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Multidimensional performance assessment of a sample of beef cattle ranches in the Pantanal from a data envelopment analysis perspective

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ABSTRACT: Beef cattle ranching is the main economic activity in the Brazilian Pantanal, undertaken in an extensive manner, mostly in natural environments and dynamic in space and time. The ongoing monitoring, assessment, and performance improvement are key aspects of the search for sustainable use of natural resources in beef cattle ranches, as these ranches are the management units in the Pantanal. In this paper we proposed a data envelopment analysis (DEA) approach to assess the performance of fourteen beef cattle ranches in the Pantanal wetland as a case study, considering financial, productive, and environmental sustainability dimensions. We modeled each dimension separately and calculated an overall performance score. We also fit fractional regression models to study the influence of potential covariates on the performance scores. The methodological approach proposed here proved to be adequate for the case study, as the results are in line with the expectations of decision-makers regarding the performance of the ranches. The overall performance analysis was influenced by the proportion of higher quality native forage resources, which depends on the dynamics and on the spatial-temporal variation of the landscapes. Therefore, overall performance requires adaptive management of ranches based on diversity conservation, which benefits the multifunctionality of products and services.
Key words: efficiency models, beef cattle, extensive production systems, sustainability.

Avaliação multidimensional do desempenho de uma amostra de fazendas de pecuária do Pantanal sob a ótica de modelos de análise envoltória de dados

RESUMO: A pecuária de corte é a principal atividade econômica do Pantanal brasileiro, praticada de forma extensiva em ambientes predominantemente naturais e espaço-temporalmente dinâmicos. Monitorar, avaliar e aprimorar continuamente o desempenho das fazendas de pecuária é um aspecto chave na busca do uso sustentável de recursos naturais, já que as fazendas são a unidade de manejo no Pantanal. Nesse sentido, objetivou-se neste artigo a adoção de modelos de análise envoltória de dados (DEA) para avaliar o desempenho de 14 fazendas pantaneiras como estudo de caso, considerando as dimensões da sustentabilidade financeira, produtiva e ambiental. Cada dimensão foi modelada separadamente e, na sequência, foi calculado um escore único de desempenho global. Foram ainda ajustados modelos de regressão fracionária para estudar a influência de potenciais covariáveis nos escores de desempenho. A abordagem metodológica aqui proposta mostrou-se adequada ao caso de estudo em questão, com resultados alinhados às expectativas dos tomadores de decisão quanto ao desempenho das fazendas. A análise do desempenho global foi influenciada pela proporção de recursos forrageiros nativos de melhor qualidade, que depende da dinâmica e variação espaço-temporal das paisagens. Portanto, o desempenho global requer uma gestão adaptativa das propriedades com base na conservação da diversidade, o que beneficia a multifuncionalidade de produtos e serviços.
Palavras-chave: modelos de eficiência, gado de corte, sistemas extensivos de produção, sustentabilidade.

INTRODUCTION

The Pantanal is the largest floodplain in the world, located in the states of Mato Grosso and Mato Grosso do Sul, in the Center-West region of Brazil. It comprises forest, savanna (cerrado), and open grasslands formations, with a dynamic landscape controlled by natural and anthropic processes, among them the flood pulse (JUNK et al., 1989). As an area subject to periodic flooding, it is not appropriate for agriculture. However, the diversity and availability of forage resources make the region suitable for beef cattle ranching in extensive systems, especially to produce beef calves (SANTOS et al., 2020).

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Production systems are based on native pastures, complemented with cultivated exotic pastures. It is important to monitor, evaluate and improve the performance of the Pantanal cattle ranches to ensure the sustainability of natural resources in this region and the livestock production systems practiced there. The challenge is to reconcile conservation and productivity, that is, to guarantee sustainability (SANTOS et al., 2017; TOMAS et al., 2019).

In the literature there are proposals to evaluate the sustainability of farming activities. For the Pantanal, SANTOS et al. (2017) developed the tool FPS - Fazenda Pantaneira Sustentável, which allows at the farm level, the evaluation of the sustainability degree by dimension, aspect and indicator/index, with support in fuzzy logic.

Considering that the Pantanal is a dynamic and fragile biome, governed by the flood pulse (JUNK et al., 1989), production systems are limited by the carrying capacity of available resources (SANTOS et al., 2011). Therefore, a performance evaluation of these systems that incorporates the environmental dimension (KUO et al., 2014) is of utmost importance in this region.

It is important to use auxiliary tools to assist in the interpretation of sustainability indicators and in the evaluation of the performance of rural properties, dealing with the complexity of these production systems. Data Envelopment Analysis - DEA (COOPER et al., 2007) models have been used in the literature for this purpose. LIU et al. (2013a) and EMROUZNEJAD & YANG (2018) identified applications in the context of agribusiness as one of the top five application areas in DEA. When it comes to the national context, the literature review of GOMES (2008) on the use of DEA models in the agricultural area showed that the technique was not widely used for applications to national cases. This observation is still current, and it is ratified by a brief search in the Scopus database, in July 2022, which returned eighteen articles on the application of DEA to agriculture and cattle ranching in Brazil, with publication dates between 2004 and 2022. In the Web of Science database, we reported twenty-eight articles, between 2002 and 2022. This set of information shows both the relevance of the type of study presented here, and the need to invest in research that focuses both on the application of DEA models to real cases of national agriculture and cattle ranching, and on the proposition of models that allow the identification of the determinants of efficiency, with a view to enhancing the sector's performance and subsidizing the formulation of public policies.

Specifically on the use of DEA models for case studies in the Pantanal, we can cite ABREU et al. (2008, 2012), GOMES et al. (2012) and PINTO et al. (2017). The first dealt with the evaluation of a breeder retention program in eleven ranches in the region. The second paper evaluated twenty-one modal livestock production systems. The research by PINTO et al. (2017) used DEA models to evaluate sustainability in rural settlements in the Southern Pantanal.

Assessing the sustainability of agricultural production systems is a complex task. The approach proposed here considers a multidimensional perspective, which culminates with the proposition of one-dimensional measure that represents aggregate performance and has the potential to subsidize policymaking or local decision-making. The central aspect is to contribute to the theme, proposing a methodological approach that considers the multidimensionality of the sustainability concept, but that can simplify the performance evaluation of productive systems. According to GERDESSEN & PASCUCCI (2013), there are two approaches to measure performance in terms of sustainability of agricultural production systems: the value approach (based on opportunity costs) and the modeling/optimization approach. DEA models belong to the latter category.

Given this context, this paper presents a proposal for performance evaluation of extensive beef cattle ranches in the Pantanal, via DEA models and considering the financial, productive and environmental dimensions.

MATERIALS AND METHODS

We used data from fourteen beef cattle ranches, located in the Pantanal biome, state of Mato Grosso, in the sub-regions of Barão do Melgaço (five ranches), Cáceres (five), and Poconé (four), with breeding (seven ranches), breeding-rearing (six), and complete (one) production systems. The data referred to the period 2019-2020. We proposed three partial models for multidimensional estimation of ranch performance from financial, productive, and environmental perspectives. We then aggregated the partial scores into a single, global performance score. We calculated the performance scores of the partial economic and production models and of the global model according to the DEA approach.

For a set of production units (ranches) and based on input and output variables, DEA models construct an efficiency frontier determined by the Pareto-efficient units (benchmarks) and that envelopes the inefficient ones. There are two basic DEA models, which differ in their assumptions regarding the convexity of the frontier: constant returns to scale (CRS or CCR), whose basis is the proportionality axiom, and variable returns to scale (VRS or BCC), based on the convexity axiom. The strategy to achieve efficiency can be by reducing inputs while keeping outputs unchanged (input orientation), or by maximizing outputs without changing input levels (output orientation). We adopted the VRS hypothesis here, since the ranches have different scales and we understood that the proportionality hypothesis is difficult to verify.

DEA is based on mathematical programming models that calculate the efficiency of each production unit (Decision Making Unit – DMU), given by the ratio between the weighted sum of outputs and the weighted sum of inputs, so that this ratio is not greater than one. In (1) and (2) we presented the linear form of the output-oriented DEA VRS models, according to the multipliers and envelope formulations (dual linear programming models), respectively (COOPER et al., 2007). In these models, o represents the unit under analysis; h_o ($= Eff_o$) is the efficiency score; λ_k is the contribution of unit k in computing the target of unit o (units with non-zero λ_k are the benchmarks of unit o); x_{ik} and y_{jk} are inputs i, i=1...r, and outputs j, I=1...s, of unit k, k=1...n; x_{io} and y_{jo} are the inputs i and outputs j of unit o; v_i and u_j are the weights (multipliers) of inputs and outputs, respectively; u_* and v_* are scale factors. Input-oriented formulations can be seen in COOPER et al. (2007).

$$\begin{aligned}
&\text{Min} \quad Eff_o = \sum_i v_i x_{io} - v_* \\
&\text{sujeito} \quad \text{a} \\
&\sum_j u_j y_{jo} = 1 \\
&-\sum_i v_i x_{ik} + \sum_j u_j y_{jk} - v_* \le 0, \forall k \\
&u_j \ge 0, v_i \ge 0, \forall j, i \\
&v_* \in \Re
\end{aligned} \tag{1}$$

$$\begin{aligned}
&\text{Max} \quad h_o \\
&\text{sujeito} \quad \text{a} \\
&x_{io} - \sum_k x_{ik}\lambda_k \ge 0, \forall i \\
&-h_o y_{jo} + \sum_k y_{jk}\lambda_k \ge 0, \forall j \\
&\sum_k \lambda_k = 1 \\
&\lambda_k \ge 0, \forall k
\end{aligned} \tag{2}$$

When researchers who know and work in the biome judgednecessary to express the relative importance of variables in the calculation of the DEA performance scores, we considered assurance region type I weights restrictions – Cone Ratio (ALLEN et al., 1997).

The financial performance model is based on the idea of agricultural production frontiers, i.e., farm income is a result of expenditures on land, labor, and capital (SOUZA et al., 2020). This model assumes as inputs the effective operational cost (expenses with animal management; pasture management, supplementation, and sanitary inputs), the expenses with other inputs, and expenses with fixed costs (expenses with labor and maintenance), and as output the gross income of the ranch's livestock activity. We adopted the VRS hypothesis and input orientation.

The productive performance model aimed to evaluate how the pastures (the basis of the Pantanal cattle production system and of its sustainability) are being used by the animals that use this resource. Since exotic cultivated pastures replaced part of the native pastures in the Pantanal, the inputs are native pasture and cultivated pasture. The outputs are the animals that constitute the production system, which are weaned calves, cows for culling and cows for breeding. We selected the output-oriented DEA VRS model. We added weights restrictions to represent the decision maker's value judgments: natural pasture ≥ cultivated pasture; calves ≥ breeding cows ≥ cows for culling. Other decision makers may have different judgments regarding the order of importance of these variables, which will imply efficiency scores potentially different from those obtained here with the order presented above.

The variables in the financial and productive models were measured per hectare. In this situation, HOLLINGSWORTH & SMITH (2003) ratify the adequacy of the VRS hypothesis.

The environmental performance model used as a performance score the landscape diversity conservation index (ICDP), a criterion of the FPS tool (SANTOS et al., 2017). The ICDP assesses the variety and quantity of the different components of a landscape and quantifies how much of this diversity has been lost after interventions in the landscape. The ICDP represents biodiversity conservation, and it is considered a good expression of environmental perspective at the landscape scale in an ecosystem as diverse as the Pantanal.

The global model aggregates, in a synthesis score, the partial performances from the financial, productive, and environmental perspectives. It is a

DEA VRS model, with output orientation. The model has a single, unitary input and the outputs are the partial scores. This model is equivalent to a multi-criteria model (CAPORALETTI et al., 1999; GOMES et al., 2012), with the particularity that CRS and VRS hypotheses are equivalent (LOVELL & PASTOR, 1999). We added weights restrictions to represent the decision makers' judgments: environmental score ≥ 2*(financial score); environmental score ≥ 2*(productive score); productive score = financial score. As previously mentioned, one should note that other researchers' recommendations on the order and scale of importance of the model's dimensions may have implications on the efficiency results.

We additionally calculated a composite efficiency score to untie efficient ranches and generate a complete ranking for the global performance score, following the proposal of ANGULO MEZA et al. (2005). The composite efficiency combines classic and inverted DEA frontiers.

Alternative approaches to DEA for performance studies and multi-criteria decision making can be found in the literature (BELTON & STEWART, 2012). Goal programming models, for example, allowed the use of multiple criteria and commonly do not calculate an efficiency score. Multi-criteria methods generally require strong interaction with decision makers for the value judgments elicitation. The advantage of DEA modeling, compared to the above alternatives, is the strong objectivity of the model and its axiomatic base. Other advantages include: the ability to handle multiple inputs and multiple outputs; not specifying a functional form for the efficiency frontier; variables can be measured in different scales; being able to analyze and quantify sources of inefficiency for each observation and identify its (their) benchmark(s); allowing different returns to scale assumptions, considering size or level of variables.

Some disadvantages are: results are sensitive to the inputs and outputs selected, as well as to the set of DMUs analyzed; the number of efficient units may increase as the number of variables increases; the weights used to calculate efficiency scores may not be unique; measurement errors may affect results; the use of statistical hypothesis tests is not straightforward, as it is a non-parametric approach.

We fitted fractional regression models to identify potential covariates that influence or explain performance, as defined by PAPKE & WOOLDRIDGE (1996) and RAMALHO et al., (2010). Let be the vector of covariates z_j for ranch j. A fractional regression assumes $E(\hat{\theta}_n(x_j, y_j|z_j)) = G(\delta' z_j)$, where $G(.)$ is a nonlinear function with values in (0,1], θ is the DEA score, x is the vector of inputs, y is the vector of outputs, and δ is a vector of parameters. The recommendation is to use a distribution function to model $G(.)$. The model is estimated by nonlinear least squares or quasi-maximum likelihood.

We used the following covariates (measured on a logarithmic scale): the productive value of the altered landscape (VPUPa), the flood degree (INUND), and the proportion of area with better quality native pasture (PpastQuali). We included total ranch area (size) as a covariate only in the environmental model fit, as in the other models the variables were normalized by area. VPUP relates the areas of landscapes with native pastures preferred by cattle (open grassland, wet grassland, and exotic cultivated pasture) and the areas of landscapes with low quality pastures (savanna, grassland with presence of bushes); "altered" refers to the addition of landscapes formed with exotic pastures as the preferred ones. INUND refers to the percentage of the ranch area that may become flooded during the peak of the flood season. PpastQuali is the percentage of the area with better quality pasture (wetland and seasonal areas with dominance of C3 metabolism grasses and/or C4 metabolism short grasses) in relation to the total area of the ranch (SANTOS et al., 2002).

The variables used in the models are presented in table 1. In this table we present the 5-number summary of each variable.

RESULTS AND DISCUSSION

About the proposed DEA approach

The DEA models proposed here proved adequate to the case study. The flexibility to consider multiple inputs and multiple outputs allowed the modeling of performance scores in different perspectives (productive, financial) and the computation of a global aggregate score, which combines the three classical dimensions of sustainability.

Second-stage regression, with DEA scores as dependent variables, enabled the identification of determinants of efficiency for the set of ranches evaluated. This class of theoretical model in DEA is one of the principal areas of recent studies in the literature, as discussed by LIU et al. (2013b, 2016) and EMROUZNEJAD & YANG (2018). We should add that LIU et al. (2013a) pointed to the study of two-stage DEA as one of the three main paths followed by applications in agriculture.

We could apply alternative DEA-type formulations. However, our objective was not to

Table 1 - 5-number summary of the variables.

Variable	Minimum	1st Quartile	Median	3rd Quartile	Maximum
Effective operational cost (BRL/ha)	9.1	146.0	178.7	240.1	386.3
Variable cost – other inputs (BRL/ha)	20.8	79.4	90.2	182.1	597.3
Fixed costs (BRLha)	44.8	85.7	136.8	164.9	283.6
Gross revenue (BRL/ha)	93.4	405.1	626.2	813.7	1106.5
Area of cultivated pasture (ha)	94.0	430.6	865.0	2634.8	9400.0
Area of native pasture (ha)	132.0	1151.8	2622.5	5219.8	13111.0
Number of cows reared (animals)	129	574	1486	2783	7000
Number of weaned calves (animals)	50	372	1063	2040	3718
Number of cull cows (animals)	18	76	120	1046	3300
Landscape diversity conservation index (dimensionless)	13.8	35.9	64.7	92.9	100.0
Degree of flooding (%)	20.0	32.4	41.3	50.3	80.0
Productive value of landscapes (dimensionless)	0.42	0.52	0.72	0.80	0.98
Total area (ha)	1001.0	3404.1	5019.5	12419.5	20406.0
Percentage of area with better quality pastures (%)	7.0	11.8	25.0	40.6	61.2

compare different formulations, since each DEA model has different assumptions regarding the convexity of the frontier and that must be considered when structuring each case. As for returns to scale, in fact, the VRS hypothesis is more “benevolent” than the CRS, since the convex frontier allows ranches with different scales to compose the efficiency frontier. We also understand that the CRS hypothesis, of proportionality between inputs and outputs, is difficult to verify in practice, since it would impose, for example, that a twofold increase in input values generates a twofold increase in output values.

Regarding the orientation of DEA models, in the literature there are also non-oriented models (COOPER et al., 2007). For example, the additive model is a non-radial model, which combines both input and output orientations; for an inefficient observation to become efficient it must simultaneously reduce inputs and increase outputs. We believed that in extensive livestock production systems this type of assumption is not easy to implement; and therefore, we adopted the radial orientation.

We used advanced DEA models, such as the assurance region type I (Cone Ratio) weights restrictions model, and the combined DEA frontiers (classic and inverted frontiers) to untie efficient observations in the global model.

DEA models are not the only option for modeling production frontiers. Stochastic Frontier Analysis (SFA) models are an alternative, and traditionally the functional relationship is limited to a single output and multiple inputs (or single input and multiple outputs), leading to a production function with a single dependent variable and multiple explanatory variables. The fitting of the errors’ probability distribution is usually via maximum likelihood (COELLI et al., 2005). However, in our case, SFA models would be restricted to the financial model, since this is the only single output model. Indeed, as DELLNITZ & KLEINE (2019) discuss, some authors have been studying the incorporation of multiple outputs into parametric frontier models. One alternative has been the use of stochastic distance functions, which have the additive separability condition as a drawback (DELLNITZ & KLEINE, 2019). In addition to this constraint, one can cite other characteristics of SFA models that led to our choice for non-parametric DEA models: SFA is a parametric approach (i.e., we need to specify a functional form for the efficiency frontier) and the need to impose additional assumptions about the production possibility set and the data generating process. In addition, SFA models assume stochastic relationships, i.e., deviations from the frontier may be due to inefficiencies or noise in the data (LETTI et al., 2022).

About DEA and SFA models we can also refer that DEA does not impose restrictive hypotheses about the frontier (technology), except for the convexity hypothesis (HJALMARSSON et al., 1996). We should add that DEA does not require hypothesis about the statistical distribution of efficiency scores, besides the possibility of incorporating multiple inputs and multiple outputs. Another favorable feature that can be cited is the flexibility and benevolence in choosing the weights of inputs and outputs in the efficiency score definition. The weights are calculated intrinsically and vary per observation (DMU). This allowed the identification of specializations and the achievement of the maximum possible efficiency score, given the sample under evaluation. According to LETTI et al. (2022), this is not the case in SFA models, which define single weights of inputs and outputs for all DMUs. HJALMARSSON et al. (1996) considered that SFA models allowed a better specification of the frontier, especially when panel data is present, the formalization of hypothesis tests and the construction of confidence intervals. Thus, HJALMARSSON et al. (1996) suggest that the choice should consider the trade-offs related to each case under study, the type of data, hypotheses about the technology etc.

In our study, we considered data from a single period. We understand that, even from the sustainability perspective, the analysis is not invalidated by not considering multiple time periods. In fact, our objective was to present, by means of a case study, the potential of this class of models, either for calculating efficiency or performance scores in the different dimensions of sustainability, or in identifying their determinants. The use of multiple time periods would imply potentially different modeling, such as network DEA models (with the inclusion of a carry-over variable between periods), DEA-Malmquist models, DEA models with time windows, etc., called dynamic DEA models (TONE, 2017).

If data were available, we could incorporate into the second-stage regression factors such as rainfall, temperature, reproduction rates etc. These factors, along with the time factor, could be considered as covariates of the second-stage regression in studying the determinants of efficiency.

As for the number of DMUs, the studies that discussed the number of observations in the DEA literature consider the relationship between the number of observations and the number of variables. It is notorious that a large number of variables in relation to the number of observations (DMUs) can decrease the discrimination power of DEA models (ties for efficient units). There are some “rules of thumb” in the literature that suggested alternative values for this relationship. The most referenced empirical proposal is that of BANKER et al. (1989), who suggested that the number of DMUs should be at least three times the number of variables (inputs and outputs). These rules are not mandatory and have no statistical basis, as discussed by COOK et al. (2014). There are cases where there are indeed many efficient DMUs. However, some advanced DEA models allow tie-breaking for 100% efficient units, as is the case of weights restrictions models or the composite efficiency score via inverted frontier, which were used here in the productive and global models, respectively.

Although the BANKER et al. (1989) rule is a suggestion, it should be noted that the three DEA models proposed here (economic, productive and global) meet this condition. In the limit, the productive model still makes use of weights restrictions, a formulation that makes it possible to get around the DEA limitations when in the presence of few observations in relation to the number of variables.

It is also important to point out that the use of a small sample of beef cattle ranches to apply the methodological approach proposed in the form of a case study was due to the scarcity of data on all or most cattle ranches in the region. This scarcity of information is motivated by the difficult access to the ranches, restricted to the dry season (between the months of August and October), and the cost of field trips.

Finally, it is worth mentioning the potential presence of outliers. This is a controversial issue in DEA modeling. While it is notorious that the presence of outliers (as in any statistical, econometric or mathematical programming methods) can influence DEA performance scores, these outlying observations may represent production practices that should be investigated; they may be important benchmarks for the sample under analysis. We should add that the DEA VRS hypothesis chosen considered scale differences and, in principle, the “accommodation” of potential outliers.

About the case study

Given the nature of DEA models, of calculating a relative performance measure and constructing an empirical efficiency frontier based on observations, the recommendations derived from DEA results are applicable only to the set under evaluation. By changing the set of DMUs, the results will potentially change. Thus, we do not intend to extrapolate the results to the entire Pantanal region from this sample of ranches. However, as follows, it is possible to observe that the results presented here meet the literature and the expectations of experts in the region about the models’ responses.

For the case study, the 100% efficient ranches according to the DEA scores and the ICDP are those coded as RANCH02, RANCH05, RANCH07, RANCH11 and RANCH13 in the financial model; RANCH01, RANCH04, RANCH06 and RANCH13 in the productive model; RANCH07 and RANCH11 in the standard global model (Table 2). In the global model with composite measure (no ties), only ranch RANCH07 has unit efficiency. Ranches 07 and 11 have the highest ICDP. Table 3 shows the main characteristics of the ranches evaluated.

Figure 1 shows the box-plots of the performance scores. The medians of the productive and environmental scores have similar and lower values when compared to the financial and global models. The global score presents the least variability. No atypical observations were identified in these diagrams.

The financial performance of ranches was influenced by VPUPa, which relates landscapes with better and lower quality pastures, while productive performance was negatively affected by the landscape conservation index and positively by the degree of flooding (Table 4). Ranch size and degree of inundation were non-significant in any of the fit. The likely explanation for the marginal effect (p-value $\leq$ 0.10) of flooding degree on productive performance is that floodable landscapes have more productive pastures with better nutritional value (CRISPIM et al., 2002).

A large part of the ranches in the Pantanal concentrates on the breeding activity, with only rearing of replacement heifers (ABREU et al., 2018). RANCH07 was the benchmark ranch for the global performance; it showed a good balance (“optimal” combination) in the evaluated dimensions. This ranch was also a reference in financial and environmental performance. In the financial performance, 70% of the operational cost was of animal costs, 20% of labor, and 10% of other costs. As for the environmental indicator, this ranch showed a high degree of conservation of the diversity of natural landscapes, besides presenting a predominance of native pastures of better quality, which reflected in the high VPUPa. Landscape diversity is a measure that incorporates not only the variety of vegetation types in the landscape, but the quantity of each. We used this measure here as a proxy for biological diversity (FORMAN & GODRON, 1986; GILLESPIE et al., 2008; NAGENDRA & GADGIL, 1999; ROCCHINI et al., 2010, 2013). Thus, the greater is the degree of conservation of the original diversity of the landscape, the lower is the expected impact on species diversity and, therefore, the better is the performance of the ranch under the environmental aspect. The landscape diversity maintenance at acceptable levels is relevant in this context, since the Pantanal in Brazilian legislation is as an area of restricted use, whose use must be ecologically sustainable (BRASIL, 2012). This implies the conservation of biodiversity, the maintenance of ecosystem services and ecological processes, regardless of the economic activity developed.

In relation to production performance, efficient ranches either had a higher proportion of pastures cultivated with higher calf production/ha, which can drastically affect environmental performance, or they performed integrated management between two ranches, adjusting management according to pasture availability

Table 2 - Data envelopment analysis (DEA) efficiency scores and landscape diversity conservation index (ICDP).

Ranch	DEA score - Financial perspective	DEA score - Productive perspective	Environmental score - ICDP	DEA score – Global performance	
				Classic	Composite
RANCH01	93.22	100.00	43.50	73.98	72.33
RANCH02	100.00	64.94	39.90	64.61	60.26
RANCH03	20.72	12.82	92.20	92.20	72.46
RANCH04	49.11	100.00	13.80	46.65	30.42
RANCH05	100.00	21.30	90.20	90.20	85.84
RANCH06	69.95	100.00	84.30	89.37	89.45
RANCH07	100.00	78.80	100.00	100.00	100.00
RANCH08	49.47	15.49	97.50	97.50	84.46
RANCH09	78.50	77.15	34.60	59.36	52.67
RANCH10	94.58	66.95	45.00	66.40	62.70
RANCH11	100.00	14.44	100.00	100.00	93.77
RANCH12	45.76	46.18	93.10	93.10	84.49
RANCH13	100.00	100.00	30.00	68.64	65.65
RANCH14	87.56	63.83	18.63	49.80	36.60

Table 3 - Beef cattle ranches profile as a function of the performance scores (data envelopment analysis – DEA and landscape diversity conservation index – ICDP).

Ranches	Profile
RANCH01 and RANCH13	Ranches with good financial and productive performance, but with low environmental performance.
RANCH02	Ranch with good financial performance, moderate productive performance, and low environmental performance.
RANCH03 and RANCH08	Emerging ranches that are investing in infrastructure and animal purchases, reflecting the low financial and productive performance, since they are still below the productive potential of the properties. However, they present high environmental performance.
RANCH04	Ranch with low financial and environmental performance, and high productive performance.
RANCH05	Ranch with good financial performance due to low investment in inventory, which reflects in the low productive performance, despite the productive potential of the property.
RANCH06	Ranch with good productive performance and moderate financial and environmental performance. However, financial aspects can be improved. This ranch has high fixed costs due to leasing. It has good environmental performance and one of the factors that contributed to this is the integrated management with two properties and leasing.
RANCH07	It represents a ranch with good financial and environmental performance. However, the productive performance is below the productive potential of the property.
RANCH09, RANCH10 and RANCH14	Ranches with low environmental, productive and financial performance.
RANCH11	Ranch that invests in inventory and, despite its low productive performance, manages to have a good financial performance.
RANCH12	Ranch with low financial and productive performance, and good environmental performance. In the case of financial performance, the ratio between cost and revenue is above 1.

between ranches, without affecting environmental performance. According to POUX (2008), ranches that maximize the use of resources (inputs) are considered as “low input” systems. These ranches seek environmentally friendly practices and optimize the use of natural resources, especially higher quality native pastures. However, it should be noted that not all ranches have landscapes with high quality native pastures, and, in these situations, they introduce exotic pastures, a level of intensification of the system. In such cases, there is an increase in altered VPUP and, depending on the proportion of landscapes replaced, there may be a decrease in landscape diversity (ICDP). NOVIKOVA & STARTIENE (2018) observed in their analysis of different production systems that sustainable intensification has a negative impact on the environment, specifically on ecosystem services.

ABREU et al. (2018) evaluated the level of intensification of Pantanal livestock production systems and a large part of Pantanal ranches were considered as extensive production systems. NOVIKOVA & STARTIENE (2018) identified advantages and disadvantages of extensive and intensive systems. ABREU et al. (2018), in describing a case study in the Pantanal on the intensification of the rearing production system, concluded that the technologies adopted resulted in a positive margin, especially in family income, covering disbursements and depreciation, but did not remunerate capital. The authors also described the importance of more efficient ranch management. When analyzing the main production systems model defined by THEROND et al. (2017), the ideal model for the Pantanal would be the biodiversity-based production system, i.e., “agro(ecological) intensification”, which optimizes ecosystem services, especially those of forage provision, and is related to the land sharing model. The proportion of landscapes that have higher quality native forage resources influenced the global performance obtained in our study. For the integrated management of a ranch’s landscapes, it is important to know its multifunctionality, defined as the intrinsic property of ecosystems to perform multiple functions simultaneously, which can generate one or multiple ecosystem services (BERRY et al., 2016). Multifunctionality, therefore, depends on the composition and configuration of the existing landscapes on the property (MASTRANGELO et al., 2014), which will provide multiple ecosystem functions/services. Therefore, these results are in line with those found by GRASSAUER et al. (2022) for multifunctional dairy farms, where each farm has an individual path that depends on its status quo, i.e., there are no unique rules and performance depends on the management of natural resources and other inputs. In the analysis presented here, the overall

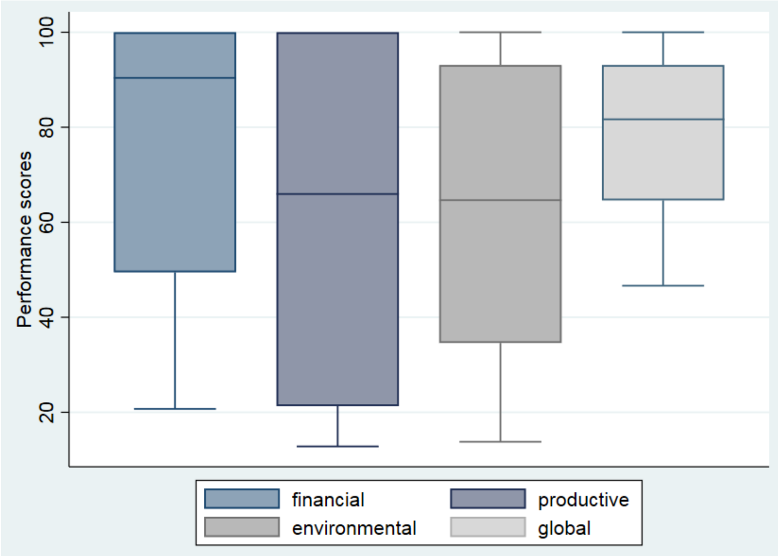

Figure 1 - Box-plots of the performance scores.

performance also depends on the characteristics of each ranch and the adaptive management of natural resources and inputs used on the ranch, either maximizing outputs or minimizing inputs according to existing conditions. These results showed the importance of the system modeling that is based on diversity, as described by THEROND et al. (2017) for the Pantanal region.

Table 4 - Fractional regression fits.

Covariable	Coefficient	Standard deviation	z	P>|z|	--------95% Confidence interval---------	
(A) financial						
VPUPa	1.7142	0.8424	2.03	0.042	0.0631	3.3653
INUND	-0.7959	0.7353	-1.08	0.279	-2.2370	0.6453
PpastQuali	-0.2939	0.3328	-0.88	0.377	-0.9461	0.3583
Constant	5.4505	3.2476	1.68	0.093	-0.9146	11.8156
(B) productive						
VPUPa	1.0630	0.6137	1.73	0.083	-0.1397	2.2658
INUND	0.6233	0.3778	1.65	0.099	-0.1171	1.3638
PpastQuali	-0.4315	0.3400	-1.27	0.204	-1.0978	0.2348
Constant	-0.2047	1.1427	-0.18	0.858	-2.4444	2.0350
(C) environmental						
VPUPa	-2.8535	0.6828	-4.18	0.000	-4.1918	-1.5152
INUND	0.4412	0.5911	0.75	0.455	-0.7173	1.5996
Size	0.2727	0.3533	0.77	0.440	-0.4197	0.9650
PpastQuali	0.8480	0.2675	3.17	0.002	0.3238	1.3722
Constant	-7.4214	4.6996	-1.58	0.114	-16.6324	1.7897
(D) global						
VPUPa	-1.7994	0.4075	-4.42	0.000	-2.5981	-1.0006
INUND	0.1713	0.2929	0.58	0.559	-0.4028	0.7455
PpastQuali	0.5132	0.1914	2.68	0.007	0.1380	0.8883
constant	-2.1214	0.9146	-2.32	0.020	-3.9140	-0.3289

VPUPa= altered landscape productive value; INUND = degree of flooding; PpastQuali = proportion of area of best quality native pasture.

CONCLUSIONS

The DEA modeling here proposed was successful in considering the multidimensional nature of sustainability and computing a one-dimensional performance measure representative of these dimensions. Second-stage regression proved adequate for the identification of performance determinants. The potential limitations of this proposal, especially regarding the small number of observations and the single time period, were circumvented with the appropriate choice of the number of variables, the convexity assumptions, as well as the restrictions and additional models to the classical DEA formulations.

Given the flexibility in structuring DEA models, it is possible to propose alternative models (given the concept of performance one wishes to measure) for each of the perspectives considered, including the environmental one. This requires defining inputs and outputs and interpreting the DEA score.

For the case study, the results proved to be relevant and representative of the decision-makers' expectations regarding the performance of the ranches evaluated. The partial and global performance scores allowed the identification of efficient ranches in the economic, productive and global aspects, which can be a benchmark for the inefficient ones. In this sense, local technical and managerial assistance actions can be supported by the best practices identified by DEA models and, together with the indicators and protocols of the FPS software, improve the performance of these ranches, to ensure the sustainability of economic activity and the biome.

The results of the fractional regression models allowed the identification of covariates that potentially influence the financial, productive, environmental and global performance of ranches. Based on these indications and on a holistic diagnosis of each ranch, management practices can be suggested to improve performance.

The existence of a database with a larger number of observations and time series would allow expanding the results obtained for the fourteen beef cattle ranches and validate its interpretation for other properties in the region. We believed that with the implementation of the FPS tool, it will be possible to create a database on Pantanal ranches, with the support of the Mato Grosso Institute of Agricultural Economics (IMEA) for periodic monitoring of economic variables.

Finally, a key point of quantitative approaches in supporting decisions is to provide a basis for dialogue between the decision agents. As it is well known, models are simplified representations of reality, generally used to better understand or manage this reality, with the potential to promote changes. Results presented here should not be considered as definitive, but as subsidies for the understanding of the performance factors of the ranches studied, under a multidimensional perspective, with developments to support decision making.

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DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed to the conception and writing of the manuscript. All authors critically reviewed the manuscript and approved the final version.

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