Department of Cundinamarca (Colombia) is located in the Andean region. It is characterized by a variety of productive systems for the livestock exploitation of beef and dairy cattle (5.2% of the national inventory), pigs (17%) and poultry (9%), which guarantee, on the one hand, the provision of food to meet the growing national demand and, on the other hand, the stability of the rural setting [16,17]. Following the new production models from developing countries, production systems in the Department of Cundinamarca are becoming more intensive and dependent on external inputs. Bodirsky et al. [18] point out how the demand for products of animal origin will continue to increase mainly in emerging countries and in urban centers as a consequence of increased purchasing power. This has led to cattle production in developing countries being transformed from extensive to other semi-intensive or intensive systems [19].

As detailed by Sorensen et al. [20] and Gibon et al. [21], each farming system is unique; therefore, the resources and decision-making practices must also be adapted to meet the problems and needs of each region. Currently, in the Department of Cundinamarca, no analysis has been carried out of the different livestock production systems in order to allow future financial, political and productive decisions to be made to improve the regional production yields. If the different productive systems are categorized, with farms that present the most homogeneous characteristics grouped together, this strategy can be applied to decision-making studies so that their strengths and weaknesses can be assessed and used to offer recommendations and develop strategies for improvement [22,23].

The aim of this work, therefore, was to help to understand the cattle production systems in Cundinamarca (Colombia) by the use of a multivariate analysis as a base

strategy for future decision-making for improving or reorienting the livestock activity of the Department toward socially-, economically- and environmentally-sustainable processes.

2. Materials and Methods

2.1. Area Studied

The information on the bovine production systems analyzed in this document corresponds to the 116 municipalities distributed in the 15 provinces of the Department of Cundinamarca (Colombia). This department includes approximately 3.2 million registered inhabitants, of whom 8.43% are agricultural producers. Among these, 53.45% are adults between the ages of 50 and 70, with 27.98% between the ages of 20 and 49. The extension of the Department of Cundinamarca is approximately 24,210 km^2, and it is crossed by the eastern mountain range of the Andes, whose extreme points are between the coordinates 03°40′04″ and 05°50′14″ north and 73°03′16″ and 74°53′39″ west [24]. The Department of Cundinamarca borders on the departments of Boyacá, Meta, Huila, Tolima and Caldas (Figure 1).

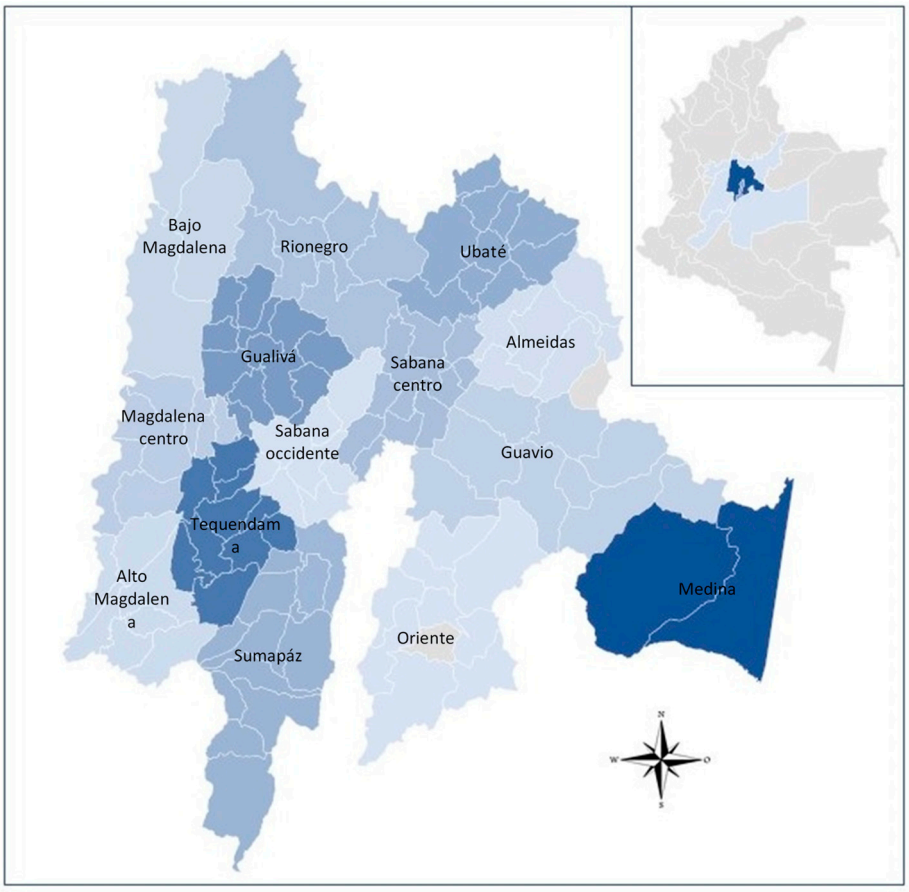

Figure 1. Geographic location of the Department of Cundinamarca (Colombia) and its provinces.

The variety of the climatic conditions of this area is determined by its altimetric position, its relief and the influence of the intertropical convergence zone that determines the rainfall regime. The precipitation pattern is highly varied, with areas on the eastern slope having averages of up to 3000 mm per year and between 1000 and 2000 mm per year in the central area [24]. The altitude of the urban areas in the Department of Cundinamarca ranges from 250 to 2950 m above sea level. In the agricultural areas, the main products are potatoes (25.4%), sugar cane (19.1%), coffee (15.2%), corn (9.1%), mango (6.1%), pea (4.7%), banana (3.5%) and other vegetables (16.3%) [16].

Regarding livestock production, the Department of Cundinamarca has highly developed cattle farming for milk, a production that is located mainly in the 'Sabana de

Bogotá' area and the Ubaté valley [25]. Notably, this department also encompasses 10.4% of the national inventory of laying hens and 8.1% of broilers [16]. In pig production, the department accounts for 7% of the national inventory of pigs [26].

2.2. Data Sources

The data analyzed in this document are taken from the most recent sources of the Colombian departmental or national administrations, including the municipal agricultural evaluations for the years 2007–2018 [27], the 2014 national agricultural census [28], the 2022 national bovine census [29], the statistical reports of the municipal bovine inventory 2019 [30] and the statistics of the Secretary of Agriculture for the Department of Cundinamarca during the years 2010–2020 [25].

According to the traditional systems of animal production in Cundinamarca, bovine production is present in all the municipalities of the department [29]. Given the complexity and diversity of the existing cattle production systems in Cundinamarca and in order to make a diagnosis regarding future production methods, it is necessary to simplify this reality through the use of quantitative variables that provide precise information and allow for classification. Based on the livestock information about the 116 municipalities collected from the administrative sources, a selection of the descriptive variables in the municipalities was made, followed by a selection of the productive variables related to bovine activity in the study area. The 41 variables finally selected are shown in Appendix A. Twenty-three variables correspond to the general agricultural features of the municipalities, 11 correspond to the inventory by municipality and seven correspond to the productive information of bovine livestock by municipality.

2.3. Statistical Analysis

The quantitative variables were characterized by descriptive statistics and their coefficient of variation (Appendix A, Table A1), and all the variables were transformed to Z points before being subjected to a multivariate analysis. The data on the variables were subjected to multivariate analysis in two stages: principal component analysis (PCA) and cluster analysis (CA). The PCA transforms the data on the diagnostic variables studied into a small set of new synthetic variables—principal components (PC)—with little loss of information. The purpose of the PCA is to reduce the number of variables and the dimensions of the problem [22,31]. The process of selecting variables in the PCA is the following: 12 variables were discarded because of their low variability coefficient and their correspondingly reduced discriminatory capacity. Another 21 variables were also discarded because of their correlation with other variables that were considered by the authors to be more important for defining the production system. Using the remaining eight variables, the authors tested the possible grouping of variables in different numbers of principal components or dimensions (five, four or three). The optimal results were obtained with four PCs (in the sense of discriminating and explaining the maximum variance), following the criterion of eigenvalues greater than one [32,33]. The PCs with varimax rotation were extracted for factor analysis. After the PCA, the municipalities were classified by a cluster analysis. There are no fixed rules in the literature concerning the choice of the number of groups. This number may be predefined by researchers (k-means cluster analysis) or undefined (hierarchical cluster analysis) [34]. In this case, the k-means analysis, which is based on the Euclidean distance for grouping using the four PC obtained, was better than the hierarchical analysis because the authors knew the approximate number of clusters that can be obtained from this type of productive system. In any case, tests were also performed using a hierarchical cluster analysis, and the results were identical (three clusters were obtained). For a larger number of clusters, the ANOVA significance level is greater than 0.05 for at least one of the principal components [22,32,35,36].

Once the groups were defined, they could be described and then compared using one-way ANOVA for each of the original quantitative variables. The assumptions of homogeneity have been verified by the Levene Test [2], where equality of variance between

groups was rejected ($p < 0.05$). To carry out the equality of means test for robust statistics, the Welch and Brown-Forsythe tests were used, which are appropriate in the case of unequal variances. These tests reject the equality of means for each factor ($p < 0.05$), comparing their means in the three clusters. The post-hoc comparison tests of means were carried out using the Games-Howell statistic, which is commonly used when the variances are not equal. The Tukey HSD statistic were used to contrast homogeneities when there was a possibility of the existence of homogeneous subsets defined by the three clusters [37]. For each of the factors, the following results were obtained: (i) For Factor 1, Clusters 1 and 2 were homogeneous and Clusters 2 and 3 were homogeneous. Therefore Cluster 2 exerts a link between 1 and 3 (ii). For both Factor 2 and Factor 3, none of the three clusters were homogeneous among themselves (iii). For Factor 4, Clusters 1 and 3 were homogeneous, and Clusters 2 and 3 were homogeneous; therefore, Cluster 3 is a kind of link bridge between 1 and 2.

In relation to the assumption of normality of the variables involved in the analysis, the Kolmogorov–Smirnov test was used [38]. In the case of the four variables (factors) in Cluster 1, only the normality of Factor 4 was rejected. In the case of the four variables in Cluster 2, the normality of Factors 1 and 4 was rejected. In the case of the four variables in Cluster 3, the normality of Factor 1 was rejected. Therefore, although normality was not met for the majority but not for all the variables involved in the analysis and given that robust statistics were used to carry out the ANOVA, the results of the analysis were considered to be valid. All the statistical analyzes were carried out using the IBM SPSS V25 statistical program.

3. Results

3.1. General Description of the Bovine Production Systems in the Department of Cundinamarca (Colombia)

The distribution of land in the Department of Cundinamarca is as follows: 1,221,964 ha is devoted to meadows (51.2% of the total vegetation cover), 1,035,179 ha is covered in forests (43.4% of the total vegetation cover) and 127,365 ha (5.34% of the total vegetation cover) is dedicated to agricultural activity.

Based on the information obtained from different official sources, Figure 2 shows the distribution of the farm animal species in the Department of Cundinamarca. Of the total registered farms in the Department of Cundinamarca, 112,446 (corresponding to 20.6% of the total registered farms) have cattle as their main activity (Figure 2). Among these, dual-purpose cattle farming accounts for 46.5% of the farms with cattle (52,298 farms), while dairy farming is carried out on 26.9% of the farms (30,285 farms). The rest of the bovine farms are dedicated to the production of meat.

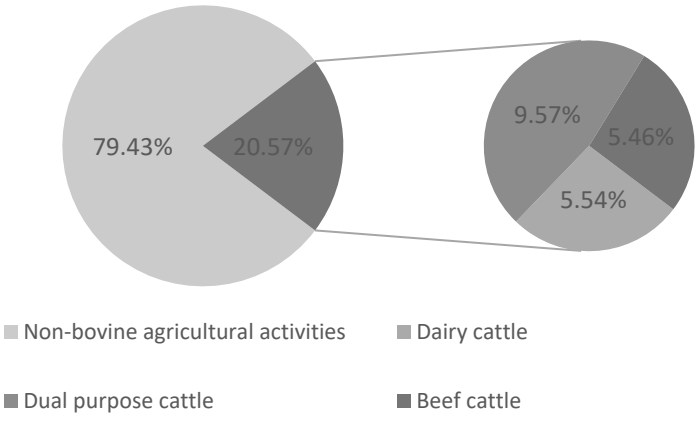

Figure 2. Percentage distribution of the number of cattle farms in the Department of Cundinamarca (Colombia) in the year 2020.

3.2. Principal Component Analysis

Table 1 shows the results of the PCA in which the dimensions of the initial set of 41 variables described in the methodology were reduced in order to generate the four components. The PCA identified a cumulative variance of 46.5% for the first two components and a cumulative variance of 75.8% for the first four principal components.

Table 1. Results of main components [a]. Eigenvalues [b] and the matrix of the rotated components of productive systems with bovine cattle in the Department of Cundinamarca (Colombia).

	Principal Components (PC)			
	1 Non-Bovine Agricultural Production	**2 Dairy and Dual Purpose**	**3 Beef Production**	**4 Bovine Inventory**
Area dedicated to agriculture by municipality (%)	**0.594**	0.284	0.261	0.184
Total cattle per farm	−0.193	−0.139	−0.115	**0.766**
Poultry/cattle ratio	**0.814**	−0.074	0.072	−0.039
Pig/cattle ratio	**0.762**	−0.111	−0.068	−0.021
Total farms with bovines	−0.228	0.012	−0.100	**−0.789**
Proportion of meat production farms (%)	0.094	−0.190	**0.971**	0.013
Proportion of dual-purpose farms (%)	−0.079	**0.948**	−0.241	−0.130
Proportion of milk production farms (%)	−0.013	**−0.703**	−0.666	0.108
Component eigenvalues	1.971	1.751	1.244	1.100
Variance proportion (%)	24.64	21.88	15.55	13.75

[a] Extraction method: principal component analysis. Rotation method: varimax normalization with Kaiser. [b] The eigenvalues in bold correspond to the variables assigned to each principal component.

According to the results of the component matrix (Table 1), the general variables by municipality and production can be grouped into four categories.

Component 1 (named non-bovine agricultural production) is strongly influenced by the variables related to the area devoted to agriculture, poultry production (technical and backyard) and pork (technical and backyard) by municipality. Component 2 (named dairy and dual purpose) includes the variables related to the number of bovine farms present per municipality that are dedicated to dairy and dual-purpose production. Component 3 (named beef production) basically includes the variables that refer to the number of farms dedicated to meat production by municipality. Finally, Component 4 (named bovine inventory) includes the variables related to the bovine inventory per farm and the proportion of farms with bovine production.

3.3. Cluster Analysis

The k-means cluster analysis produced three groups, which grouped the municipalities with clear common characteristics together in each cluster. Figure 3 shows the distribution of the clusters to which the municipalities belong, according to the two main components that represent their bovine productions. The horizontal axis shows Component 2, with the municipalities containing the highest percentage of farms with milk production on the left, and farms with dual-purpose production on the right. The ordinate shows Component 3, with the municipalities containing the highest percentage of farms dedicated to meat production at the top, and the municipalities with the lowest percentage of meat production farms at the bottom.

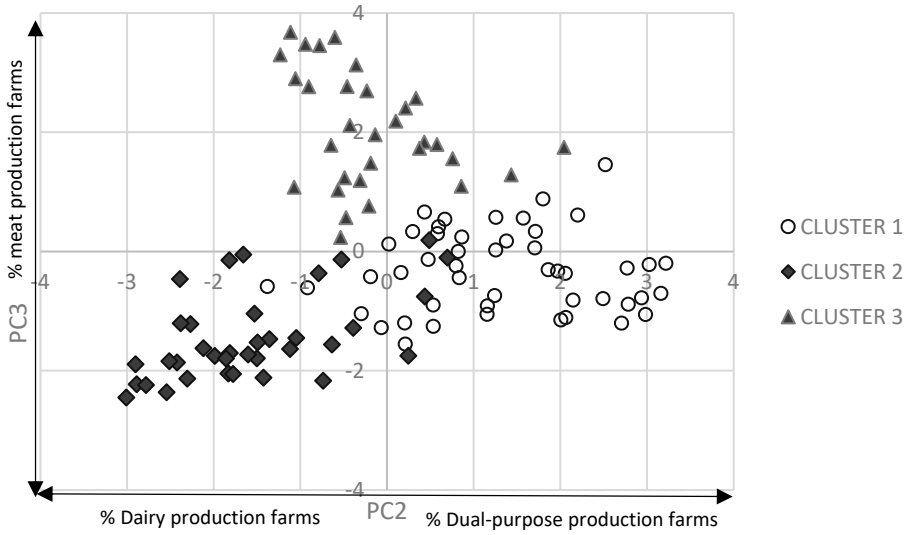

Figure 3. Distribution of the different dairy, dual-purpose and meat bovine production systems in the different municipalities of the Department of Cundinamarca (Colombia) according to Components 2 and 3.

The analysis of agricultural information from the 116 municipalities in the Department of Cundinamarca (Colombia) in 2020 allowed us to characterize the bovine production systems in the Andean area. The municipalities were classified into three clusters based on their main components as follows: Cluster 1 (dual purpose); Cluster 2 (dairy purpose) and Cluster 3 (beef purpose). The averages established for each variable according to each cluster are presented in Table 2 (agricultural generalities), Table 3 (bovine inventory) and Table 4 (productive information) and show the systems dedicated to the production of dual purpose, milk and beef production in the Andean region.

Table 2. Agricultural generalities of the clusters identified in the Department of Cundinamarca in 2020 (mean and standard deviation).

Variable	Cluster 1 n = 48	Cluster 2 n = 36	Cluster 3 n = 32
Altitude (m.a.s.l.) ***	1868.5 ^{b,*} ± 671.9	2386.6 ^{a} ± 508.6	1024.6 ^{c} ± 610.9
Average annual temperature (°C) ***	18.4 ^{b} ± 4.6	15.0 ^{c} ± 3.1	23.4 ^{a} ± 3.9
Municipality area (ha)	23,333.5 ± 20.496.7	18,036.1 ± 30,458.0	19,225.0 ± 18,040.7
Size per property (ha) **	5.2 ^{a,b} ± 4.5	3.8 ^{b} ± 4.5	8.5 ^{a} ± 9.5
Agricultural area (%) **	13.7 ^{a,b} ± 12.5	11.5 ^{b} ± 11.3	20.2 ^{a} ± 15.4
Forest area (%)	40.5 ± 19.2	39.5 ± 23.2	47.9 ± 26.5
Prairy area (%)	52.1 ± 20.4	54.0 ± 23.1	42.5 ± 24.9
Number of farms/municipality *	5162 ^{a} ± 2863	5293 ^{a} ± 3409	3383 ^{b} ± 2550
Total bovine farms **	1506 ^{a} ±2000	728 ^{b} ± 620	436 ^{b} ± 358
Cattle/farm *	14.7 ^{b} ± 13.8	31.8 ^{a} ± 38.4	22.3 ^{b} ± 18.3
Technical swine production(animals) ***	881 ^{b} ± 1683	6015 ^{a} ± 9353	1778 ^{b} ± 3143
Backyard swine production (animals)	69 ± 75	112 ± 142	70 ± 80
Pigs/Cattle ratio *	0.09 ^{b} ± 0.1	0.61 ^{a} ± 1.1	0.45 ^{b} ± 1.0
Total equines (animals)	981 ± 1.031	790.0 ± 922	871 ± 860
Total goats (animals)	116 ± 115	118 ± 241	111 ± 109
Total sheep (animals)	417 ± 668	366 ± 409	384 ± 340
Total technical poultry (animals) *	154,862 ^{b} ± 263,124	553,987 ^{a} ± 1060,835	312,595 ^{a,b} ± 426,223
Total backyard poultry (animals)	1775 ± 4162	899 ± 2266	1543 ± 2376
Poultry/cattle ratio **	15.8 ^{b} ± 31.1	46.2 ^{a,b} ± 86.5	79.1 ^{a} ± 126.7

m.a.s.l.: meters above sea level; ha: hectares. Different letters ($^{a, b, c}$) in the same row indicate significant differences (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$). HSD Tukey test of means subsets.

Table 3. Bovine inventory and distribution of the clusters in the Department of Cundinamarca in 2020 (mean and standard deviation).

Variable	Cluster 1 n = 48	Cluster 2 n = 36	Cluster 3 n = 32
Total cattle	13,422.4 ± 14,000.9	13,744.1 ± 10,435.9	9498.1 ± 15,304.5
Dairy cattle (%) ***	17.7 ^{b} ± 14.5	61.9 ^{a} ± 21.5	9.7 ^{b} ± 10.6
Dual-purpose cattle (%) ***	57.5 ^{a} ± 21.5	21.7 ^{b} ± 16.1	26.7 ^{b} ± 15.5
Beef cattle (%) ***	24.8 ^{b} ± 13.9	16.4 ^{b} ± 12.6	63.6 ^{a} ± 20.9
Total dairy cows ***	3123.6 ^{a,b} ± 4362.1	4273.3 ^{a} ± 3171.6	1386.6 ^{b} ± 2230.5
Total beef cattle ***	3545.7 ^{b} ± 5589.0	2246.3 ^{b} ± 2990.7	5813.2 ^{a} ± 9179.7

Different letters ($^{a, b}$) in the same row indicate significant differences (*** $p < 0.001$). HSD Tukey test of means subsets.

Table 4. Productive information of the clusters identified in the Department of Cundinamarca in 2020 (average and standard deviation).

Variable	Cluster 1 n = 48	Cluster 2 n = 36	Cluster 3 n = 32
Cutting grasses (%)	8.0± 13.5	7.7 ± 11.7	7.4 ± 10.5
Native grasses (%)	70.2 ± 24.3	66.9 ± 22.9	69.0 ± 27.2
Improved pastures (%)	21.8 ± 23.2	25.5 ± 22.9	23.6 ± 25.7
Specialized dairy cow production (kg/d) *	16.7 ^{a,b} ± 5.6	19.9 ^{a} ± 5.2	14.4 ^{b} ± 5.0
Traditional dairy cow production (kg/d) ***	6.7 ^{b} ± 3.5	11.0 ^{a} ± 3.4	5.8 ^{b} ± 1.8
Average production cow D.P. (kg/d) ***	5.9 ^{b} ± 2.4	8.7 ^{a} ± 3.5	6.3 ^{b} ± 2.5
Total milk per municipality (kg/d) ***	24,231 ^{b} ± 31,116	61,311 ^{a} ± 51,309	8815 ^{b} ± 13,535
Dairy farms (%) ***	14.7 ^{b} ± 14.1	65.9 ^{a} ± 18.8	8.4 ^{b} ± 9.5
Dual-purpose farms (%) ***	64.6 ^{a} ± 19.7	21.9 ^{b} ± 16.5	25.0 ^{b} ± 15.0
Farms beef production (%) ***	20.7 ^{b} ± 12.6	12.2 ^{c} ± 10.1	66.6 ^{a} ± 19.5
Carrying capacity (LSU/ha) ***	1.2 ^{b} ± 0.6	2.3 ^{a} ± 1.2	1.2 ^{b} ± 0.4
Average slaughter weight (kg)	414.3 ± 78.3	420.8 ± 81.5	430.8 ± 50.3

D.P.: dual purpose; LSU (Large Stock Unit): Livestock unit 500 kg weight. Different letters ($^{a, b}$) in the same row indicate significant difference (* $p < 0.05$; *** $p < 0.001$). HSD Tukey test of means subsets.

Table 2 shows the averages corresponding to the general agricultural variables for each established cluster. Significant differences were found among the clusters that pertained to altitude (m.a.s.l.), average annual temperature (°C) and size per property (ha). Regarding the total number of sheep, goats, equines, backyard pigs and backyard poultry, no significant differences were found among the municipalities in each identified cluster, nor between the percentage area of forests and grasslands.

Table 3 shows the averages corresponding to the bovine inventory variables by municipality and the distribution for each cluster. Very highly significant differences ($p < 0.001$) were found between clusters for the variables: dairy cattle (%), dual-purpose cattle (%), beef cattle (%), total dairy cows and total beef cattle.

Table 4 shows the averages corresponding to the productive information variables for each cluster. Very highly significant differences ($p < 0.001$) were found between clusters in the following variables: traditional dairy cow production (kg/d), average production cow D.P. (kg/d), total milk per municipality (kg/d), dairy farms (%), dual-purpose farms (%), beef production farms (%), and carrying capacity (LSU/ha).

Each cluster contains a number of municipalities that have similar productive characteristics. In Table 5, the three clusters reflect the agricultural characteristics of the municipalities of the Department of Cundinamarca. Cluster 1 groups the municipalities that are located mostly at altitudes close to 1850 m.a.s.l, which mark a medium climate in the tropics (18 °C), while Cluster 2 groups the municipalities that are located at altitudes close to 2350 m.a.s.l, which denote a cold climate (15 °C). Finally, Cluster 3 groups the municipalities located at altitudes close to or below 1000 m.a.s.l, which feature a warm climate (23 °C). Some of the main characteristics that identify the cattle production systems of the municipalities from each cluster are presented in Table 5.

Table 5. Main descriptors of the clusters identified in productive cattle systems in the Department of Cundinamarca (Colombia).

Cluster	C Number of Municipalities	Characteristics
1	48	Municipalities with a medium climate, with a high proportion of **dual-purpose farms**. In this cluster, 64.6% of the municipal farms correspond to dual-purpose production, and 57.5% of the bovines are also dual purpose. The average farm size is 5.2 ha, with 14.7 cattle per farm, a carrying capacity of 1.2 LSU/ha and a milk production per dual-purpose cow of 5.9 kg/d. There is little other livestock activity other than some technical poultry farming and marginal sheep, goat and horse production.
2	36	The cold-climate municipalities are mainly dedicated to **dairy production**. In this cluster, 65.9% of the farms correspond to dairy production and 61.9% of the bovines are also dairy. The farms are on average 3.8 ha, with 31.8 cattle per farm, a carrying capacity of 2.3 LSU/ha and a milk production per cow of 19.9 kg/d in specialized systems and 11 kg/d in traditional systems. In relation to other non-bovine livestock activity, the municipalities in this cluster have a large number of farms dedicated to the technical production of pigs and poultry, although sheep, goat and horse production are marginal.
3	32	The municipalities with warm climates are mainly dedicated to **beef production**, with approximately 20% of their area being used for agriculture. In this cluster, 66.6% of the farms correspond to beef production and 63.6% of the bovines are also beef. The farms for cattle breeding are, on average, 8.5 ha, with 22.3 cattle/farm and a carrying capacity of 1.2 LSU/ha. In relation to other non-bovine activity, there is considerable technical poultry activity, a little pig farming and marginal sheep, goat and horse production.

In the present study, the analysis allowed us to identify a group of 48 municipalities, mainly with medium climates (Cluster 1), located in the peripherical zone of the Cundinamarca Department, where 64.6% of the farms are dedicated to dual-purpose cattle production based on raising males for meat and milking females for milk production. In contrast, 36 of the Department's municipalities that are located mostly in cold climates (Cluster 2) have 65.9% of their farms dedicated to dairy bovine production systems. The remaining 32 municipalities are mostly in areas with warm climates (Cluster 3), located towards the eastern and western valleys of the Department of Cundinamarca. In this location, 66.6% of its farms are dedicated to the production of beef cattle.

Figure 4 shows a graphic representation of the productive systems (dual purpose, dairy and beef production) and their location in the Cundinamarca region.

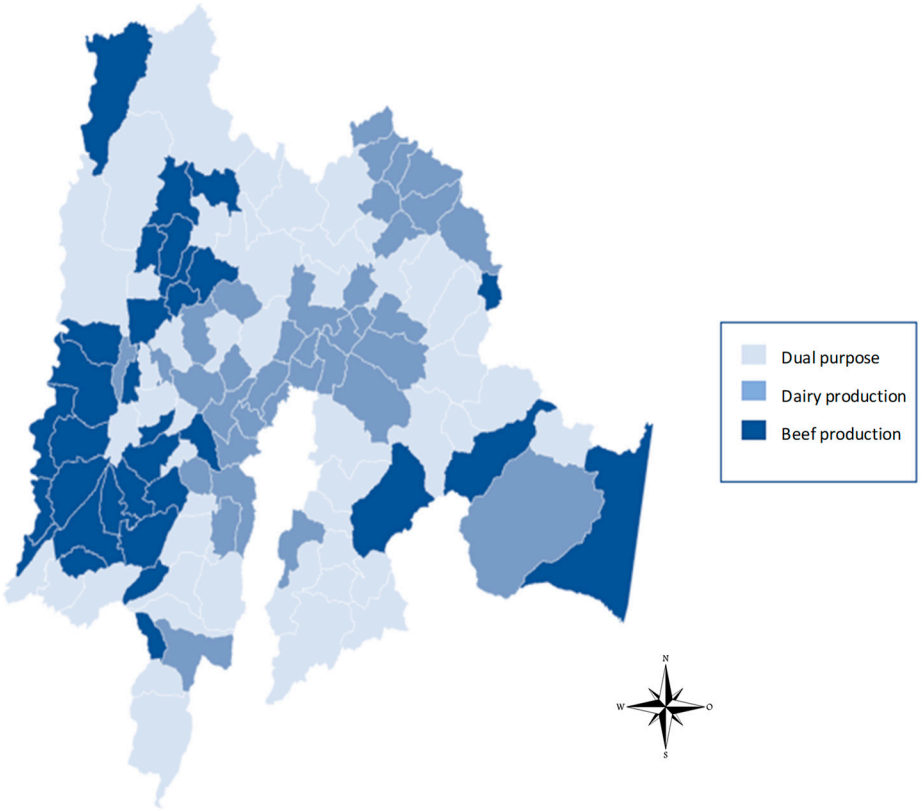

Figure 4. Geographical distribution of cattle production systems according to clusters in the Department of Cundinamarca in 2020 (Colombia).

4. Discussion

4.1. General Approach to the Established Clusters

As described previously, this work is intended to provide an understanding of the cattle production systems in Cundinamarca (Colombia) as a base strategy for future decision-making formulated to improve the livestock activity of the Department or reorient it toward socially-, economically- and environmentally-sustainable processes. Currently, there are hardly any references to the productive organization of bovine cattle in Cundinamarca (Colombia). However, the volume of information obtained from the regional or national administration of the Colombian government can be considered sufficiently representative for characterizing and illustrating the cattle production systems in this region [2,36]. In order to specify more precisely the animal production systems in Colombia, the present study has been carried out regarding the bovine production systems (dual-purpose, dairy and beef) used in the Department of Cundinamarca, where producers provide raw materials (milk or fat cattle) to the markets of the cities or towns. The National Department of Statistics of Colombia normally includes in its national agricultural survey the results of two bovine milk production systems in the country: specialized dairy and dual-purpose [16]. Both of these systems were identified in the clusters of this present study.

The methodology used by our study has allowed us to identify three clusters, from which we highlighted the productive aspects related to agricultural, dual purpose, dairy and beef productions present in the municipalities of Cundinamarca (Colombia). However, unlike other studies and characterizations, the methodology we have used has given us an overview of the diversity of the municipalities in terms of productive systems, climate and altitude, among other diversity factors, as a consequence of the abrupt relief produced by the eastern cordillera of the Andes, which crosses the Department. In 1983, Llorente [39]

identified the productive structure of cattle farming in Colombia not by its productive purpose but by using the terms of extractive systems, traditional extensive grazing, improved extensive grazing, intensive grazing with supplementation and confinement. Later, in 1995, Steinfeld and Mäki-Hokkonen [40] classified Colombian livestock production systems using criteria such as integration with crops, the relationship of livestock systems with land use and the relationship of livestock production systems with the different agro-ecological zones. Seré [41] classified milk production in the highland and lowland tropical ecosystems, while Holmann [42] estimated the distribution of cattle in the dual-purpose systems and specialized dairies in the lowlands (dry and humid) and highlands of tropical Latin America.

The diversity of the climates that exist in the Department of Cundinamarca, generated by the different altitudes, produces a diversity of agro-ecological conditions, which makes the Department suitable for exclusive livestock production or livestock mixed with agriculture, such as the activities identified in the clusters in this study. In fact, Llorente (1983) [39] identified in Colombia the presence of five subsystems within the extensive improved grazing system (breeding, dual-purpose, complete cycle, milk and fattening), three subsystems within the supplemented intensive grazing systems (dual-purpose, milk and fattening) and two subsystems in confinement (milk and fattening). Finally, Steinfeld and Mäki-Hokkonen in 1995 [40] classified the livestock systems in Latin America and the Caribbean according to whether they were being conducted in tropical high-altitude zones, humid and sub-humid tropical zones, or arid and semi-arid tropical zones. For this, they classified the livestock systems into two groups as follows: those dedicated exclusively to raising cattle in confined areas or those which exploit their pastures for animal husbandry, and those with mixed production models which integrate livestock activity with agricultural activities such as irrigated or rainfed agricultural cultivation.

No significant differences were found between the municipal areas destined for grasslands, with the clusters showing a general average of 50.1%. These were mostly occupied by native pastures (68.8% of the total meadows), while only 14.8% of their surface was used for agricultural production. This is an indicator that the cattle systems in Cundinamarca are based on grass and confirms the findings of Llorente [39], who found that over 90% of the cattle farming in Colombia uses grazing and who mentioned that only 48% of the area dedicated to bovine cattle farming in Colombia is based on traditional extensive grazing systems with grazing animals, generally using alternate systems or large pastures, with mineral supplementation and minimal inputs. Llorente [39] also reported that 36.4% of the Colombian bovine production is based on extractive systems, characterized by having a low number of grazing animals per hectare, with minimal to no use of external inputs and technification.

In Colombia, the cattle production is based on grazing, and for this reason, the total area of prairies is directly linked to cattle production. A comparison with the area dedicated to agricultural activity shows that cattle raising constitutes the main economic activity in the countryside for the rural population. Sarmiento et al. [43] and Jaramillo et al. [44] report that this is due to the lack of generational replacement, which leads to a lower supply of labor in the Colombian agricultural sector, as cattle production needs less labor than agriculture. It is also estimated that the fall in the profitability of agricultural activity has had a negative effect on generational change; consequently, some farmers and experts have tried to solve the problem by encouraging product diversification and participating in associations [45].

Furthermore, some non-bovine livestock production does exist in all rural areas of the municipalities, with significant differences found in the inventory of pigs in technical systems, which is greater in the municipalities classified in Cluster 2 (cold climate), and in poultry in the municipalities' technical systems in Clusters 2 and 3 (cold and warm climates, respectively). Due to their high financial investment, these systems are usually managed by medium and large producers [41,42].

4.2. Cluster 1: Municipalities with a Medium Climate and Dual-Purpose Production

The productive information described for Cluster 1 (Table 4) is identified with municipalities that have medium climates and dual-purpose production systems (57.5% of its cattle are dual-purpose and 64.6% of its farms are dedicated to this type of production). In Colombian bovine cattle, Rivas [46] described these systems as those in which the females are dedicated to milk production and the males are raised and fattened for sale as meat, and identified an approximate rate of milk production of close to 2.8 kg/animal/day, while in nearby countries such as Ecuador the milk production of dual-purpose cattle was approximately 4.6 kg/animal/day.

The average production identified for Cluster 1 was 5.9 kg/day, a value close to that reported by the URPA of the Secretary of Agriculture of the Department of Cundinamarca, which in 2013 gave the average milk production from dual-purpose farm animals as 6.43 kg/animal/day [47]. Carulla and Ortega [48] reported that this type of production is characterized by daily milking to obtain an average of between 3–5 L/animal/day, and that this type accounts for 60% of the milk in Colombia.

Farms included in Cluster 1 are located around 1868.5 m.a.s.l., a value that is within the range reported by Carulla and Ortega [48], who mentioned that these systems are followed mainly in mid-tropical areas (1200 and 2000 m.a.s.l.) and in low-tropical areas (<1200 m.a.s.l.) where *Bos taurus* × *Bos indicus* crossbreeds are mainly used.

A high value in carrying capacity (LSU/ha) is associated with a high technological level in the productive systems. In Cluster 1, dual-purpose cattle farms have a value of 1.2 LSU/ha, which is considered normal for small and medium livestock producers in Colombia, according to those referenced by González et al. [49]. The Center for Livestock and Agricultural Studies (CEGA) carried out a description of the livestock systems in Colombia in the year 2000 [50], in which they categorized the dual-purpose systems as traditional extensive systems and improved systems. The former was based on the use of natural or introduced grassland of low productivity without fertilization or health programs, while the latter were based on grasslands with improved pastures in association with native or introduced legumes, including weed control and fertilizer application, a permanent supply of mineralized salts, preventive health management and breeding and genetic improvement programs based on controlled mounting and artificial insemination.

For dual-purpose systems in Colombia, González-Quintero [51] et al. found that medium- and large-size farms were associated with better infrastructure and better livestock management practices; however, this was not reflected in an improvement of productive parameters. The authors determined that producers need to improve their livestock activity plans, with the purpose of increasing their productivity and developing strategies to mitigate their negative impacts on the environment. The information obtained regarding the productive system can serve as a guide for establishing policies and programs for their technological improvement [38,52], as in the present research.

4.3. Cluster 2: Municipalities with a Cold Climate and Dairy Cattle Production

The productive information described in Cluster 2 (Table 4) is identified with cold-climate municipalities and dairy production systems (with 61.9% of the cattle designated for milk and 65.9% of the farms dedicated to this type of production). These systems are identified with those described by Carulla and Ortega in Colombia [48] and are associated with highly technical dairy farms that have intensive processes of fertilizing the land, animal supplementation with 7–8 kg/day of balanced feed or formulated rations and a production of up to 27 L/animal/day. In general, these authors mentioned that the specialized dairy systems in Colombia are mainly implemented at altitudes of 2000 m above sea level, with cow breeds such as Holstein, Brown Swiss, Jersey and Norman producing two milkings per day when supplemented with balanced feed. They also pointed out that the average production in this system is 12 to 14 L/animal/day [48], which accounts for 40% of Colombia's milk production [53]. These results coincide with those identified for the dairy systems of Cluster 2, as they are located in municipalities at an

average altitude of 2386 m above sea level, although the average milk production was higher in the present study, which found a production of 19.9 kg/animal/day.

The present work identified two subsystems within the milk production systems: (1) specialized production, characterized by the use of specialized breeds, nutritional supplements, rotational grazing by strips and generally mechanical milking, and (2) traditional or peasant production, featuring the use of mixed-race animals, little or no fertilization of the pastures and the practice of manual milking, among other relevant aspects. The general average of milk production in specialized dairy is 18 kg/animal/day, while the general average of milk in traditional dairy is 7.9 kg/animal/day.

The URPA (Regional Unit for Agricultural Planning) of the Secretary of Agriculture of the Department of Cundinamarca reported an average milk production of 10.25 kg/animal/day for specialized dairy and 7.23 kg/animal/day for traditional dairy in 2014 [47]. These figures are lower than those found in this study, in which the averages were 19.9 kg/animal/day for specialized dairy and 11 kg/animal/day for traditional dairy, respectively.

The carrying capacity (LSU/ha) for milk production systems (2.3 LSU/ha) was significantly higher than for the dual-purpose systems shown in Cluster 1, which denotes a higher degree of technology associated with semi-intensive production systems and characterized by the use of high-yield pastures with electric fences, periodic irrigation and fertilization associated with the food supplementation program systems proposed for Colombia by the CEGA [50]. For the same variable, Carulla and Ortega [48] mentioned that specialized dairy systems had an average between 1–2 LSU/ha as a stocking rate indicator, which is a lower figure than that which was found by our study.

The average number of cattle per farm (31.8) was significantly different ($p < 0.05$) in the municipalities classified in Cluster 2 as compared to those in Clusters 1 and 3. In this context, it is important to highlight that the International Farm Comparison Network (IFNC) mentioned that 80% of Colombian dairy farmers have less than 20 animals, 15% have between 20 and 50 animals and 5% have more than 50 animals [54].

The milk producers were classified as specialized dairy, family-owned dairy farms or small-scale dairy and dual-purpose cattle or tropical dairy [55,56]. Small-scale and family-owned dairy farms are important for food security [57]. The results of the present research provide important information related with the characteristics of Cluster 2 that authorities can use to support efficient technological models and promote policies to improve the dairy systems. The adoption of technology could be affected by factors such as farm size, availability of capital and labor, education and land ownership; therefore, training is essential for achieving an effective impact on sustainable rural development in the areas of Cundinamarca where dairy production is competitive [58].

4.4. Cluster 3: Municipalities with Warm Climate and Beef Production

The productive information described for Cluster 3 (Table 4) is identified with municipalities that have warm climates and beef production systems (63.6% of cattle in these areas are meat-producing breeds and 66.6% of the farms are dedicated to beef production). The carrying capacity in these systems is 1.2 LSU/ha, which coincides with the activity of the complete cycle of breeding and fattening referenced by Mahecha et al. [59] for extensive, improved Colombian livestock systems. This carrying capacity is related to the intensification of livestock activity, and so the clusters with more extensive systems (Clusters 3 and 1) are found in municipalities where the farms are on average larger (8.5 ha and 5.2 ha, respectively). The Agustín Codazii Geographical Institute (IGAC) [60] pointed out in 2002 that 50% of Columbia's rural properties are under three hectares, and that livestock occupies 58% of small properties.

In the warm climate of the Cundinamarca area, as in Cluster 3, most of the livestock activity is carried out on native pastures (69.0%), a situation similar to that found in the other clusters obtained. This coincides with reports that mention that in the central-eastern region of Colombia, 62% of the soils are covered by grasslands, which are mostly native and

low-yield [60]. The slaughter weight (430.8 kg) of this cluster was similar to the national average reported by DANE (2020), with an average weight of 435.5 kg [61].

Most beef farms in Colombia are managed under low-input grazing systems. The natural pastures are usually overgrazed, which leads to the degradation of soils and water resources as well as deforestation when the animals receive limited supplementation of forages and concentrates and have low productivity (daily gain weight <0.5 kg per day) and stocking densities lower than 0.5 Animal Unit (A.U) per ha (1 A.U = 454 kg) [51,62,63]. The systems of Cluster 3 might have a competitive advantage in market niches that demand quality and "natural animal products" associated with the perceived positive ecosystem services and landscape conservation if the government, community and private sector promote the replace of extensive pasture lands with agrosilvopastoral systems that integrate crops, trees, pastures and livestock according to goals established by the nation to reduce greenhouse gas (GHG) emissions and to promote sustainable livestock systems [64].

4.5. Progress of Proposals for Improved Sustainability

Based on the productive characterization of the sector, it is possible to get a better picture of the characteristics and intensification of bovine productive systems in the Department of Cundinamarca, whose activity is present in all municipalities, and from there, to begin to identify problems and solutions that farmers and experts can propose for its improvement and sustainability over time [51,52].

The diversity that exists in different municipalities, such as the climate (determined by altitude), the wide range of bovine cattle activities (dual-purpose, dairy and beef), agriculture and the livestock species being produced, are among the departments' main strengths. However, this is offset by the low technological development in most of the bovine livestock farms, which is related to variables such as a low carrying capacity, as in Clusters 1 and 3 and the low employment generated by bovine production in Colombia [65], which has around 38 million ha being used for livestock farming and over 70% ha being extensively managed with a low density of cattle. The low carrying capacity is linked to the deforestation processes caused by areas of forests being cleared for livestock activity. In this way, extensive cattle farming is the principal driver of the expansion of the agricultural frontier in Colombia, which represents 60% of the deforested area in the country [66].

However, because of the fragile forest ecosystems, deforestation is a worrying issue in Colombia, especially because around 44% more land being deforested between 2015 and 2016. These models of extensive tropical cattle farming have serious consequences for the environmental degradation caused by the low efficiency and profitability of individual farms. Cundinamarca also suffers from this process and needs to preserve its forest cover, as it is a vital factor in regulating its water resources [54–57].

This study has been a first basic work, but it is advisable to continue working to obtain data on important aspects of the system such as technology, feeding, reproductive management (including the possibility of using artificial insemination), economic factors and of environmental and social aspects, in order to look deeper into the sustainability of the production systems. Proposing increases in production; suggesting changes in the breeds used; or making simple comparisons with the systems developed in other geographical latitudes regarding different topography, soils and even cultural customs could generate unsustainable livestock systems. In an attempt to transform weaknesses into strengths, solutions based on this characterization must begin to be built to promote employment, income and environmental conservation. In this sense, the conservation of biodiversity, including encouraging the planting of trees with the implementation of silvopastoral systems, carrying out forage conservation, and giving added value to the products generated by these systems could be some of the necessary steps to ensure greater sustainability of the systems due to the high social, economic and environmental impacts that they can generate.

This study revealed the potential for the creation of differentiated beef and milk products which form the clusters identified, promoting sustainable production systems

with possible price premiums for such products. Given Colombia's current transition to a post-conflict period, incentives for the rural areas to be more productive are expected in the following years [67]. The results of this study thus provide a valuable contribution to the literature and will assist decision-makers in the cattle sector by bringing evidence on the characteristics of livestock systems in Cundinamarca. Therefore, decision-makers could promote strategies that clearly combine environmental, production and market aspects to contribute to the upscaling of a sustainable livestock sector, with an adequate policy framework, control mechanisms and market strategies which include conservation or restoration safeguards.

5. Conclusions and Implications

The municipalities in the department of Cundinamarca (Colombia) feature diverse systems of agricultural production, corresponding to their particular relief and climate in the Andean location. Of these systems, bovine production is the livestock activity present in all the municipalities, and it is carried out by both small and large producers with different levels of technology. This study contributes to generate information about the cattle systems in Colombia and proposes a novel classification of the cattle production systems in the Cundinamarca department. There, cattle raising is the main livestock activity which drives economic development in this area, while other livestock activities such as sheep farming, goat farming, horse production, backyard pig farming or backyard poultry farming are marginal.

Based on the grouping of municipalities according to the characteristics of cattle farms, three models of production were identified that correspond to dual-purpose milk and beef production in medium, cold and warm climate areas, respectively. According to the three models of production identified in the clearly-defined geographical areas of the department of Cundinamarca, it is possible to form a more realistic picture of the current intensification level of bovine productive systems, and from there to begin to identify problems and solutions that farmers, decision-makers and experts can propose for its improvement and sustainability over time. The updated description of the livestock system in the Cundinamarca region provided here could help both official and private organizations to make key decisions for livestock development in Colombia. It is advisable to continue working to obtain data on important aspects of the system such as technology, feeding, reproductive management (including the possibility of using artificial insemination), economy and environmental and social aspects, in order to delve deeper into the sustainability of production systems.

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Appendix A

Table A1. General description of the variables evaluated.

Description	Variable	Average	Standard Deviation	Coefficient of Variation
General agricultural features of the municipalities	Altitude (m.a.s.l.)	1796.5	800.5	44.6
	Temperature (°C)	18.7	5.1	27.2
	Municipal area (ha)	20,556.1	23,398.2	113.8
	Size per farm (ha)	5.7	6.5	114.8
	Agricultural area (%)	14.8	13.3	89.9
	Forest area (%)	42.2	22.7	53.8
	Grassland area (%)	50.1	22.8	45.6
	Farms/municipality	4711.7	3053.3	64.8
	Total bovine farms	969.4	1416	146.1
	Cattle/farm	22.1	25.9	116.8
	Total pigs in technical production	2722.1	5958.6	218.9
	Total backyard pigs	82.8	102.7	124.1
	Pigs/Cattle	0.4	0.8	233
	Total equines	891.3	948.3	106.4
	Total goats	115.3	161.3	139.9
	Total sheep	392.4	514.8	131.2
Bovine inventory/municipality	Total technical poultry	322,241.4	669,554.4	207.8
	Total backyard poultry	1439	3210.3	223.1
	Poultry/cattle	42.7	87.6	205.1
	Calves <1 year	2465.7	2679.4	108.7
	Steers 1–2 years	2970.7	3438.1	115.7
	Heifers and bulls 2–3 years	2503.7	2951.6	117.9
	Bulls and cows > 3 years	4499.5	4779.9	106.2
	Total cattle	12,439.7	13,406.9	107.8
	Dairy cattle (%)	29.2	27.5	93.9
	Dual-purpose cattle (%)	37.9	24.7	65.3
	Bovine meat (%)	32.9	24.9	75.7
	Total dairy cows	3001.2	3663	122
	Total beef cattle	3767.9	6333.49	168.08
	Pasture cut (%)	7.7	12.1	156.3
	Native grasses (%)	68.8	24.5	35.6
	Improved pastures (%)	23.4	23.7	101
Productive information on bovine livestock/municipality	Specialized dairy Average production cow (kg/d)	18	5.6	31
	Traditional average production cow (kg/d)	7.9	3.8	48.1
	Dual-purpose cow average production (kg/d)	6.9	3	44.1
	Total milk by municipality (kg/d)	31,486.1	41,106.9	130.6
	Dairy farms (%)	28.9	29	100.5
	Dual-purpose farms (%)	40.4	26.8	66.4
	Meat farms (%)	30.7	26.6	86.5
	Carrying capacity (LSU/ha)	1.5	0.9	59.2
	Average slaughter weight (kg)	420.9	72.2	17.1

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