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Characterization of the dual-purpose cattle production system of smallholder livestock farmers in the Colombian Caribbean

Caracterización del sistema de producción bovina doble propósito de pequeños ganaderos del Caribe colombiano

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ABSTRACT

This study characterizes the dual-purpose cattle production system among smallholder livestock farmers in the Colombian Caribbean, focusing on socioeconomic, productive, and environmental dimensions. Data from 536 producers were collected through structured questionnaires and analyzed using descriptive statistics and factorial analysis for mixed data (FAMD). Results indicate that most producers are over 51 years old, have low educational attainment, and that 49% live below the poverty line. Record-keeping practices are deficient, and milk production represents the main source of income, with an average yield of 3.4 L cow^{-1} day^{-1}. Pasture management is limited, with minimal fertilizer use and scarce forage renewal. Environmental practices vary, with some producers maintaining forest patches and implementing waste management strategies. According to the factorial analysis of mixed data, key factors differentiating smallholder livestock farmers were the number of animals per farm, production of milk per day, infrastructure, pasture types, and total pasture area. To sustainably address the major limitations of the production system, the adoption of basic management strategies such as record keeping, improved pastures, weed control, and rotational grazing can enhance overall performance. These practices represent feasible leverage points to improve productivity per animal while reducing pressure on land and forest resources.

Palabras clave:
Manejo ganadero
Análisis de datos mixtos
Manejo de pasturas
Desarrollo rural
Condiciones socioeconómicas

RESUMEN

Este estudio caracteriza el sistema de producción bovina doble propósito entre pequeños ganaderos del Caribe colombiano, con énfasis en dimensiones socioeconómicas, productivas y ambientales. Se recopilaron datos de 536 productores mediante cuestionarios estructurados que fueron analizados utilizando estadística descriptiva y análisis factorial de datos mixtos (FAMD). Los resultados indican que la mayoría de los productores son mayores de 51 años, presentan bajos niveles educativos y que 49% vive por debajo de la línea de pobreza. El uso de registros es deficiente y la producción de leche constituye la principal fuente de ingresos, con un rendimiento promedio de 3,4 L vaca por día. El manejo de pasturas es limitado, con escaso uso de fertilizantes y poca renovación forrajera. Las prácticas ambientales son variables, ya que algunos productores mantienen parches de bosque y aplican estrategias de manejo de residuos. Según el análisis factorial de datos mixtos, los factores clave que diferencian a los pequeños ganaderos incluyen los métodos de ordeño, la producción de leche, la infraestructura y los tipos y área total de pasturas. Para abordar de manera sostenible las principales limitaciones del sistema productivo, la adopción de estrategias básicas de manejo, como el registro de información, el establecimiento de pasturas mejoradas, el control del enmalezamiento y la implementación del pastoreo rotacional, podrían mejoral el rendimiento del sistema. Estas prácticas representan puntos de intervención factibles para mejorar la productividad por animal y, al mismo tiempo, reducir la presión sobre el uso del suelo y los recursos forestales.

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According to the 2025 National Livestock Census, 76% of cattle farms in Colombia are owned by individuals with a bovine inventory of fewer than 50 head (ICA 2024), which classifies them as small-scale producers. These farmers typically engage in dual-purpose cattle production, which represents 40% of the country's livestock operations (DANE 2022). This indicates that, beyond specialized cattle farming, the dual-purpose production system is the most widespread in Colombia, contributing 55 and 39% to the national milk and meat output, respectively (Bravo Parra et al. 2021).

The dual-purpose cattle production system (DPCS) refers to a model in which both milk and meat are produced simultaneously. In this system, cows are partially milked during morning sessions and the remaining milk is consumed directly from the udder by the calf (Cortés et al. 2012; González-Quintero et al. 2020a). The animals are kept on pasture, generally under an extensive management scheme with minimal use of external inputs. Productivity levels tend to be low; milk yields range from 3 to 6 L cow^{-1} day^{-1}, particularly in mid- and low-altitude regions of the Andes, the Caribbean region, Llanos Orientales, and the Amazon. Meat production is derived primarily from the sale of cull cows and/or steers intended for rearing and fattening (Bravo Parra et al. 2021).

The environmental and socioeconomic importance of DPCS in Colombia is driven by their wide distribution and their contribution to the national food supply, particularly through milk and meat production, the extensive land area they occupy, and the income they generate for thousands of smallholder producers. Consequently, the management of these systems has direct implications for the environmental dynamics of livestock landscapes and the quality of life of rural populations. Therefore, improving DPCS to increase farmers' income while minimizing negative environmental impacts has the potential to substantially influence regional and national dairy and meat supply, enhance quality of life in rural areas, and contribute to forest and biodiversity conservation.

However, the multivariate nature of these systems, which involves interactions among multiple parameters, makes it necessary to identify the variables associated with better performance in DPCS and, consequently, to group farmers and practices that may lead to improvements in cattle production conditions. Given the above, evaluating the performance and conditions of DPCS requires the integration of data related to herd structure, productive yields, environmental factors, and the socioeconomic characteristics of producers.

These variables include both quantitative and qualitative data, and their joint analysis can be effectively conducted using methodologies such as factorial analysis for mixed data (FAMD), which enables the integration of continuous and categorical variables within a single analytical framework. This approach preserves the information contained in both data types and facilitates the identification of underlying patterns, associations, and gradients that would not be captured through separate analyses. By reducing dimensionality while maintaining interpretability, factorial analysis for mixed data is particularly suitable for the evaluation of heterogeneous production systems (Pagès 2004).

Accordingly, the aim of this study was to characterize the dual-purpose bovine production system developed by small-scale producers in Colombia's Caribbean region, based on productive, environmental, and socioeconomic dimensions, using factor analysis for mixed data to identify strengths to enhance and weaknesses to address.

MATERIALS AND METHODS

This study was conducted from September 2024 to April 2025, during which 536 small-scale producers located in three departments of the Colombian Caribbean region were interviewed. In Córdoba, participants were selected from the municipalities of Montería (n=162), Planeta Rica (n=76), and Ayapel (n=39); in Bolívar, from Magangué (n=48), Morales (n=41), and Mompox (n=31); and in Sucre, from San Benito Abad (n=63), San Marcos (n=49), and Sucre (n=27). The criterion used to identify small-scale producers was based on the most recent Unique Vaccination Registry, which defines eligible producers as those owning no more than 50 head of cattle. Additionally, to facilitate the analysis, producers were grouped into very small producers, those who had fewer than 20 animals, and small producers for those who had 20 or more animals. Sampling locations were selected from the municipalities with the highest cattle inventories in each department, and the estimated number of farmers per municipality was derived from the 2021 Colombian cattle

census, which reports the number of cattle farms in each area. The inclusion and exclusion criteria were based on the quality of the information reported by the producers. All respondents and their corresponding questionnaires passed the quality control assessment.

Given that the dynamics of livestock production among small-scale producers in the Colombian Caribbean region involve both qualitative and quantitative data, a structured questionnaire was developed to organize the information provided by each producer into four components: (1) general information; (2) herd management and composition; (3) pasture management; and (4) environmental information. Each component included both numerical and categorical questions (Table 1).

Table 1. Assessed variables within each component of livestock production among small-scale producers in the Colombian Caribbean region.

Component	Numerical variables	Categorical variables
General information	Producer age (Years) Monthly income (COP) Non-bovine animals (broilers, layers, horses, donkeys and mules, pigs, fishes, sheep) (No.)	Producer's educational level House type Public services Water source Food preparation Type of population
Herd management and composition	Categorized cattle inventory (No.) Cattle per farm (No.) Lactating cows (No.) Stocking rate per farm (AU ha^{-1}) Liters per day (L Day^{-1}) Liters per cow (L cow^{-1}) Lactation duration (Days) Open days (Days) Calving interval (Days)	Supplementation Record Management Milking Method Reproduction system Reproductive records Farm infrastructure
Pasture management	Pasture area (ha) Improved pasture area (ha) Crude protein (%) Ash content (%) Ether extract (%) Neutral detergent fiber (%) Acid detergent fiber (%)	Grazing method Improved pastures Fence type Fertilization Post type Pasture renovation
Environmental information	Forest area (ha) Number of tree species (No.) No. of trees (No.)	Presence of forest Forest type Topography Solid waste management Wastewater management Carcass disposal management

AU=Animal Units; COP= Colombian pesos.

Grass sampling

A total of 54 forage samples were collected, corresponding to the most representative species in the region, as identified through the characterization and interview process. Accordingly, *Brachiaria humidicola*, *Cynodon nlemfuensis*, *Dichanthium aristatum*, and *Bothriochloa pertusa* were sampled to determine crude protein (CP) using the Kjeldahl method, ether extract (EE)

by continuous solvent extraction, and ash content (Ash) through dry ashing in a muffle furnace at approximately 550 °C, neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using neutral and acid detergent solutions, respectively, according to the methodologies described by AOAC (2019). All samples were collected at the pre-flowering stage, cut at a height of 5 cm, and pre-sun-dried to reduce moisture content and prevent decomposition before being transported to the laboratory.

Statistical analysis

Unsupervised data mining techniques were applied using SPSS v.25 and IBM SPSS Modeler v.18 for data exploration and descriptive analysis of quantitative variables. To further explore the relationships and assess similarities and/or differences among observations, a factor analysis of mixed data (FAMD) was performed in R using the FactoMineR package (Lê et al. 2008) and the factoextra package (Kassambara and Mundt 2020) for the visualization of individuals and variables.

Factorial Analysis of Mixed Data (FAMD) was used because the dataset comprised a combination of quantitative variables (e.g., pasture areas, stocking rate, productive indicators) and qualitative variables (e.g., grazing management, infrastructure, and management practices). FAMD allows the simultaneous analysis of both data types within a single multivariate framework, ensuring that neither quantitative nor qualitative variables dominate the factorial structure. This approach preserves the original information contained in each variable type while reducing dimensionality and facilitating the identification of underlying patterns, gradients, and associations among variables. Additionally, the factorial coordinates derived from FAMD provide an appropriate basis for subsequent clustering analyses, enabling the construction of producer typologies and the identification of homogeneous groups of farms with similar structural and management characteristics (Pagès 2004).

RESULTS AND DISCUSSION

General information

The observed age distribution revealed that most producers fell within the intervals of 51–64 years (42.9%), 65–79 years (27.2%), and 36–50 years (17.9%). Only 7.5% of respondents were under 36 years of age, while 4.5% were over 79 years. These findings suggest a potential aging trend within the study population, consistent with national data and projections from DANE (2025). According to these sources, Colombia's rural population has progressively declined and aged since 1960, primarily due to displacement caused by armed conflict and limited employment opportunities. The aging and decline of the rural population may represent a major constraint to the sustainability of dual-purpose production systems. In tropical regions, where the average age of producers is approximately 55 years, the limited incorporation of younger farmers may progressively reduce the capacity to perform essential activities, which are predominantly manual and labor-intensive, such as milking and grazing management (Galina et al. 2016).

Regarding educational level, 10% of producers reported having no formal education, 43% had completed primary education, 32% secondary education, and 15% had pursued higher education, including professional, technical, or technological training. These findings are consistent with those reported by Aguilar and Serrano (2015) in a study of 242 livestock farms in the municipality of Montería, Colombia, where 38% of producers had only completed primary education. This may suggest that the educational development of livestock producers in the region has remained relatively unchanged in recent years. This may be one of the factors contributing to the stagnation of these production systems, as socioeconomic constraints such as limited education and restricted access to information can hinder the adoption of technologies that improve system efficiency (Tey and Brindal 2012). Furthermore, the adoption of new technologies has been shown to increase significantly with higher levels of education (Galina et al. 2016). The main water sources for both human and animal consumption consist of deep wells (37%), aqueduct systems (21%), and earthen ponds (19%). The remaining beneficiaries obtain water from alternative sources such as rainwater harvesting, wetlands, streams and/or rivers, or a combination thereof.

Of the total respondents, 29% reported not belonging to any differentiated population group. However, a significant proportion of livestock producers are victims of violence

(33%), underscoring the importance of programs aimed at improving the conditions and productive performance of livestock activities in the region. This is further supported by the fact that 24% of respondents were older adults, indicating that a substantial proportion of producers belong to vulnerable population groups, including women-led households. These households rely heavily on income generated from the DPCS and represent a population segment more likely to adopt technologies aimed at improving animal welfare and female reproductive performance, while strengthening activities related to milk production and dairy processing (Villarroel-Molina et al. 2022).

For 90% of producers, cattle ranching is the primary source of income. The remaining 10%, while still deriving some household income from bovine production, relies on other economic activities they consider more important, such as agriculture or the rearing of non-bovine livestock. Additionally, domestic animals are present on the farms and may contribute modestly to household income (Table 2). This pattern is consistent with findings reported by Aguilar and Serrano (2015) in Montería, Colombia, where between 50 and 80% of producers in various zones of the municipality obtained their income exclusively from livestock production. Meanwhile, the proportion of producers who combined livestock with agricultural activities ranged from 16.7 to 39.5%. A study conducted in rural households in Mexico revealed that, for small-scale livestock producers, income diversification can serve as a strategy to increase monetary inflows. This diversification typically involves the rearing of non-bovine species and the cultivation of staple and/or commercial crops, followed by engagement in non-agricultural labor and the extraction of natural resources (Mora and Cerón 2015), which plays a particularly relevant role in Colombia's Caribbean region, where some of the interviewed producers have farms located near wetlands and rivers, making fishing an occasional source of income.

Table 2. Average Income for producers according to different ranges of monthly income and non-bovine Livestock Holdings.

Monthly income*		
Range	**Producers (No.)**	**Average income**
<460,198**	31	347,612±96,221
460,199 – 1,000,000	101	712,693±128,946
1,000,001 – 1,423,000***	131	1,139,877±119,145
1,423,001 - 2,000,000	133	1,643,609±159,966
2,000,001 - 3,000,000	101	2,318,416±327,793
>3,000,000	39	4,023,205±1,453,887
Non-Bovine livestock		
Species	**Producers (No.)**	**Animals (No.)**
Layers	168	16±12
Donkeys and mules	65	2±1
Goats	5	12±10
Horses	168	2±1
Sheep	10	14±7
Turkeys	73	5±4
Broiler	67	43±30
Pigs	136	5±4
Fishes	39	1514±1939

*Monthly income (COP); **Extreme monetary poverty threshold for Colombia year 2025; *** Monetary poverty threshold for Colombia year 2025.

A total of 49% of producers reported a monthly income below the monetary poverty threshold established for Colombia in 2025. Additionally, 24.6% earn less than COP 1,000,000, and 5.7% fall below the extreme monetary poverty threshold defined for the same year. In contrast, 26.1% of respondents earn more than COP 2,000,000. On average, the monthly income across the study population is COP 1,570,423 (Table 2), which is used to support households averaging three members. In dual-purpose cattle systems managed by small-scale producers in the department of Putumayo, Colombia, the primary source of income has been reported to come from milk sales (Flórez et al. 2024). Similarly, in comparable production systems in the Sumapaz region of Colombia, where monthly income for 55.2% of producers ranged between one and two legal minimum wages (Bermúdez et al. 2017), which is notably higher than that observed in the population under study.

The spatial projection analysis of socioeconomic variables showed low variability among producers, particularly among very small producers (Figure 1), indicating that they live under similar socioeconomic conditions. Monthly income was located near the lower values of Dimensions 1 and 2, suggesting that income generated from livestock and other activities is insufficient to clearly differentiate the population. As a result, producers appear to rely on diversification strategies to supplement household income and increase economic resources.

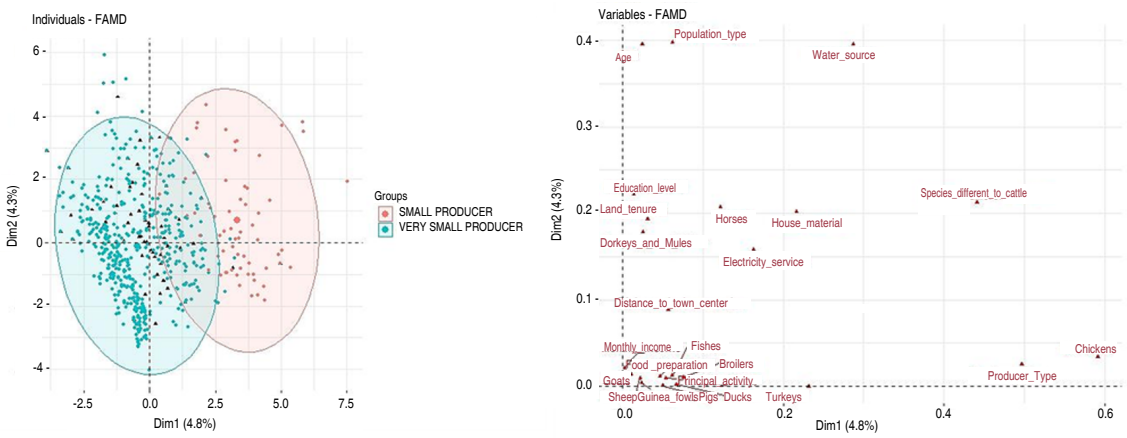


Figure 1. Spatial projection for variables related to socioeconomical variables.

Herd management and composition

Record-keeping practices in the evaluated livestock systems were found to be notably deficient. A total of 77% of producers do not document the performance of their operations, while the remaining 23% record production events manually and do not use any software tools to facilitate parameter analysis. This pattern is consistent with findings from other regions of Colombia, such as Sumapaz, Putumayo, and Norte de Santander, where, despite some level of record-keeping related to production performance and animal inventory, digital tools are not employed, and financial records are not maintained. As a result, there is no formal control over the financial status or profitability of the livestock operations (Flórez et al. 2024; Celis et al. 2024; Bermúdez et al. 2017). Although record-keeping does not guarantee improved productive performance, a positive trend toward higher yields has been observed when it is implemented, particularly because it supports more informed decision-making based on the actual performance of the production system (Sánchez et al. 2020).

In general, respondents measure daily milk production, as it is sold to companies involved in dairy processing, especially cheese making. However, the producers do not retain historical records of milk weights. A similar situation applies to reproductive records: producers do not maintain formal documentation, but they have knowledge about approximate dates of births and/or deaths, which allows for rough estimations of open days and calving intervals, though these are not recorded for subsequent evaluation. Finally, services per conception are not measured in the

studied population, as the predominant reproductive strategy is natural mating, which occurs without strict producer oversight (Rosero et al. 2022).

Nutritional management in the evaluated systems is primarily based on the quality and availability of forage accessible to cattle in pasturelands. Nevertheless, 93% of producers implement some form of supplementation, including mineralized salt, silage, crop residues, hay, and multinutritional blocks used by 76, 30, 14, 12, and 6% of supplementing producers, respectively.

In these pasture-based production systems, supplementation plays a critical role in maintaining adequate nutritional status and productive performance, as the regional grasses do not fully meet bovine nutritional requirements. Continuous provision of mineralized salt has been shown to improve weight gain and productive indicators (Salamanca 2010). In Puerto Boyacá, Colombia, Castañeda et al. (2022) reported enhanced body condition scores, milk yield, and milk composition in dual-purpose cows supplemented with silage derived from native and cultivated species such as Guayabo de monte (*Bellucia grossularioides*), Totumo (*Crescentia cujete*), and mango (*Mangifera indica*).

The dual-purpose cattle production systems managed by the interviewed producers are primarily oriented toward milk production. The sale of animals for beef is generally limited to weaned steers or cull cows, which explains the absence of weight records. This pattern; however, is closely tied to the productive culture of each region in Colombia. For instance, in the Colombian Orinoquía, where extensive rearing systems are traditionally used for growing and fattening cattle, dual-purpose operations tend to focus more on producing steers for meat markets (Molina-Benavides et al. 2020). Infrastructure for dairy activities is notably scarce. None of the producers have designated handling areas for milking, and milk collection is carried out using portable containers. A significant limitation arises from the type of material used for these containers: 70% of producers use plastic vessels, 27% use aluminum, and only 3% have access to stainless steel equipment.

Small-scale livestock producers in the region typically do not invest in or construct dedicated facilities for animal handling. This trend is evidenced by the fact that 94% of producers report having a corral on their farms, only 48% of these corrals are equipped with a chute, 10% include a loading ramp, and none possess a squeeze chute. In grazing areas, the supporting infrastructure is limited to salt dispensers, water troughs, and feed bunks, which are implemented by 78, 47, and 45% of producers, respectively.

Consistent with the characteristics of dual-purpose systems that prioritize milk production, the surveyed farms exhibit a predominance of females over males, particularly females of productive age. These animals yield an average milk production of 3.4 L Day^{-1}, resulting in a mean daily milk output per farm of 17.5 L (Table 3). These findings align with those reported by González-Quintero et al. (2020b), who, in a characterization of dual-purpose cattle systems across several departments in Colombia, documented average milk yields per cow ranging from 2.8 to 3.4 L Day^{-1}. Similarly, Cuevas et al. (2018) reported an average milk yield of 3.62 L Day^{-1} per cow in dual-purpose systems in Sinaloa, Mexico. In contrast, Castañeda et al. (2022) observed higher yields 5.62 L Day^{-1} per cow in Gyr × Holstein crossbred cows managed under comparable production systems.

Table 3. Herd Composition and Productive Parameters Observed in Dual-Purpose Livestock Systems of Small-Scale Producers in the Colombian Caribbean Region.

Cattle inventory			
Cattle per farm (No.)			18.8±11.5
Total, females (No.)			13.9±9.5
Total, males (No.)			4.8±5.3
Categorized inventory			
Females 0-3 months (No.)	0.6±1.2	Males 0-3 months (No.)	0.3±0.7
Females 3-9 months (No.)	1.0±1.6	Males 3-9 months (No.)	1.3±1.9

Table 3

Categorized inventory			
Females 9 -12 months (No.)	0.2±1.5	Males 9 -12 months (No.)	0.6±1.4
Females 1-2 years (No.)	2.9±3.1	Males 1-2 years (No.)	1.5±3.5
Females 2-3 years (No.)	2.1±3.1	Males 2-3 years (No.)	0.3±1.1
Females 3-5 years (No.)	4.3±4.4	Males 3-5 years (No.)	0.4±0.8
Females > 5 years (No.)	2.6±3.5	Males > 5 years (No.)	0.1±0.7
Productive parameters			
Animal units per farm (AU*)			13.1±7.9
Stocking rate (AU ha^{-1})			1.6±1.7
Liters per day (L Day^{-1})			17.5±12.9
Liters per cow (L cow^{-1})			3.4±1.3
Milking cows (No.)			5.4±4.2
Lactation duration (Days)			289±51.5
Open days (Days)			104±22
Calving interval (Days)			388.7±76.1

*AU=Animal units.

The spatial projection analysis of variables related to herd composition and management showed that Dimensions 1 and 2 explained 13.7 and 9.7% of the total variation among producers, respectively (Figure 2A). Very small producers exhibited lower dispersion compared with small producers, although both groups partially overlapped, indicating similarities between them. However, small producers showed greater variability, particularly in production levels and management practices. Variables associated with production scale, such as the total number of animals per farm and milk production per day and per farm, contributed most strongly to the differentiation of producers along Dimension 1, rather than indicators of technological sophistication. In contrast, variables related to management and infrastructure including record keeping, availability of cattle pens, pen construction material, presence of a loading ramp, and supplementation with salt and hay contributed more to differentiation along Dimension 2.

Overall, producers were primarily differentiated by herd size and management practices, which is consistent with the fact that larger cattle inventories require greater infrastructure. However, the general population exhibited a low adoption of technological practices, indicating that higher production levels are mainly achieved through a greater number of milking cows rather than increased productivity per cow. Nevertheless, certain management practices, such as nutritional supplementation and effective record-keeping strategies, appear to play an important role in improving production outcomes.

Rotational grazing was implemented for 51% of the respondents, while 31 and 18% practice alternate and continuous grazing, respectively. For farm demarcation and pasture division, 94% of producers use wooden posts, primarily with barbed wire, whereas electric fencing is employed by only 32% of the population. Silvopastoral practices such as live fences are carried out by just 25 producers. These findings highlight a limitation in controlling grazing intensity, because rotational systems particularly when combined with fencing (traditional or electric) contribute to more efficient pasture management (Senra et al. 2005) but in the study region, nearly half of the respondents do not adopt this practice. However, for smallholder producers in the region, the adoption of technologies requiring economic investment may be limited. In this context, continuous grazing should be managed through appropriate control of stocking rate to allow pasture regeneration. Briske et al. (2008) reported that continuously grazed systems under optimal stocking management can achieve productivity levels comparable to those of rotational grazing. Nevertheless, in the long term, the implementation of adequate rest periods for pastures, as practiced in rotational grazing, can improve

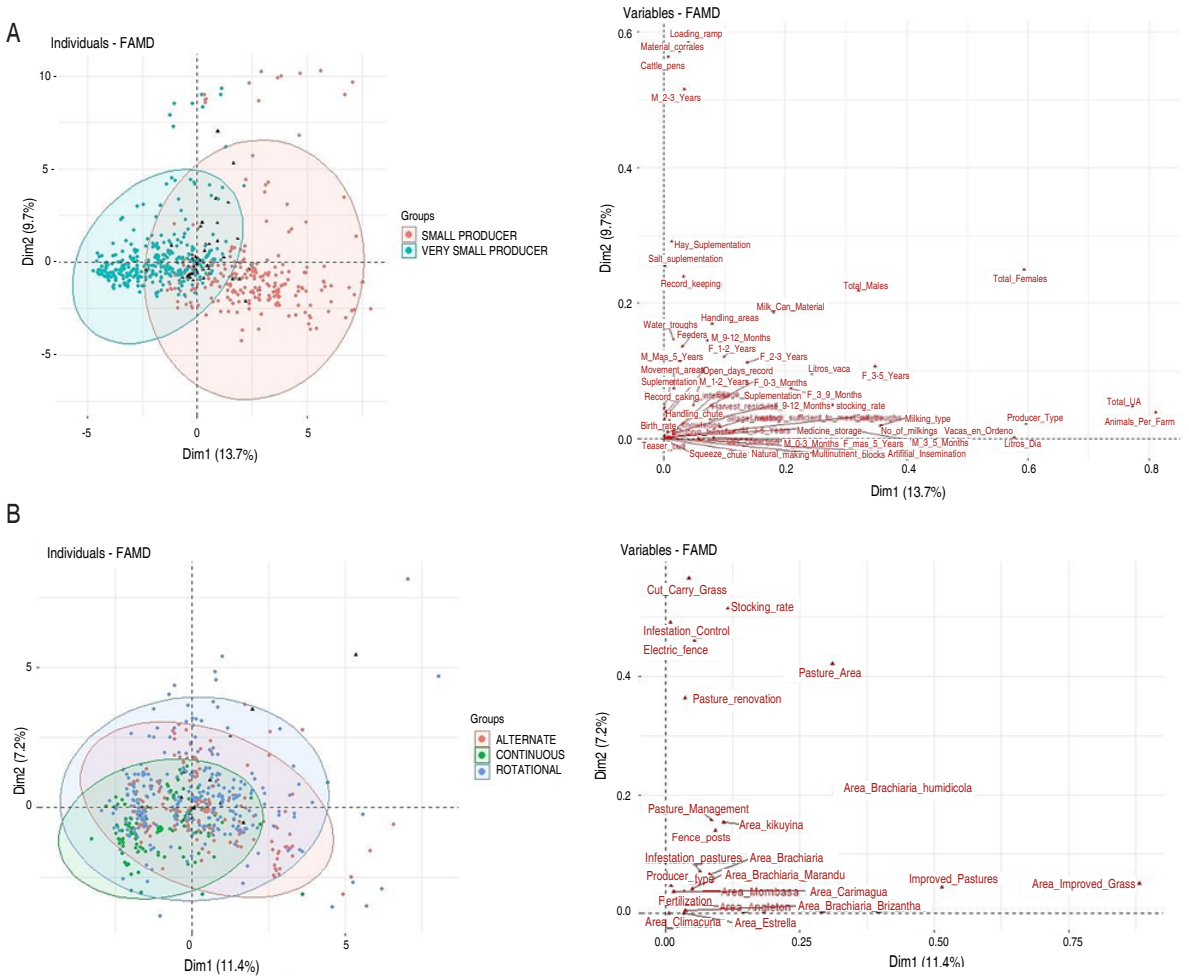


Figure 2. Spatial projection for variables related to herd composition and management (**A**), and pasture management (**B**).

soil conditions and, consequently, forage quality (Teague et al. 2011).

Regarding pasture care and management, 88% of producers do not apply fertilizers to their pastures, and 97% do not carry out forage renewal. These practices may lead to a progressive decline in forage availability for livestock, driven by soil compaction and pasture degradation. On average, the farms surveyed have a grazing area of 10.8 hectares, of which approximately 50% is established with improved pastures, primarily comprising *Brachiaria humidicola*, *Cynodon nlemfuensis*, and *Dichanthium aristatum*. The remaining area is predominantly covered by *Bothriochloa pertusa*, one of the most prevalent species in the Colombian Caribbean region, known for its ability to proliferate under low-management and low-technification conditions (Table 4).

The grazing area reported by producers in this study is comparable to that documented by González-Quintero et al. (2020b), who, in a characterization of dual-purpose cattle systems in Colombia, found that producers with fewer than 20 animals managed an average of 16.2 hectares, while those with 21–30 head of cattle operated on approximately 40.4 hectares, working with stocking rates of 1.2 and 1.5 AU ha^{-1}, respectively, which is consistent with those observed in the present study and align with production systems in which forage serves as the primary nutritional base.

Table 4. Observed averages for grazing area and nutritional composition of dominant forage species in the region.

Area of the farm occupied by pastures						
					Total	Average
Pastures (ha)					5,824.65	10.8±7.8
Improved pastures (ha)					2,701.55	5±6.2
Nutritional value						
Species	**Area (ha)**	**Ash (%)**	**Crude protein (%)**	**NDF (%)**	**ADF (%)**	**EE (%)**
Dichanthium aristatum	631.0	10.1±1.4	6.1±0.9	58.4±3.8	41±6.3	1.7±0.4
Brachiaria humidicola	1,251.5	10.3±1.3	6.9±1.1	56.6±4.1	42.5±6.1	1.8±0.6
Cynodon nlemfuensis	2,16.5	9.4±1.2	7.8±1.2	56.6±3.7	42.3±5.9	1.7±0.7
Bothriochloa pertusa	1,809.7	10.3±1.7	6.0±1.4	58.0±4.2	43.68±6.4	1.7±0.17

NDF=Neutral detergent fiber; ADF=Acid detergent fiber; EE=Ether extract.

The spatial projection analysis of variables related to pasture management, when producers were grouped as small or very small, did not show strong differentiation. This likely reflects the similarity in pasture management practices and forage species used across producers in the region. In contrast, when producers were grouped according to grazing strategies, Dimensions 1 and 2 explained 11.4 and 7.2% of the total variation, respectively (Figure 2B). Despite this, a high degree of overlap among groups was observed, confirming similarities in pasture management among farmers.

Along Dimension 1, variables related to pasture improvement such as the area established with improved grasses and the presence of higher quality forage species, particularly *Brachiaria humidicola* showed the greatest variation. Dimension 2 was mainly influenced by management intensity variables, including the use of cut and carry grass, stocking rate, weed infestation control, use of electric fencing, and pasture renovation. These results suggest that higher stocking rates require improved pasture management, including the establishment of forage species with high nutritional value and good adaptation to local environmental conditions. In this context, *Brachiaria humidicola* emerged as a key species associated with higher stocking rates and, consequently, larger herd sizes, due to its high adaptability to the region's environmental conditions, including tolerance to drought, waterlogging, and acidic soils.

Producers practicing continuous and alternate grazing showed less variability than those implementing rotational grazing systems, likely due to a greater reliance on less improved pastures and a higher prevalence of *Bothriochloa pertusa*. In contrast, producers using rotational grazing were associated with better pasture conditions, the use of improved forage species, and greater adoption of technological resources such as electric fencing.

Environmental information

Livestock farming in the region has the potential to serve as a tool to halt or reverse deforestation processes and, likewise, to function as a refuge for the conservation of local fauna and flora. Among producers, 61% maintain primary or secondary forest patches on their farms, some extending up to 15 hectares. Additionally, the surveyed farms may be traversed by rivers or border wetlands, which, if managed appropriately and conscientiously, have the potential to act as ecological corridors that facilitate wildlife movement across the landscape. Similar patterns are observed in dual-purpose production systems in the Colombian Orinoquia, where livestock farms in Casanare, Meta, Vichada, and Arauca share pasture areas primarily with natural forest (Molina-Benavides et al. 2020).

Wastewater management and proper disposal of residues are areas requiring improvement within the evaluated production system. Only 29% of producers have a septic tank to prevent contamination of natural water bodies. Regarding solid waste, 49% appropriately dispose of plastic containers, 50% do the same with glass containers, while 46% do not implement adequate handling practices for pharmaceutical and biohazardous waste. A similar trend is observed in the management of livestock mortalities: 19% allow carcasses to decompose naturally, 63% bury them, and 18% resort to incineration.

On average, farms host 269 trees, encompassing up to nine different forest species of interest, whether for timber production, shade provision, or livestock feed. A total of 67 distinct forest species were recorded, among which Campano (*Albizia saman*), Roble (*Tabebuia rosea*), Totumo (*Crescentia cujete*), Guácimo (*Guazuma ulmifolia*), Mango (*Mangifera indica*), and Matarratón (*Gliricidia sepium*) stand out (Table 5).

Table 5. Main forest species are present in the region and farm area covered by forest.

Variable		Amount
Trees (No.)		269±718
Species (No)[a]		6±2
Forest Area (ha)		0.6±1.23
Main forest species		
Species	**No. of farms**	**Use**
Campano (*Albizia saman*)	310	Timber, shadow
Roble (*Tabebuia rosea*)	307	Timber, shadow
Totumo (*Crescentia cujete*)	259	Shadow, livestock feed
Guacimo (*Guazuma ulmifolia*)	254	Shadow, livestock feed
Mango (*Mangifera indica*)	158	Shadow, fruit
Matarratón (*Gliricidia sepium*)	103	Livestock feed

[a]Number of forest species of interest present on farms.

CONCLUSION

Dual-purpose cattle production systems in the studied region tend to be highly similar in their socioeconomic characteristics, herd structure, pasture management, and environmental conditions. However, this similarity is largely concentrated on unfavorable aspects of the system, including low household income, limited access to public services, the need to rely on non-livestock activities to complement income, low productive performance, a predominance of native or low nutritional-value pastures, and inadequate practices that increase the risk of soil and water contamination. The variables that most differentiated the population were those associated with the capacity to generate higher economic returns. Most producers rely on off-farm activities to supplement their income; in addition, those with higher production levels generally maintain improved pastures, which support greater productivity, as well as adequate infrastructure for animal management.

Despite this general scenario, a subset of producers implements practices that differentiate them from most of the population. The adoption of basic management strategies such as record keeping, the establishment of improved pastures, the availability of cattle pens, weed control in paddocks, and the implementation of rotational grazing favored the formation of groups with comparatively better productive and management conditions. These variables represent practical entry points for gradual improvement of the production system, as they depend largely on producers decisions and can contribute to higher productivity per animal without requiring major structural changes.

From a strategic perspective, improving productivity per animal appears to be a more sustainable pathway than increasing the number of low-producing animals per farm. Expanding herd size under current conditions would require allocating more land to pasture, particularly if low-productivity grasses continue to predominate, thereby placing additional pressure on land use. Such expansion could threaten valuable forest resources within farms, especially riparian corridors and forest patches, which currently play an important role in biodiversity conservation in the region.

Finally, the information generated in this study can serve as a baseline scenario for future evaluations using system dynamics approaches. Such analyses could explore alternative scenarios to identify optimal combinations of productive performance, pasture area and management, and conservation areas, aiming to maximize economic returns while minimizing negative environmental impacts. This approach could support the design of integrated strategies for improving the sustainability of dual-purpose cattle systems in the Colombian Caribbean.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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