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# Assessment of land use relations and the sustainability of agricultural systems: considering different views to foster social learning

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#### ABSTRACT

Soil degradation creates diverse problems across varying dimensions, including food and water insecurity as well as greater vulnerability to climate change especially in Brazil. This uncover the complexity of land use as well as the challenges to asses it. In this article, a multiple case study is presented. Results obtained from three surveys using the IQRM method are discussed to assess the extent to which agricultural land is capable of supporting the uses and management adopted by farmers. When inferring about the degree of adequacy of land use and management, IQRM makes it possible to indicate situations that deserve greater attention because they demonstrate a need for improvements or because they represent references of good environmental performance in a given context. The method IQRM integrated different kinds of knowledge in land use assessment. It is a crucial factor to foster social learning processes and sustainability in the Brazilian context.

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Land use; sustainability assessment; sustainability indicator; land use changes

## Introduction

Since the publication of the first Human Development Report in 1990, sustainability and sustainable development have become mainstream in the development literature (Amadei, 2021). Following the extension of the theory of sustainable development to the field of land science, the concept of sustainable land use became widely accepted around the world (Xie et al., 2020).

Although, sustainability assessment lacks scientific tradition (Gibbes et al., 2020; Toumia et al., 2017; Amadei, 2021; Wu, 2021), despite growing advocacy among practitioners (Dubinsky et al., 2019; Gallopin, 1996; Maturano et al., 2021; Sala et al., 2015; Seghezzo et al., 2017), it is drawing increasing attention from the scientific community as it works to establish the scientific foundation of the concept.

According to Ben Eli (2018), the concept of sustainability allows for multiple interpretations, encouraging key players to avoid making unambiguous commitments or taking decisive actions to achieve professed, common goals. The author argues that, 'insight into the kinds of structures which mediate a system's state open the door to proactive design of new structures and mechanisms, which are necessary for yielding effective change: in this case, promoting the sustainability agenda' (Ben-Ali, 2018 p. 1337).

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Despite the conceptual confusion surrounding the term, the Sustainable Development Goals (SGDs) give special attention to the fostering of 'sustainable agriculture' and to combat the 'desertification of land.' In turn, such objectives and targets are measured using pre-established indicators that provide an assessment of progress toward the achievement of the SDGs, here sustainable agriculture and the neutralization of land degradation.

Polizel et al. (2021) report that a side effect of the expansion of agricultural activities in the Brazilian Cerrado was a loss of its native vegetation, declining biodiversity, and increasing greenhouse gas emissions. Recent expansion is mainly occurring in the northern Cerrado, a region known as MATOPIBA. This region is considered to be the area with the greatest growth potential for arable land in Brazil and extends over parts of the states of Maranhão, Piauí, and Bahia, as well as the entire state of Tocantins (De Miranda et al., 2014)

Considering the agricultural expansion, land tenure, and land use mechanisms in the Brazilian region, it is imperative to analyse rural farms more closely, as most show some degree of environmental irregularity. Thus, our interests here mainly concern the basic and central features of sustainability assessment methodologies and how these can be further improved, if not modified, in order to provide an adequate approach for further assessing and quantifying the sustainability of land use.

The application of the Index-Indicator of Quality of Human-Environment Relations Method, the IQRM, as conceived and proposed by D'Agostini and Schlindwein (1998) in combination with qualitative research approaches, is an attempt to gain a systemic perspective of the perceived challenges facing farmers, to understand the underlying social complexity that gives rise to these perceived challenges, as well as to facilitate and improve the problematic situation as understood from the perspectives of the various stakeholders. These objectives result in the following research questions:

- RQ1: What questions characterize the complexity of family farming systems in the context of the study?
- RQ2: To what extent can IQRM help understand and address this issue?

To answer these questions, the possibilities of the IQRM method as a support tool in the identification of critical situations and alternative solutions as well as in the definition of strategic actions that foster effective social learning in the continuous improvement of the sustainability of agricultural systems are discussed.

#### **Conceptual framework**

In the introduction, we mention IQRM as a sustainability assessment methodology, as used in the present work. D'Agostini and Schlindwein (1998) aim to develop an integrated and quantitative measure of sustainability that can be objectively employed to compare different strategies of agricultural land use. Their intention was to introduce a sustainability assessment methodology based on actual land use rather than on land capability.

From the perspective of D'Agostini and Schlindwein (1998), sustainability must be regarded as an emergent property of the system that cannot be accounted for by a single parameter, measured either in their biotic or abiotic compartments. Sustainability is intended to be related to a specific human-nature relationship and not to a specific unchanged environmental condition. There is a change of perception in terms of systems assessment. In this regard, Ben-Eli observes:

The kind of change required to transform the prevailing trajectory of human affairs is presented as a second order change: a change that requires a major shift, and a complete transformation of the system itself, not only in a few aspects of its behavior .... A piecemeal approach—focusing on one aspect while neglecting others—is not likely to yield effective results for the whole. (Ben Eli, 2018, p. 1337)

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Central to the approach of IQRM is the recognition that farmers use land on the basis of several different criteria, which may include economic, technical, and ecological aspects. Consequently, it is the hierarchy of these criteria, constructed on the basis of the farmers' values, that determine the characteristics of the farming system and also its environmental performance (Eulenstein et al., 2003a). A difference in approach is highlighted here: according to the literature, sustainability assessment methodologies are also developed based on a criterion hierarchy that mostly takes some pre-selected requirements into consideration. Often, the most important criterion for the purpose of assessing land use is the one directly related to environmental conservation; see Seghezzo (2017); Mvongo et al. (2021), and Bayram (2021).

The significance of the criteria hierarchy in defining the characteristics of farming systems is that an indicator of suitable land use should not be limited to the inventory of objective parameters and survey data (Eulenstein et al., 2003a). IQRM brings a methodology that simultaneously and equitatively considers criteria for specific agricultural land use as well as the human who decides the type of land use, as a part of the assessment process.

In addition, this sustainability assessment methodology, by the authors of IQRM, introduces the concept of 'entropic cost.' By 'entropic cost' they understand:

The fraction of the energetic demand of a productive process in dissipative structures which cannot the converted into the desired product. The entropic cost is related to all energy flows involved in the productive process and not only to the direct or apparent flows. (D'Agostini & Schlindwein, 1998, p. 59)

According to Eulenstein et al. (2003b), the concept of entropic cost results from an analogy with the concept of entropy, as expressed by the second law thermodynamics. However, it should not be considered as equal or similar to entropy, which has well defined physical units as property of the system. Therefore, the entropic cost expresses a relative and indirect measure of the energy expenditure of an open farming system, including all the energy input necessary to overcome the deleterious effects of the kind of agriculture being practiced.

To some extent, the concept of entropic cost embodies all those costs that Schaller (1993; as cited in Eulenstein et al., 2003a) calls the 'hidden costs of modern industrial farming.' It includes not only those costs related to environmental problems associated with conventional agriculture but also those related to the social and psychological impacts of demands that cannot be evaluated in either monetary or direct energy terms. By introducing this concept, the authors of IQRM are also considering some of the issues raised by Addiscott (1995; as cited in Eulenstein et al., 2003a), who propose the 'Principle of Minimum Entropy Production' as a useful framework within which sustainability should be discussed.

It is worth mentioning here some interesting experiences using IQRM. Eulenstein et al. (2003b) applies IQRM at different sites in Brazil and Germany. The results confirm the main assumptions adopted by IQRM, also indicating its potential use in agricultural landscapes planning strategies. Diz (2002) assesses the effectiveness of the actions of the 'Projeto de Recuperação, Conservação e Manejo dos Recursos Naturais – Microbasins/BIRD,' implemented by 'Empresa de Pesquisa Agropecuária e Extensão Rural (Epagri)' in Santa Catarina, Brazil. The author finds that those practices adopted by farmers improved the environmental performance in comparison to those whose family farms were not included in the project. Similarly, Salazar (2000) apply IQRM in the context of the project 'Investigación Adaptativa en las Províncias de Ichilo e Sara,' implemented by the 'Centro de Investigación Agrícola Tropical – CIAT,' in Santa Cruz, Bolivia. Their results confirm the positive influence of the indicator for the emergence of the sustainable production systems assessed in the study.

## Methodology

A qualitative approach was chosen not only to help researchers explore issues within their context, reveal the diverse views of stakeholders, identify underlying assumptions, and encouraging stakeholder participation (Yin, 2016), but also to advance the construction of a theoretical proposition regarding the use of sustainability indicators as well as their effectiveness in guiding of land use and management relations.

Based on the study of multiple cases (Yin, 2015), qualitative research protocols were combined with IQRM in an interactive manner, thus facilitating the comprehensive insight that is intended by IQRM. Both belong to an interpretive paradigm. According to Schwaninger (2004, p. 412), in this tradition, 'the methodologies of this practice and research highlight the subjectivity of observers perceiving and interpreting the world ... they are often termed "soft" methodologies ... Under this group, we can subsume diverse heuristics rooted in the behavioral sciences.' Ontologically, this approach places people at the centre of the study, as opposed to technology, structure, or organization, in addition to making their perceptions, beliefs, values, and interests the main concern (Pérez-Ríos, 2012).

From the presentation of the research overview and the different contexts involved, the procedures for data collection, interviews, workshops, systematization, and analysis of the situations assessed are described in the light of what presupposes and guides the use of the IQRM method. The systematized results provide references for simulating changes in the management procedures adopted and the comparative discussion of the effects in the respective contexts.

## The IQRM methodology

IQRM is an interpretative classification of use land use, from which an indicator of sustainability is calculated. The diagram in Figure 1 provides an overview of how this methodology is organized. The methodology is organized in two complementary parts:

- (1) Part 1 (left side of Figure 1): the interpretative classification of land use parcel referenced; and
- (2) Part 2 (right side of Figure 1): the calculation of the indicator of sustainability region or farm referenced.

## The interpretative classification system (Part 1)

Four steps must be followed in the first part of the method applied to field parcels:

Step 1. Inventory of the characteristics of management of the farming system, necessary to estimate the entropic cost. In the methodology, the entropic cost is estimated in relative terms, not in absolute physical units. This takes into consideration the components of management of the productive process in farming systems, especially those related to the management of the environment (mechanization, soil coverage, runoff control) and inputs (seeds, fertilizers, pesticides) (see Appendices A and B).

Step 2. Framing the quality of use relations based on the quantification of entropic costs. The classification criteria assume different relative importance according to the entropic cost of the productive process. Assuming values between 1.0 and 7.0 (see appendix C), the entropic cost is classified into three categories: low (from 1.0 to 2.3), medium (from 2.4 to 3.7), and high (greater than 3.8) (see appendix D). These groups determine the weight of the classification criteria. At higher entropic costs, the conservationist criterion is the most important; at low values of the entropic cost, the edaphological-economics is the most important one.

Step 3. Framing the quality class of the land use relation. The methodology is organized on the basis of three classification criteria: a conservationist criterion, an operational criterion, and an edaphological-economic criterion. For each criterion, a set of soil (or site) attributes was selected.



Figure 1. Framework for sustainability assessments methodology of land use adapted from .Eulenstein et al. (2003b)

These criteria, with their attributes, were then arranged into five classes and organized in a chart according to preferential agricultural land uses (see Appendix E). This classification implies that the site attributes are assessed in relation to their significance for the preferential land use and, therefore, their significance can change from one land use to another. The field parcels are then classified into five classes (from 1 to 5) based on soil or site attributes, with class 1 being the best. The classification criteria, listed with their attributes, are: Conservationist criterion (parcel slope); Operational criterion (parcel slope, presence of stones, soil depth), and Edaphological-Economic criterion (soil fertility (ca, Mg, P), surface soil horizon, soil depth, parcel slope, and soil drainage).

Step 4. Definition of the categories of adequacy of the human-agricultural landscape relationship and according to categories of land use. The first step is the association or aggregation of steps 2 and 3. The results of this association can also assume numerical values between 1.0 and 5.0. In the second part, these values are distributed in five categories (A to E) of land use. An extra category (F) is attributed to all the situations where the land use is other than agricultural or where agriculture is not possible. The category 'A' expresses the best suitability of present land use whereas the category 'E' expresses the worst conditions (see Appendix F). As pointed out by the method, in addition to referring to the quality of current use relations, it also allows us to highlight use limitations and indicate possibilities of promoting better conditions for sustainability in the human-agricultural landscape relationship based on the notation **nNKim** (see, Figure 1).

#### The calculation of the indicator of sustainability (Part 2)

The Index-Indicator of the Quality of the Use Relation and Land Management can be calculated for the farm or region based on the results for individual parcels. This indicator should reflect the quality with which a given agricultural landscape is being used and, by extension, expresses the sustainability of this specific land use. IQRM is calculated as follows:

$$IQRM = \sum_{i=1}^{n} Vi.Ai$$
 (1)

Where Vi = relative value of the class of human-agricultural landscape relationship for parcel i; Ai is the relative area of parcel i; *n* is the number of parcels being assessed. Ai = relative area of parcel i. The IQRM-Indicator can assume values between zero and one (0 < IQRM < 1). Values close to 1 indicate that the human-agricultural landscape relationship of a specific farming system is near to a sustainable state.

#### Contexts of the cases under study

After reviewing some of the main features of the conceptual framework to apply IQRM, we set forth examples of its application to the three cases: Forter Project (FP), Ribeirão São João Sub-Basin (RSSB)), and São João Irrigated Fruit Farming (SJIFF). This will show how IQRM can be used as a conceptual guide to help assess the human-agricultural landscape relationship.

The case studies were developed in the state of Tocantins, located in the northern region of Brazil. The state occupies an area of 277,720,520 km<sup>2</sup> and comprises more than 1.5 million inhabitants. It is the fourth most populous state in the North Region and the twenty-fourth most populous in Brazil. Including the Cerrado biome, Tocantins is predominantly a tropical climate. In the economy, cattle raising and soybean cultivation stand out. The case studies were conducted in the central and southeastern regions of Tocantins, as shown in Figure 2.

## Forter Project (FP)

The FP was a technical cooperation initiative involving the Japan International Cooperation Agency (JICA), the 'Empresa Brasileira de Pesquisa Agropecuária' (Embrapa), the 'Universidade Estadual do Tocantins' (Unitins), and the 'Instituto de Desenvolvimento Rural' (Ruraltins).



Figure 2. Study area location map.

Developed between 2003 and 2007, the FP sought to strengthen the system of technical support for small farmers in the state; mainly through the organization of farmers and the generation of technical, economic, and social references aimed at regional agricultural development.

Developed in the city of Natividade, in the southeastern region of Tocantins, the region has an altitude below 500 meters and predominantly comprises a smooth-undulating relief. The characteristic vegetation is Cerrado in its different phytophysiognomies – stricto census cerrado, cerradão, cerrado, and campos sujos. The climate presents moderate water deficiency in winter, with an average annual rainfall of 1,400 mm distributed from November to April. The soils are classified as Cambissolos, Neossolos, Latossolos, Gleissolos and Plintossolos, with texture ranging from medium to sandy, along with high acidity and depleted nutrients. Further, there are rocky outcrops that represent significant extensions of the environment.

In the region, livestock predominates over agriculture, with 61.3% of agricultural land occupied by pasture, nature, and cultivation and only 1.2% is dedicated to agricultural production. The main crops (rice and corn), along with the raising of small animals, make up the population's food base. Livestock production almost entirely comprises cattle, but pigs are making an ever increasing contribution, especially since pigs constitute an important alternative for income and food security.

Despite their varying capitalization states while living in traditional and 'quilombola' communities, these farmers have difficulties in accessing technical information and official credit, with most still practicing slash-and-burn migratory agriculture.

## Ribeirão São João Sub-Basin (RSSB)

RSSB was an initiative of the Unitins, sponsored by the 'Programa Petrobras Ambiental,' that sought to build a collective awareness based on an education and environmental management program. In summary, among the activities carried out between 2004 and 2008, besides a wide environmental

diagnosis of *Ribeirão São João Sub-Basin* involving natural resources (water, soil, flora and fauna) and the main economic activities of the community, several other studies were also carried out, including an assessment of land use and management among farmers.

*RSSB* is located between the cities of Porto Nacional and Palmas, central region of Tocantins. The area of approximately 34,000 hectares has a predominantly flat or smooth undulating relief with an altitude between 200 and 300 m, with some hills and mountains reaching altitudes of 500 to 600 m. The vegetation is composed of coverings of the cerrado type, campo-cerrado and riparian forests, and, for different types of agricultural uses, annual crops, pastures, fruit, and olericulture. The climate is classified as humid or sub-humid, with an average annual rainfall of 1500 mm and a small water deficiency. The soils can be classified as Latossolos, Areias Quartzosas, Plintossolos e Concrecionários of medium or sandy texture, acid and poor in nutrients.

Within the limits of *RSSB*, there are rural settlements, along with medium and large farmers. Among family farmers, agricultural production is mainly focused on the cultivation of vegetables for marketing and the production of rice, corn, and manioc associated with the raising of small animals for family consumption. In addition to these activities, others that are less significant, such as the production of milk, honey, and fish, represent alternatives for food security and income generation for families.

#### São João Irrigated Fruit Farming (SJIFF)

The project was implemented in 2012 by the Ministry of National Integration in partnership with the Government of the State of Tocantins, under the operational management of the National Secretariat for Water Infrastructure and the State Secretariat for the Environment and Water Resources.

SJIFF is located in the city of Porto Nacional. In operational terms, it consisted of the abstraction of water from the UHE Lajeado reservoir and its distribution through a system of pressurizing stations connected through a pipe network that conducts the water under pressure to the individual water intake of each agricultural lot.

With a total area of about 5,500 hectares, there are 270 family plots with an area of 8 hectares and another 28 commercial plots with an area of up to 35 hectares. The legal reserve area is collective, comprising the Permanent Preservation Areas strip on the shores of the UHE Lajeado reservoir.

The relief is predominantly flat and the climate is humid or sub-humid with an average annual rainfall of 1500 mm and a small water deficiency. The typical Cerrado vegetation that grows on soils classified as Latossolos, Neossolos Quartzarênicos, Plintossolos e Concrecionários is present.

The uses of soil are characterized by the cultivation of fruit species (pineapple, banana, coconut, mango, papaya, and açai) and oleraceous (watermelon, pumpkin, manioc, green corn, and broadleaved plants in general). Fruit production is mostly sold in markets in the southeast and midwest regions of Brazil, while the rest is sold in local markets. The vegetables are sold on the local market and are also intended for family consumption and for raising small animals.

# **Results and discussions**

## Entropic cost of production processes

The results of average entropic cost of parcels for the respective preferred inventoried uses, the number of parcels, and the area covered, as well as the average entropic cost for all parcels of the cases under study are summarized in Table 1.

The highest entropic cost (2.4) in the FP, still low in light of what is taken into account in the method, refers to the use of oleraceous, and is associated with more intensive management, typically using pesticides, fertilizers, and improved seeds.

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Case	Preferential Use	N. of parcels	Area (há)	Average entropic cost*	Average entropic cost in all parcels**
FP	Annual crops	29	16.4	1.8	1.28
	Perennial crops	11	5.9	1.2	
	Oleraceous	1	0.3	2.4	
	Pastures	18	123.5	1.2	
	Irrigated rice	2	2.4	1.2	
RSSB	Annual crops	21	34.6	2.1	2.25
	Perennial crops	7	5.0	2.1	
	Oleraceous	17	7.7	2.4	
	Pastures	10	100.2	2.3	
SJIFF	Annual crops	15	23.5	2.9	2.48
	Perennial crops	12	63.6	2.4	
	Oleraceous	9	43.7	2.4	

Table 1. Entropic cost calculated from the inventory of the situations of cases under study.

\* sum of the product between entropic cost and the area of the parcel with a particular preferential use, divided by the sum of the areas submitted to this use; \*\* sum of the product between entropic cost and the area of parcels, divided by the sum of the area. (reduced 1 to 2.3; medium 2.4 to 3.7; high  $\ge$  3.8);

Considering the 61 assessed parcels, the average entropic cost is 1.28, indicating that the management procedures adopted by farmers are not very intense, especially due to the low use of external inputs.

Additionally, there is a small variation in entropic cost associated with different preferential uses in the RSSB. It is possible to point out the preferential use of oleraceous as that with the greatest management intensity, especially because it involves the use of external inputs such as seeds and fertilizers, as well as greater energy expenditure with mechanization. In general, considering all 55 parcels, the average entropic cost (2.25) indicates that low-intensity management procedures are present.

A similar variation in entropic costs is observed, associated with the use of perennial and oleraceous crops in the SJIFF. For these values, it is possible to note the preferential use of annual cultures as that with the greatest management intensity, especially because it involves the use of external inputs, such as seeds and fertilizers, and greater energy expenditure with mechanization. In general, considering all 36 parcels, the average entropic cost (2.48) indicates that present low-intensity management procedures.

#### Index-Indicator values (IQRM)

As shown in Figure 3, IQRM values refer to the eleven farms assessed in the FP and reflect the quality of the current land use and management relations.

In the case of farms 4B and 5C, IQRM values are related to the combination of preferential uses, irrigated rice, and pastures, with low values of entropic cost, respectively 1.2 and 1.1, which represents low-intensity management. However, the IQRM for these farms is also the result of physical characteristics of the environment that are more favorable to the established relations and the considerable extension of the parcels under these uses in relation to the total area of the farms.

Among the farms with IQRM values below the considered average, we highlight 1A and 9E, where the values are influenced by the characteristics of the environment that are unfavorable to the preferential use of annual crops, that is, the land has low fertility and is significantly stony. In family farm 1A, the low value of IQRM is also associated with more intense management in the preferential use of annual crops, mainly due to an intense motorized mechanization. Further, it is possible to infer that, according to the typology used by the FP, farms 4B and 5C offer important references for the adequacy of use and management of land scape for other farms.

In the same way, in Figure 4, IQRM values refer to the eleven family farms assessed in the study, reflecting the quality of current land use and management relations in RSSB.



Figure 3. IQRM of the family farms assessed in FP.





Only four of the farms in the RSSB had a higher than average IQRM. For farms G-II and J-III, this is directly related to a good combination of preferential use, especially annual crops and pastures, with low values of entropic cost, 2.0 and 1.8, respectively.

The IQRM for these farms is also a result of the good physical characteristics of the environment, such as the absence of stones, flat topography, and good soil depth, in addition to the considerable extension of the parcels under these uses in relation to the total area of the farms.

In Figure 5, the IQRM values refer to the ten family farms assessed in the study, reflecting the quality of the use relations and current management of the farms of SJIFF. Most of the farms investigated had a higher than average IQRM, although it was still low. For farms 2B, 4D, 5E, 6 F, 7 G, and 9I, the result is directly related to the combination of preferential use, especially perennial and oleraceous crops, with low values of entropic cost.

The IQRM for these farms, despite the physical characteristics of the environment being quite favorable to the preferential uses, such as the absence of stones, flat topography, and good soil depth, are strongly influenced by the high values of entropic cost.



Figure 5. IQRM of the family farms assessed in SJIFF.

## nNKim notation and the relation adequacy degree

Among all 61 assessed parcels, the categories of adequacy A, B, and C were distinguished among 24 different situations in the FP. The notation (Figure 6) was verified in 10 parcels associated with the preferential use of pastures, involving the highest percentage in terms of occupied area (41.6%).

Similarly, among the 55 assessed parcels, the values of the quality class of the use relations allow to distinguish three categories of adequacy of the human-agricultural land scape relationship (A, B, and C) in the RSSB. However, from the notations obtained, 26 different situations were identified, which represent different degrees of adequacy of the land use and management relation. The most repeated situation is found in 7 parcels, all related to the preferential use of oleraceous; corresponding to the Figure 7.

Among the 36 assessed parcels, the values of the quality class of the use relations allow to distinguish only 1 category of adequacy of the human-agricultural landscape relationship (C) in the SJIFF. However, by the notations obtained, 12 different situations were identified, which represent



Figure 6. Most representative situation of FP land use and management.



Figure 7. Most representative situation of RSSB land use and management.



Figure 8. Most representative situation of SJIFF land use and management.

different degrees of adequacy of the land use and management relation. The most repeated situation is found in 6 parcels related to the preferential use of oleraceous and perennial crops; these corresponds to Figure 8.

As IQRM is a method that is not restricted to assessing the quality of the current use and management relation, but allows for referring to potential use relations, from the discussions that follow, the main limitations are pointed out and the possibilities for improvement are indicated for the quality of land use and management relations in each context.

Table 2 summarizes the comparative aspects for the set of family farms for each case, with an emphasis on the entropic cost and average IQRM as well as the most representative notation.

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Aspects	FP	RSSB	SJIFF
Case	А	В	С
Evaluated parcels	61	55	36
Identified situations	24	26	12
Average entropic cost	1.28	2.25	2.48
Average IQRM	0.78	0.78	0.56
Quality Classes	A/B/C	A/B/C	С
Most representative notation	<sup>B</sup> B <sub>Esp</sub>	<sup>B</sup> B <sub>Efe</sub>	BC CPfo
Parcels (Number)	10	7	6
Area (%)	41.5	38.4	31.2
Use	Pasture	Oleraceous and perennials	Oleraceous

### Quality of land use and management relations - current situation

The results of the studies under analysis show that the average entropic cost of the group of rural farmers that make up the different contexts is, in general, reduced (1.0 to 2.3) or average (2.4 to 3.7), demonstrating a low intensity in management procedures.

The reduced entropic cost (1.2) is common among farmers in the FP, as traditional agriculture predominates, whose logic of land use and management relations is determined by minimizing the use of external inputs. Even in the use of annual crops, where management is normally more intense, the entropic cost was still reduced (1.8), characterized by the use of minimal mechanization to prepare the soil, as well as comprising seeds and fertilizers produced on the farm or in the community.

Farmers in the RSSB generally show a reduced entropic cost (2.25), characterized by a little more intensity due to the use of minimal mechanization in soil preparation and the use of external inputs such as seeds and fertilizers. In addition to the satisfactory presence of vegetation cover on the soil, which gives greater control of drainage without greater risks to the degradation of the environment.

The average entropic cost (2.48) of SJIFF demonstrates more intensive management, especially for the preferential uses of annual crops (2.9) as well as perennial crops and oleraceous (2.4). Such situations are characterized by the use of mechanization in the preparation of the soil, cultural treatments and harvesting, as well as the use of external inputs such as seeds, fertilizers and pesticides, in addition to insufficient vegetation cover, which results in unsatisfactory control of drainage and risks environmental degradation.

From the average IQRM of the farms that make up each context, it is possible to infer that the best land use and management relations are present in the FP (0.78) and the RSSB (0.78). Nevertheless, despite the good quality of the land use and management relations among the farmers that make up the FP, the evolution and improvement of these relations is limited by its own characteristics, the low use of external inputs.

Thus, the RSSB becomes more interesting because, in addition to a greater IQRM, it presents a greater diversity of situations (26) characterized by management with the common presence of the use of techniques and inputs considered 'modern,' which are associated with a more conservative collective environmental awareness.

On the other hand, and not less important, are the farmers of the SJIFF, with a low average IQRM (0.56). As all farmers have a low IQRM (0.50 to 0.59), the attention of rural extension agencies and agricultural research institutions becomes critical in order to guide farmers to the best use of the management techniques adopted in the face of preferential uses and the characteristics of the physical environment.

## Degree of adequacy of the relation

The most common situation among those evaluated in the context of the FP is represented by the preferential use of pasture (BBEsp), whose use relationship is classified in the quality class (B); that is, it is compatible with the characteristics of the environment and can last for an indefinite

period with limited risks to its sustainability. It is also verified that the criterion of greatest influence in the definition of the class of use relation is practically always the edapho-economic (E) one.

The environmental attribute that most limits the class of preferential use relation pasture among the different types of production systems is the stony one (s), almost always significant, making mechanization and plant development difficult. On the other hand, the attribute fertility (f) is directly related to the definition of the class of use relation for annual crops.

The management procedures associated with the conservationist criterion (p) are the most important for defining the value of the entropic cost of the production process. However, as the total entropic cost is still low, resulting from low intensity management and without greater risks to the degradation of the physical environment, the logic of operating the methodology prevails, which prioritizes an order of criteria where conservationist > operational > edaphic-economic.

In addition, although little representative of the situations assessed in the FP, it appears that the use of intense mechanization and plant diversity characterized by intercropping or rotations of agricultural species have a strong effect on the magnitude of the entropic cost associated with operational management (o). In the same way, inputs, such as improved seeds and commercial fertilizers, combined with those produced on the farm determine the entropic cost of edaphic-economic management (e).

The potential adequacy category (B) shows that the adequacy category of the current use class (B) cannot be improved with only changes in management procedures, and as the entropic cost of the production process is quite low, its improvement is only possible if the option of preferential use pastures is changed.

Therefore, even if these relations of preferential use pastures are compatible with the characteristics of the environment and there are no risks to their sustainability, farmers should be instructed to keep wide vegetal coverage on the soil in order to minimize exposure and drainage issues as well as to avoid water contamination.

### Simulations of changes in management and the quality of use relations

Based on the results of the assessment of the current situation of land use and management, some simulations of changes in management procedures were carried out and the implications of these on the entropic cost, the IQRM values, and the quality of use classes' degree of adequacy of the areas were analyzed.

As pointed out by Souza et al. (2006) the intervention proposals recommended by the FP are restricted to management changes regarding the preferential uses annual crops and perennial crops. These involved the introduction of procedures and the use of external inputs, such as improved seeds, seed treatment, mineral fertilization, and intercropping with leguminous species.

The dependence on non-renewable energy sources is, without a doubt, the most important agriculture performance indicator (Tellarini & Caporali, 2000). As in this multiple case study, Lewandowska-Czarnecka et al. (2019) identifies that farms have different capacities to reduce their dependency on external inputs; this depends on specific regional factors and the internal character-istics of each respective household.

Substitution of on-farm natural resources with external inputs (Riedel et al., 2007) has put agroecosystems in Europe under the threat of intensification and specialization processes.

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#### Effects of simulations on entropic cost

The new values of average entropic cost were obtained considering the set of parcels assessed in the respective use (Table 3). The effects of management changes resulted in an increase in entropic cost for all parcels assessed with preferential uses annual crops and perennial crops, as well as in the average entropic cost values of the respective family farms and different contexts.

In the FP, the increase in the average entropic cost among the family farms varied by up to 35%, with this increase being more expressive in the preferential use of perennial crops (2.3) than annual crops (2.1), a variation of 13.5% and 78.3%, respectively.

In the RSSB and SJIFF, the simulated management changes also resulted in an increase in the average entropic cost of farms, with similar effects and variation of up to 27%. This increase was more significant in the preferential use of perennial crops (14%) than annual crops (33%).

Such effects are directly related to an intensification of edaphic-economic and operational management, with repercussions for conservation management. As an example, there is the use of leguminous species from the market grown in intercropping with perennial crops, which are capable of promoting a broader vegetation cover and improving the control of drainage.

## Effects of simulations on IQRM values

The results of the management changes recommended in the FP reveal a negative variation in the IQRM of the different family farms, with a significant effect on the quality of the use relations. In the simulations of management changes, values were obtained between 0.67 to 0.87, with an amplitude of 0.20 and a considered average value of 0.76.

As previously discussed, the quality of the land use relation among the parcels and farms in FP is strongly influenced by the significant presence of stony and low soil fertility, conditions that are not favorable to the preferential use of 'annual crops.' Therefore, although the technical interventions recommended by the FP can be considered an alternative to overcome the limitations of the physical environment, they also increase the risk of degradation of the environment, including an increase of water pollution.

In the RSSB, simulations of management changes did not have a significant effect on the quality of the use relations among the assessed farms. From the simulations of changes in management, values were obtained between 0.67 and 0.89, that is, an amplitude of 0.22 with a considered average value of 0.78.

Such results are because the recommended procedures and inputs are already present in the current situation, which characterizes most of the parcels and farms in the RSSB.

In the SJIFF, management changes had significant effects on improving the quality of use relations, with IQRM values between 0.58 and 0.70, amplitude of 0.22 and considered average value of 0.65.

Case	Preferential Use	Number of parcels	Area (ha)	Average entropic cost – current situation*	Average entropic cost – management simulation**
FP	Annual crops	29	16.4	1.8	2.1
	Perennial crops	11	5.9	1.2	2.3
RSSB	Annual crops	21	34.6	2.1	2.4
	Perennial crops	7	5.0	2.1	2.8
SJIFF	Annual crops	15	23.5	2.9	3.3
	Perennial crops	12	63.6	2.4	3.2

Table 3. Comparative values of entropic cost of the preferential uses 'annual crops' and 'perennial crops' for the current situation and simulations of management changes.

\* sum of the product between entropic cost and the area of the parcel with a particular preferential use, divided by the sum of the areas submitted to this use; \*\* sum of the product between entropic cost and the area of the parcels, divided by the sum of the area.

Although some procedures and inputs recommended in the management change simulations are already present in the current situation, the adoption of the intercropping of annual and perennial crops with leguminous species acquires special relevance in the expression of the quality of the use relations among farmers in the SJIFF. This is due to the fact that intense mechanization increases soil exposure and susceptibility to erosion factors, such that the intercropping with leguminous species improves soil coverage and drainage, while also reducing the risks of water pollution, even in low slope conditions and deep soils.

On family farms whose IQRM values remained unchanged, even in the face of increased entropic costs after simulations of management changes, the use relations are more appropriate to the characteristics of the physical environment.

#### Effects of simulations on the degree of adequacy of the class of use

Simulations of management changes find a decrease in the adequacy category 'B' to 'C' in most of the situations assessed in the FP. This means that, for these parcels, the use relations that were compatible with the characteristics of the environment are now only technically tolerable and that the persistence of such relations represents real risks to their sustainability.

In the RSSB, changes in management did not significantly change the quality of the use relations, with the maintenance of most of the situations classified in the adequacy category 'B.' Thus, in a large part of the total area, the use land relations and management continue to be compatible with the characteristics of the environment and may last indefinitely with limited risks to its sustainability.

At SJIFF, the simulations of management changes had a positive impact on the quality of the use relations, promoting an improvement of the adequacy category from 'C' to 'B.' Consequently, the use relations that were only technically tolerable in view of the characteristics of the environment and with risks to sustainability became largely compatible, complete with limited risks to its sustainability.

## Conclusions

In the present study of multiple cases using IQRM, there is clear evidence of the ability of this method to capture the most diverse possible situations of land use and management in view of the conditions of the environment, thus adding meaning to the assessment and better guiding the definition of intervention actions for promote sustainable agriculture.

We can conclude, like Polizel et al. (2021), that the Brazilian Cerrado has an intense history of land-use cover changes, with conversion of many hectares of native vegetation to agricultural lands, and that the recent deforestation rates are still high for the region. The authors report that the deforestation areas for small farms were more concentrated in the Tocantins and Maranhão states. For medium-sized farms, deforestation polygons were observed with a higher concentration in the Tocantins state. However, sustainability assessment studies in Tocantins focus on large productions.

Therefore, the Tocantins state is a strategic Brazilian region to monitor in order to minimise natural vegetation loss and preserve its ecosystem services through more efficient environmental governance. In that regard the IQRM methodology is promising as an instrument of assessment and guidance in projects that promote sustainable agriculture and rural development. As recommended in SDG indicator 2.4.1, which monitors the proportion of agricultural land scape by its suitability status, the IQRM also provides an assessment of progress toward sustainable agriculture, where the use and management relations of parcels are interpreted, classified, and framed as tolerable, compatible, or adequate in light of the characteristics of the physical environment.

In the IQRM method, the conditions of family farming systems are interpreted, not just described. 'Human factors' evidently affect this interpretation. However, more than the loss of desirable objectivity in methods, due to the 'human' look of the interpreter, IQRM allows the context to be 384 🛞 J. M. ALVES ET AL.

better contemplated in a complex evaluation. 'Everything that is said is said by an observer to another observer that could be himself' (Maturana & Varela, 1980, p. 8). Therefore, IQRM incorporates the subjectivity of the observer, but it does so with the objectivity expected in methods designed to be able to objectively refer to the assessment of indeterminate sustainability. Furthermore, considering and integrating different kinds of views and knowledge in land use assessment, IQRM it can be also consider key tool to be use in social learning process.

In FP, technical interventions should favour the reduced use of external inputs (fertilizers, seeds and pesticides) or expand the adoption of soil conservation practices (soil cover, minimum cultivation and crop rotation and succession). In RSSB, technical interventions should advocate the adoption of soil conservation practices, especially techniques associated with improving soil fertility (green manure and use of organic waste). At SJIFF, technical interventions should prioritize cropping systems (intercropping and succession) as well as improving fertility and soil protection.

When inferring about the degree of adequacy of land use and management, IQRM makes it possible to indicate situations that deserve greater attention because they demonstrate the need for improvements or because they represent references of good environmental performance in a given context. The IQRM comprises a simple and operational instrument, capable of guiding discussions to define the priorities for research and rural extension in the face of the legitimate interests of farmers.

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No potential conflict of interest was reported by the author(s).

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