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CHARACTERIZATION AND EFFICIENCY OF BEEF CATTLE PRODUCTION SYSTEMS IN MATO GROSSO DO SUL

Urbano Gomes Pinto De Abreu[1]
Eliane Gonçalves Gomes[2]
Thiago Bernardino De Carvalho[3]
Luciana Alvim Santos Romani[4]
Ivan Bergier[5]
Risely Ferraz De Almeida[6]
Guilherme Cunha Malafaia[7]

ABSTRACT

Objective: to characterize modal beef cattle systems in municipalities in Mato Grosso do Sul (MS), through the use of unstructured data analytics methodologies aimed at diagnostic analysis, in order to identify intensification trends in the systems.

Theoretical Framework: Mato Grosso do Sul (MS) is a significant beef cattle producing region in Brazil, ranking fifth in the country with an inventory of approximately 20 million head. The beef production systems in MS, presents a wide variety of production systems, which have been changing over time.

Method: used the representative farms methodology to collect data on 13 beef cattle production systems in MS. We then employed unstructured data analytics methodologies to conduct a diagnostic analysis, with the goal of identifying trends towards intensification in these systems. We estimated the efficiency measures of these different production modes and highlighted those with the best performance.

Results and Discussion: Corumbá (cow-calf) and Naviraí (rearing and fattening) systems being allocated to separate groups. This separation is justified by the fact that they are the most extensive and most intensive production systems, respectively. The other two groups were cow-calf systems/full cycle and rearing/fattening systems. In addition, we calculated efficiency scores using a production approach. The average efficiency, calculated using data envelopment analysis models, was 54.2%. A fractional regression fit to the efficiency scores and the types of production systems as covariates suggested that there are statistically significant differences between the production systems.

Research Implications: the typical farms on a municipal scale in MS reflect the sustainability factors of beef cattle activity in the state. The managerial implications involve guiding the technical and scientific analysis of the processes.

Originality/Value: unstructured machine learning methods successfully synthesized production variables, enabling the classification of systems into clusters of homogeneous municipalities based on practiced livestock production systems. The two-stage DEA methodology used in this analysis helped identify significant contextual variables for beef cattle production.

Keywords: Sustainable Intensification, Multivariate Statistics, Data Envelopment Analysis

[1] : EMBRAPA Pantanal, Corumbá, Mato Grosso do Sul, Brazil. E-mail: urbano.abreu@embrapa.br
[2] EMBRAPA SOLOS, Rio de Janeiro, Rio de Janeiro, Brazil. E-mail: eliane.gomes@embrapa.br
[3] CEPEA, Centro De Estudos Avançados Em Economia Aplicada/ ESALQ-USP, Piracicaba, São Paulo, Brazil. E-mail: tbcarval@cepea.org.br
[4] Embrapa Agricultura Digital, Campinas, São Paulo, Brazil.E-mail: Luciana.romani@embrapa.br
[5] Embrapa Agricultura Digital, Campinas, São Paulo, Brazil.E-mail: Ivan.bergier@embrapa.br
[6] Universidade do Estado da Bahia, UNEB, Salvador, Bahia, Brazil. E-mail: riselyferrazpecege@gmail.com
[7] EMBRAPA Gado de Corte, Campo Grande, Mato Grosso do Sul, Brazil.
E-mail: guilherme.malafaia@embrapa.br

SISTEMAS TÍPICOS DE GADO DE CORTE EM MATO GROSSO DO SUL

RESUMO

Objetivo: o objetivo deste trabalho foi caracterizar os sistemas modais de produção de gado de corte em municípios do Mato Grosso do Sul (MS), por meio da utilização de metodologias de análise de dados não estruturados voltados à análise diagnóstica, a fim de identificar tendências de intensificação nos sistemas.

Referencial Teórico: Mato Grosso do Sul (MS) é uma importante região produtora de gado de corte no Brasil, ocupando o quinto lugar no país, com um rebanho de aproximadamente 20 milhões de cabeças. Os sistemas de produção de carne bovina no MS apresentam uma ampla variedade de sistemas de produção, que vêm se modificando ao longo do tempo.

Método: utilizamos a metodologia de fazendas típicas para coletar dados sobre 13 sistemas de produção de gado de corte no MS. Em seguida, empregamos metodologias de análise de dados não estruturados para conduzir uma análise diagnóstica, com o objetivo de identificar tendências de intensificação nesses sistemas. Estimamos as medidas de eficiência desses diferentes modos de produção e destacamos aqueles com melhor desempenho.

Resultados e Discussão: os sistemas Corumbá (cria-bezerro) e Naviraí (cria e engorda) foram alocados em grupos distintos. Essa separação se justifica pelo fato de serem os sistemas de produção mais extensivos e mais intensivos, respectivamente. Os outros dois grupos foram sistemas de cria/ciclo completo e sistemas de recria/engorda. Foi calculado calculamos os escores de eficiência utilizando uma abordagem de produção. A eficiência média, calculada utilizando modelos de análise envoltória de dados, foi de 54,2%. Um ajuste de regressão fracionária para os escores de eficiência e os tipos de sistemas de produção como covariáveis sugeriu que existem diferenças estatisticamente significativas entre os sistemas de produção.

Implicações da Pesquisa: As fazendas típicas em escala municipal do MS refletem os fatores de sustentabilidade da atividade pecuária de corte no estado. As implicações gerenciais envolvem a orientação da análise técnica e científica dos processos.

Originalidade/Valor: métodos de aprendizado de máquina não estruturados sintetizaram com sucesso os dados de produção, permitindo a classificação de sistemas em clusters de municípios homogêneos com base em sistemas de produção praticados. A metodologia DEA em dois estágios utilizada nesta análise ajudou a identificar variáveis contextuais significativas para a produção de gado de corte no estado de Mato Grosso do Sul, distinguindo os sistemas mais intensificados.

Palavras-chave: Intensificação Sustentável, Estatística Multivariada, Análise Envoltória de Dados.

SISTEMAS TÍPICOS DE GANADO DE CARNE EN MATO GROSSO DO SUL

RESUMEN

Objetivo: El objetivo de este estudio fue caracterizar los sistemas modales de producción de ganado de carne en municipios de Mato Grosso do Sul (MS), mediante el uso de metodologías de análisis de datos no estructurados para el análisis diagnóstico, con el fin de identificar tendencias de intensificación en los sistemas.

Marco teórico: Mato Grosso do Sul (MS) es una importante región productora de ganado de carne en Brasil, ocupando el quinto lugar a nivel nacional, con un rebaño de aproximadamente 20 millones de cabezas. Los sistemas de producción de carne en MS presentan una amplia variedad de sistemas de producción, que han ido cambiando a lo largo del tiempo.

Método: Se utilizó la metodología de finca típica para recopilar datos sobre 13 sistemas de producción de ganado de carne en MS. Posteriormente, se utilizaron metodologías de análisis de datos no estructurados para realizar un análisis diagnóstico, con el objetivo de identificar tendencias de intensificación en estos sistemas. Se estimaron las medidas de eficiencia de estos diferentes modos de producción y se destacaron aquellos con mejor desempeño.

Resultados y Discusión: Los sistemas Corumbá (cría de terneros) y Naviraí (cría y engorde) se clasificaron en grupos distintos. Esta separación se justifica por ser los sistemas de producción más extensivos e intensivos, respectivamente. Los otros dos grupos fueron sistemas de cría de ciclo completo y sistemas de cría y engorde. Se calcularon los índices de eficiencia utilizando un enfoque de producción. La eficiencia promedio, calculada

mediante modelos de análisis envolvente de datos, fue del 54,2 %. Un ajuste de regresión fraccional para los índices de eficiencia y los tipos de sistemas de producción como covariables sugirió la existencia de diferencias estadísticamente significativas entre los sistemas de producción.

Implicaciones de la Investigación: Las fincas municipales típicas en Mato Grosso do Sul reflejan los factores de sostenibilidad de la ganadería de carne en el estado. Las implicaciones gerenciales implican orientar el análisis técnico y científico de los procesos.

Originalidad/Valor: Los métodos de aprendizaje automático no estructurado sintetizaron con éxito los datos de producción, lo que permitió la clasificación de los sistemas en grupos de municipios homogéneos según los sistemas de producción practicados. La metodología DEA en dos etapas empleada en este análisis permitió identificar variables contextuales significativas para la producción de ganado vacuno de carne en el estado de Mato Grosso do Sul, distinguiendo los sistemas más intensificados.

Palabras clave: Intensificación Sostenible, Estadística Multivariante, Análisis Envolvente de Datos.

1 INTRODUCTION

In 2022, Brazil had the world's second-largest cattle herd (12% of the global herd, after India with 18%) and produced 14% of the world's beef (second only to the United States with 17%) (ABIEC, 2023). At that time, Brazil was the leading exporter, holding around 19% of the market, followed by the United States at 11%, Australia at 9%, India at 8%, and Argentina at 6% (ABIEC, 2023). The livestock sector contributed 28% to the national agribusiness GDP and 6.7% to the country's total GDP in 2023 (CEPEA-CNA, 2024). From 2012 to 2022, the Brazilian cattle herd increased by 13%, rising from 179.5 million to 202.8 million head. According to ABIEC (2023), the North and Central-West regions of the country experienced the most significant herd expansions, each at around 14% during this period. These statistics highlight the sector's importance to the Brazilian economy and agricultural industry. Beef cattle farming plays a significant role in the meat production industry in Brazil (Souza et al., 2016). There are two distinct groups of beef cattle production systems in the country. The first group emphasizes advanced technology, efficient management, and effective marketing practices. In contrast, the second group focuses on extensive production, low technological intensity, and inefficient management and marketing standards, leading to low productivity and significant environmental impacts (Carvalho and De Zen, 2017). According to Pereira et al. (2024), beef cattle production systems in Brazil have transitioned from extensive to intensive models, with support from public policies promoting sustainable and low-carbon livestock farming. However, the authors highlight the importance of involving small and medium-sized

landowners in this transition, particularly in terms of adopting digital and precision technologies and gaining access to rural credit. The state of Mato Grosso do Sul (MS) is located in the Center-West region of Brazil and is a significant player in the beef cattle market. It is one of the most important states for national beef cattle production. In 2022, MS had approximately 22.5 million head of cattle, which represented about 11% of the national herd. These cattle are distributed across approximately 55 thousand properties in all municipalities of the state, accounting for 2% of properties with cattle in the country (ABIEC, 2023). Beef cattle farming have been integral to the economic development of the state, and there is a wide variety of production systems that have evolved over time (Santos, 2015). Similar to the rest of the country, the beef cattle production systems in MS are diverse and exhibit different technological indicators. Variations in natural resources, social and economic profiles of farmers, land ownership and use, as well as economic conditions, contribute to the differences in these systems (Gomes et al., 2012).

In this study, we aimed to characterize the various modal systems of beef cattle farming in certain municipalities of MS. We used unstructured data analytics methodologies to conduct a diagnostic analysis, with the goal of identifying trends towards intensification in these systems. Additionally, we estimated the efficiency measures of these different production modes and highlighted those with the best performance.

2 TYPICAL FARMS

The data was collected using panel methodology to define typical properties, as outlined by Plaxico and Tweeten (1963). Panels involve meetings between researchers, local technical agents, and rural producers to discuss and define a typical production system for a specific region. The production models that are most commonly found in the region under study, and best represent the local productive system, are defined as typical properties, as explained by Santos et al. (2014). The authors also note that it's not unusual for more than one typical property to exist in the same region for beef cattle systems. The data for this study were obtained from panels organized by the rural unions of the municipalities mentioned below, carried out between 2014 and 2021. Thirteen beef cattle production systems were characterized on a municipal scale, representing full-cycle (Miranda), cow-calf (Amambaí, Camapuã, Corumbá, Naviraí, Ribas do Rio Pardo, Rio Verde, and Três Lagoas), and rearing/fattening (Bonito, Dourados, Naviraí, Paranaíba, and Três Lagoas) systems in MS. The data includes information on herd structure (number of cattle in each category), area (in hectares), and financial details

such as total revenue (RT, in R$), effective operating cost (COE, in R$), and total cost (CT, in R$) based on Matsunada et al.'s cost methodology from 1976.

3 METHODOLOGY

This data was analyzed using unstructured machine learning techniques for dimensionality reduction (using the principal components method) and clustering definition (based on the K Means metric), as outlined by Alpaydin in 2010. Principal component analysis (PCA) is a multivariate analysis technique used to reduce the dimensionality of a problem while retaining most of the information from the original set of variables. PCA constructs linear combinations of variables based on their dependence structure, preserving the original covariance structure using a few factors that summarize the original multivariate structure. Morettin and Singer (2023) discuss this approach in detail. Cluster analysis aims to group observations based on similarity, using a distance metric to maximize the distance between groups and minimize it within the group. In this case, the K means method was used to partition the groups. This approach aggregates observations into K groups (defined by the user or simulated) to minimize the sum of the squares of the distances of each observation to the center of the cluster (Morettin and Singer, 2023). In order to calculate the efficiency scores, we used a data envelopment analysis (DEA) model based on the hypothesis of variable returns to scale and orientation to outputs (DEA VRS-O), as defined in Cooper et al. (2011). This model helps identify increasing, constant, or decreasing returns to scale in the empirical production efficiency curve. From a sample of observations, DEA mathematical programming models optimize each individual observation and estimate an efficiency frontier based on the best practices of the sample. In the DEA VRS-O model formulation below, "h_o" represents the efficiency of unit o under evaluation, "x_i's" are inputs, "y_j's" are outputs, and "λ_k" is the contribution of unit k in the formation of the target of unit o (a non-zero λ_k indicates a benchmark for unit o). This model, known as the envelope formulation, describes the composition of the efficiency frontier, the benchmarks for inefficient units, and allows the calculation of targets to achieve efficiency for inefficient units.

$$\text{Max} \quad h_o$$
$$\text{sujeito a}$$
$$x_{io} - \sum_k x_{ik}\lambda_k \geq 0, \forall i$$
$$-h_o y_{jo} + \sum_k y_{jk}\lambda_k \geq 0, \forall j$$
$$\sum_k \lambda_k = 1$$
$$\lambda_k \geq 0, \forall k$$

The DEA model used farm size (in hectares) and the number of animals (cows, steers, calves, heifers) as inputs, with total farm revenue (in R$) as the output. In addition to assessing farm efficiency, it's important to identify contextual factors that affect these scores. In this study, we're interested in determining if the type of production system impacts livestock production performance. To achieve this, we utilized a two-stage DEA approach (Simar & Wilson, 2011).

The first stage calculates efficiency, while the second stage involves fitting a regression model with efficiency as the dependent variable and potential contextual factors as the independent variables. In this article, we chose fractional regression (Ramalho et al., 2010; Souza and Gomes, 2015, 2023) to model the second stage. Let the vector of contextual variables be denoted as zj for a unit j.

A fractional regression $E\left(\hat{\theta}_n(x_j, y_j|z_j)\right) = G\left(\delta' z_j\right)$ assumes a nonlinear function (*G(.)*), where the DEA score *(θ)* is dependent on inputs *(x)*, outputs *(y)* and contextual factors *(z)*. δ's are parameters to be estimated. Since *G(.)* is a monotonic distribution function, the model interprets the response function as dependent on the linear construct. The model can be estimated using nonlinear least squares or quasi-maximum likelihood.

4 RESULTS AND DISCUSSIONS

In Table 1, you can find the average values of the variables for each of the 13 production systems that were analyzed. Please note that the RT values do not include the CT, as the CT values consist of depreciation and opportunity costs. However, it's important to mention that all systems generate revenues that are sufficient to cover depreciation costs, as observed by Santos et al. (2014). Table 1 displays the average number of animals, revenues, costs, and estimates of correlations of variables with the first two principal components.

Table 1

Average number of animals, revenues, costs, and correlations of variables with the first two principal components (CP1 and CP2).

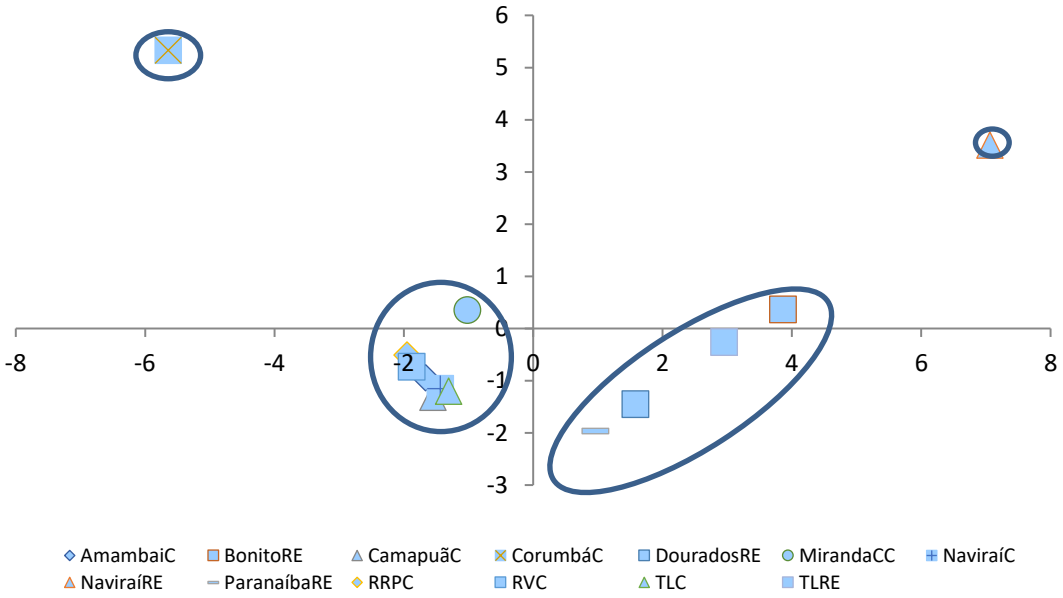
	Averages			Correlations between the variables analyzed and the CPs	
	Beef cattle life-cycle production systems	Cow-calf systems	Rearing and fattening systems	CP1	CP2
SBC	191	227.14	0	-0.796	0.588
SHC	191	214.00	0	-0.764	0.602
WBC	95	0.00	442.6	0.916	0.384
WHC	99	101.86	0	-0.761	0.638
H1Y	98	100.57	0	-0.760	0.639
SC	148	285.57	0	-0.656	0.695
CC	332	310.71	0	-0.710	0.642
S	94	0.00	439.6	0.916	0.384
LS	93	0.00	437	0.916	0.385
FS	92	0.00	435.4	0.915	0.385
Total_T (Hectares)	1.500	2.154,01	901,75	-0.491	0.811
CT (BRL)	1,359,461.31	913,469.19	2,345,638.96	0.757	0.613
COE (BRL)	403,026.19	263,237.22	1,399,457.29	0.810	0.537
RT (BRL)	1,038,517.88	491.551.84	1,904,793.62	0.718	0.644
n° systems	1	7	5		

SBC - suckling bull calves, SHC - suckling heifer calves, WBC - weaned bull calves, WHC - weaned heifer calves, H1Y - heifers at one year, SC - single cow, CC - calving cow, S - steers , LS - lean steer, FS - fat steer, Total_T - total area occupied by the beef cattle system, CT - Total Cost, COE - Effective Operating Cost, RT - Total Revenue, n° systems –number systems.
Source: Developed by the authors.

After reducing the dimensionality, it was found that two main components (CP1 and CP2 in Table 1) accounted for 86% of the total variance of the data. By examining the correlations of the variables with these two components, it was evident that the first main component had both strong positive and negative correlations ($r > 0.6$) with the more intensified systems, such as rearing and fattening systems with smaller areas and a higher number of cattle for rearing and fattening (Table 1). These two main components were then used for cluster analysis using the K-means metric, as described earlier. The resulting grouping of the systems is illustrated in Figure 1, with the Corumbá (breeding) and Naviraí (rearing and fattening) systems being allocated to separate groups. This separation is justified by the fact that they are the most extensive and most intensive production systems, respectively. The other two groups formed were the rearing/full cycle and the rearing and fattening. This analysis method successfully generated groups of production systems with similar characteristics. A noticeable pattern is the high concentration of breeding systems in MS and the full-cycle system being closest to the breeding systems. This suggests that on properties with larger areas and lower RT, these systems likely share similar technological aspects and are developed in extensive

systems. Furthermore, all animals produced in these systems are directly used for the production of replacement animals in other municipalities, particularly for breeding and fattening purposes.

Figure 1
Graph showing the first two control points in relation to the analyzed production systems and identification of the formed groups.



AmambaiC – cow-calf in Amanbaí, Bonito – rearing/fattening in Bonito, CamapuãC – cow-calf in Camapuã, CorumbáC – cow-calf in Corumbá, DouradosRE – rearing/fattening in Dourados, MirandaCC – full cycle in Miranda, NaviraíC – cow-calf in Naviraí, NaviraíRE – rearing/fattening in Naviraí, ParanaibaRE – rearing and fattening in Paranaíba, RRPC – cow-calf in Ribas do Rio Pardo, RVC – cow-calf in Rio Verde, TLC – cow-calf in Três Lagoas, TLRE – rearing and fattening in Três Lagoas.
Source: Developed by the authors.

Historically, cow-calf systems form the foundation of the entire beef production chain. They are generally developed in extensive systems in areas with lower monetary value per hectare. In a benefit/cost analysis of the phases of beef cattle farming conducted in the traditional manner, in production systems considered typical farms, Euclides Filho (2000) concluded that breeding is the activity with the lowest profitability and the one that presents the greatest risk. However, it's essential to note that breeding is also the activity that supports the entire subsequent structure. Therefore, any investment in technological resources made in this activity will result in increased efficiency, leading to benefits for the entire beef production chain (Euclides Filho, 2000).

Rebreeding and fattening systems are developed in smaller areas, but they are the ones that provide the highest RT values and, at the same time, the highest TC and COE (Table 1). The four modal systems grouped together show that the RT values (in BRL) are in ascending order, from the systems presented in Figure 1: ParanaíbaRE (436,640.13 BRL), DouradosRE (648,321.00 BRL), Três LagoasRE ($1,520,782.28 BRL) and BonitoRE (1,640,740.38 BRL).

Animals in rearing and fattening systems are typically obtained from breeding systems and then exposed to nutritional and managed grazing methods, based on their age and weight. These phases represent the greatest adoption of technologies and the most utilized management techniques. Efforts to enhance the efficiency of rearing and fattening systems necessitate increased investments and greater pressure to boost economic returns. Various techniques, from simple modifications to major transformations in the production system, can be employed for this purpose. One important change to improve efficiency involves stratifying animals at weaning based on their weights adjusted for a standard age and the mother's age. This strategy not only reduces the risk for the capital invested in feed but also increases the enterprise's profit. Therefore, it is crucial to establish a nutritional management criterion based on weight stratification at weaning and subsequent monitoring of individual performance during the rearing and fattening phase (Santos et al., 2024).

In the analysis of the DEA VRS-O model, the average efficiency of the sample was 54.2%. Two systems operated at 100% efficiency, managing modal rearing and fattening systems in the municipalities of Paranaíba and Naviraí. The system in Naviraí generated the highest total revenue in the sample (5,277,483.62 BRL), while Paranaíba operated in a smaller area (300 hectares). This suggests that the analysis identified the most intensive systems in terms of economic efficiency among those evaluated. The two systems with the lowest efficiency were for breeding in Corumbá and Rio Verde, municipalities with a predominance of extensive breeding, likely due to the environmental characteristics inherent to the Pantanal (Abreu et al., 2010). Out of the 13 systems evaluated, 11 operated in a region of decreasing returns to scale, one in increasing returns, and one in constant returns. The total area variable was disregarded in the calculation of efficiency scores according to this model, indicating the need for technological improvement to achieve greater financial gain in each of the identified inefficient systems. These results align with the discussion by Pereira et al. (2024) regarding the transition from extensive beef cattle farming systems to more intensive ones, given the better performance of the latter.

The fractional regression model was used to fit the efficiency scores along with covariates representing different production systems. The analysis indicated statistically significant differences between the production systems, as detailed in Table 2. The rearing and fattening systems demonstrated the highest efficiency, followed by the full-cycle and breeding systems. This fit resulted in a correlation of 71.8% between observed and predicted values.

Table 2

Fit of the fractional regression.

	Coefficient	Standard deviation	z	P > |z|	Confidence interval 95%	
Beef cattle life-cycle production systems	-0.6346	0.3127	-2.03	0.042	-1.2474	-0.0218
Cow-calf systems	-0.9613	0.3652	-2.63	0.008	-1.6771	-0.2454
Constant	0.6902	0.3127	2.21	0.027	0.0774	1.3030

Source: Developed by the authors.

The beef cattle production system can vary based on factors like the production environment. This system tends to become more specialized in its stages to enhance efficiency. Among the different stages, breeding is considered the most complex and least profitable, which makes it challenging to adopt new technologies. However, it is essential for initiating the meat production chain. Calves at this stage require veterinary care to enter the growth phase, and providing a high-quality diet for breeding cows is crucial for the weight performance of the calves. The productivity of a breeding herd can be evaluated practically through birth and weaning rates. It's important to note that the nutrition of pregnant cows is a key factor in improving the long-term efficiency and productivity of cows and calves, as well as the quality of the carcass and meat (Zago et al., 2017).

The rearing and fattening phase begins with newly weaned calves and ends with steers ready for slaughter. This can take place in confinement, semi-confinement or improved pasture systems. Management, nutritional and genetic technologies are developed and directed to increase efficiency in land use and shorten the production cycle, ultimately saving land and reducing the time to reach market weight.

Silva (2015) discusses changes in beef cattle production systems in the microregions of the state of MS between 2004 and 2015. In 2004, the complete cycle was the main production system in three microregions of MS, accounting for 30% of the total. By 2015, calf production became the main system in one of these regions, and beef cattle production became the focus in another, indicating a specialization in these areas. In the third region, Aquidauana, it was noted that there was no single representative type of property, with half of the production coming from breeding properties and the other half from rearing-fattening properties. Therefore, two representative properties were identified, one from each system. As a result, the full cycle system appears to be the least common in intensive livestock farming. In the study, the model grouped the full cycle system with the breeding systems, which are characterized by lower technology adoption (Figure 1).

5 CONCLUSION

Unstructured machine learning methods successfully synthesized production variables, enabling the classification of systems into clusters of homogeneous municipalities based on practiced livestock production systems. In the future, these groups could serve as a basis for new inferences, such as assessing the balance of greenhouse gas emissions.

The two-stage DEA methodology used in this analysis helped identify significant contextual variables for beef cattle production in the state of Mato Grosso do Sul, distinguishing the most intensified systems. This approach is crucial for developing production systems because it helps identify areas that need improvement to enhance the activity sustainably in each region of the state.

The typical farms on a municipal scale in MS reflect the sustainability factors of beef cattle activity in the state. There is a significant technological evolution aiming to combine environmental, economic, and social aspects with technical, scientific, and social factors. The managerial implications involve guiding the technical and scientific analysis of the processes, while the policy implications are mainly concerned with the need for properly designed regulations with competitive impact that stimulate innovations (Santos et al., 2022). This will direct public and private policies to improve livestock activity in technical, scientific, environmental, and social aspects. For example, within the scope of the Mato Grosso do Sul Livestock Advancement Program (PROAPE), there is a focus on technological advancement with the Early Cattle Program and the Sustainable and Organic Meat from the Pantanal – MS (Amaral et al., 2021; Abreu, et al., 2021).

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