Mercator, Fortaleza, v. 23, e23003, 2024. ISSN:1984-2201

HOW DOES NATURE AFFECT COMPETITIVENESS AND INNOVATION?

https://doi.org/10.4215/rm2024.e23003

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Article history:
Received 04 March, 2023
Accepted 22 November, 2023
Published 01 January, 2024

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Abstract

The aim is to strengthen the understanding of nature as an attribute of competitiveness and innovation from a regional perspective. A dialectical relationship is used to consider competitiveness, innovation, and nature as interconnected and not separated dimensions. The expansion of the sugarcane frontier in the south of the Brazilian state of Goiás is taken as empirical evidence. The method compares two municipalities, Mineiros and Goiatuba, with similar economic structures but located respectively in unfavorable and favorable environments. While Mineiros is less competitive than Goiatuba, the challenge of producing sugarcane in soils with higher erodibility stimulated investments in knowledge creation.

Keywords: Competitiveness, Regional Innovation, Nature, Sugarcane, Brazil.

Resumo / Résumé

COMO A NATUREZA INTERFERE NA COMPETITIVIDADE E INOVAÇÃO?

O objetivo é reforçar a compreensão da natureza como um atributo da competitividade e da inovação em uma perspectiva regional. Uma análise dialética é utilizada para considerar competitividade, inovação e natureza como dimensões interligadas e não isoladas. A expansão da fronteira canavieira no sul do estado de Goiás é utilizada como evidência empírica. O método compara dois municípios, Mineiros e Goiatuba, com estruturas econômicas semelhantes, mas localizados respectivamente em ambientes favoraveis e não favoráveis. Enquanto Mineiros tem uma competitividade menor que Goiatuba, o desafio de produzir cana-de-açúcar em solos com maior erodibilidade estimulou investimentos na geração de conhecimento.

Palavras-chave: Competitividade, Inovação Regional, Natureza, Cana-de-açúcar, Brasil.

COMMENT LA NATURE AFFECTE-T-ELLE LA COMPETITIVITÉ ET L'INNOVATION ?

Le but de ce texte est de renforcer la compréhension de la première nature comme attribut de la compétitivité et de l'innovation dans une perspective régionale. Une analyse dialectique est utilisée pour considérer la compétitivité, l'innovation et la nature comme des dimensions interconnectées plutôt que séparées. L'expansion de la frontière de la canne à sucre dans le sud de l'État brésilien de Goiás est considérée comme une preuve empirique. La méthode compare deux municipalités, Mineiros et Goiatuba, avec des structures économiques similaires, mais situées respectivement dans des environnements défavorables et favorables. Alors que Mineiros est moins compétitif que Goiatuba, le défi de produire de la canne à sucre dans des sols plus érodables a stimulé les investissements dans la génération de connaissances.

Mots-clés: Compétitivité, Innovation régionale, Nature, Canne à sucre, Brésil.

INTRODUCTION

Technological advancements have greatly reduced the constraints imposed by natural conditions on economic activities. However, certain natural attributes such as soil, relief, and climate still exert a significant influence on geographic space, especially in regions that rely heavily on natural resource-based activities. Despite numerous studies on the role of regions in driving innovation and economic growth in a global competitive landscape (SCOTT, 1996; STORPER, 1997), the bias towards urban and industrial regions (WALKER, 2001) delegated to the production of raw materials, food, and energy a minor attention in regional analyses.

The increasingly environmental crisis has highlighted the need to integrate nature into regional approaches (DONALD; GRAY, 2019). Some scholars are also defending the necessity to consider the complex interplay between social, institutional, political, and natural factors in specific places to understand energy transition (ASHEIM, 2020; COENEN et al., 2021). In light of these conditions, regional analysis is becoming more concerned about nature. However, it is still necessary to progress further in "how" to interconnect economic, social, and natural elements in a globalized world. This idea does not seek a new form of theorizing region but recovering and dialectically superseding previous work that has considered the so-called "man-environment relationship" in French regional geography (LA BLACHE, 1909; CHOLLEY, 1936, 1948). These authors analyzed nature-society relations recognizing the effects of society in nature (i.e., environmental degradation) and the role of natural space as a raw material in the composition of geographic space (ISNARD, 1978).

Based on a reinterpretation of French regional geography given the changes in capitalism marked by planetary urbanization (BRENNER; SCHMID, 2014a), this paper aims to strengthen the understanding of nature as an attribute of competitiveness and innovation from a regional perspective. For that, we propose a dialogue with regional competitiveness (CASTILLO, 2015; HUGGINS et al., 2014; PORTER, 2000) and combinatorial knowledge base (ASHEIM; GRILLITSCH; TRIPPL, 2017; MANNICHE; MOODYSSON; TESTA, 2017) theories.

The empirical evidence of this study is the expansion of sugarcane cultivation in the southern region of the Brazilian state of Goiás (CASTRO et al., 2010; MESQUITA; LUNA; SOUZA, 2021). To be more precise, we aimed to analyze the cases of Mineiros and Goiatuba municipalities, situated in the southwestern and southeastern regions of Goiás, respectively. These two localities are part of the same productive framework, yet they differ significantly in terms of their soils and topographies.

The paper is structured into more four sections. In the first section, we explore the theory of region in French geography, which views the natural dimension as integral to economic and social organization. In the second section, we focus on the municipalities of Mineiros and Goiatuba and utilize remote sensing and geographic information systems (GIS) to map the pedological conditions and sugarcane areas in 2009 and 2019. Moving on to the third section, we examine the relationship between nature, competitiveness, and innovation in the south of Goiás. Lastly, we present our conclusions and policy recommendations.

NATURE IN REGIONAL STUDIES

Emphasizing nature as an influential factor in regionalization does not constitute a new proposal, but rather a challenge in situating the contribution of regional studies at the beginning of the twentieth century from French geography in the current moment of capitalism. Vidal de La Blache formulated the concept of the natural region based on man-environment relationships, insisting on the role of human initiative in transforming, ordering, and valorizing natural landscapes (CLAVAL, 2007). It is not the types of soil, forms of relief, vegetation, and climate, as isolated items, that underlie the thinking behind a natural region, but its combination with human groups (LA BLACHE, 1909). Despite recognizing it, according to Mamigonian (2003), the scientific body assembled by La Blache was essentially formed by human geographers, who understood little about physical geography. Thus, they lacked a theoretical instrument that could creatively couple natural and human facts.

This link was promoted by André Cholley, who theorized on how combinations contribute "to creating a particular environment at the very place where it occurs, which serves as a framework for the

manifestations of life, particularly those which express the activity of human groups" (CHOLLEY, 1948, p. 85)[1].

Cholley (1948) identified three types of combinations, with the first resulting from physical factors only, and the second combining physical and biological factors. These are less complex combinations, given that the influence of a social factor in their configuration is absent. In contemporary capitalism, considering urbanization as a global phenomenon that encompasses political, economic, and sociocultural relationships across the planet (BRENNER; SCHMID, 2014b), even natural environments in regions without the direct presence of society are part of a global urban pattern. Then, it is no longer feasible to consider combinations that only account for physical and biological factors.

The central point in the work of Cholley (1948) is in the third type of combination, which results from how societies create a convergence between physical and biological elements to overcome challenges imposed onto economic activity. Thus, understanding the influence of nature on the economic and social conditions of a region largely depends on the technical capacity of the local agents. In regions where production is based on traditional knowledge, natural challenges have a greater significance in the combinations, while in regions that use technologies anchored in a scientific base, the natural dimension tends to be controlled. Hence, this view represents a dynamic understanding of combinations as a means of comprehending regional reality.

In the current world, regional differentiation stems from the articulation of places in a spatial division of labor that serves the capital and transforms productive conditions in search of competitiveness and profits (MASSEY, 1979; SANTOS, 2021). Following this perspective, physical, biological, and social elements combine and recombine by inserting the region into a spatial division of labor. The natural system becomes linked not only with local social groups but with a globalized logic that guides the use of natural resources.

The idea of regional combinations between social, economic, and natural elements is typically used to analyze geographical indications, such as in the denomination of origin classification for products like wine, olive oil, and cheese. For instance, understanding the terroir in viniculture and winemaking relies on physical elements like soil types, erosion control, and climate, as well as biological elements that impact grape type and quality. Additionally, cultural elements like savoir-faire are present in the wine production technique (DOUGHERTY, 2012). In this sense, the region's particularities affect the product's specificity and value.

To broaden the scope of the theory of combinations, it should not be limited to geographical indications but also applied to all regions that rely on natural resources. Despite the standardization and homogeneity of the final product of commodities, there exist notable differences in the production process, use of natural resources, technology, research and university links, social implications, and environmental sustainability among regions. Each region that produces soybean, maize, iron ore, or oil possesses a distinctive combination of natural and social factors, even though they are often subjected to the control of remote interests.

To match urbanization, modern agriculture follows industrial principles, functioning as a complex production system that demands inputs and high technology (WALKER, 2004). But it does not eliminate the role of natural aspects. Agriculture deals with living beings that thrive in specific environments and develop differently in others (GRIGG, 1995). Plants are sessile organisms and grow towards essential resources, such as light, water, and mineral nutrients throughout their lifespan (TAIZ; ZEIGER, 2002). Thus, each plant's process and life cycle are linked to a particular environment.

The spatial diffusion of plants undertaken by man, replacing nature for a social logic, requires a technical system that enables the artificial replication of the appropriate conditions for plants (SANTOS, 2021). In industrial agriculture, as in sugarcane production, techniques are not used harmoniously with nature. On the contrary, this concerns mastering it to impose urban socioeconomic rationality. The point is that this logic is confronted by different phytophysiologies, which may facilitate or restrict the crop's introduction, creating particular combinations with the economic and social process.
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THE NATURAL COMPONENT IN THE EXPANSION OF THE SUGARCANE IN THE SOUTH OF GOIÁS, BRAZIL

The southern region of the state of Goiás constitutes a zone interconnected with the expansion of the Asian – predominantly Chinese – demand for food, which boosted the growth of the grain-meat chain throughout the 1990s and 2000s. At the beginning of the twenty-first century, the south of Goiás also reacted to a further demand – primarily from the state of São Paulo, but also locally – for ethanol, which resulted from expanding the fleet of flexible-fuel vehicles in Brazil (CASTRO et al., 2010). In the 2000/2001 harvest, Goiás accounted for 2.8% of the country's sugarcane production, 3.0% of the ethanol production, and 2.5% of sugar production. In the 2020/2021 harvest, Goiás accounted for 11.3% of Brazil's sugarcane production, 16.1% of ethanol production, and 5.6% of sugar production (UNICADATA, 2022).

Sugarcane is a semi-perennial crop that may be planted at various times of the year, except during the dry season, and in various types of soils, from clay to sandy, but requires flat relief, with slopes no steeper than 12% (the limit for most mechanical harvesters). The availability of natural water (rainfall) is also required, or irrigation by capturing surface water resources (drainage network) or subsurface water resources such as phreatic or even deeper water resources such as large underground aquifers, provided they are accessible by tube wells or similar. In the dry season, when planting has immediately preceded it, so-called rescue irrigation is practiced. It should be noted that soils may be adapted (corrections, fertilization, including fertigation), but relief and climate are more challenging to manage, especially when they require more complex conservation practices and, consequently, are more costly to produce.

The increase in sugar and bioethanol production intensified the competition for land with better logistical conditions and edaphoclimatic aptitudes between sugarcane and activities previously located in the region, chiefly grains and pasture (ABDALA; RIBEIRO, 2011). In some cases, depending on the company's economic power, sugarcane entered more favorable environments. However, in others, the high competition for more appropriate land already occupied forced sugarcane to move to areas less suitable for agriculture. Generally, these were zones of degraded pasture (within the limits of a 12% slope) or remnants of the Cerrado, whether they were areas of permanent preservation (APP) or so-called market reserves, i.e., that could still be deforested (TRINDADE; FARIA; CASTRO, 2018).

We suggest a comparison of sugarcane production in two municipalities of Goiás: Mineiros and Goiatuba. Mineiros is located in the southwest part of Goiás, where the environment has limitations that require a more intensive application of conservation practices. On the other hand, Goiatuba is situated in the southeast of the state, where the environment is more favorable for sugarcane production. Figure 1 illustrates the location of these two municipalities.

In Goiatuba, there are two sugarcane mills, the Bom Sucesso, founded in 2010, and Goiasa-Goiatuba Álcool Ltda, founded in 1991. The Bom Sucesso mill reported that in the 2017/2018 harvest, it processed 2.1 million tons of sugarcane (USINABOMSUCESSO, 2018). Goiasa processed 2.8 million tons in the 2018/2019 harvest (JORNALCANA, 2018). Mineiros, in turn, has an Atvos unit, which belongs to the Odebrecht group, the Morro Vermelho sugarcane mill, founded in 2010, which processed 3.8 million tons in the 2018/2019 harvest (ATVOS, 2019).

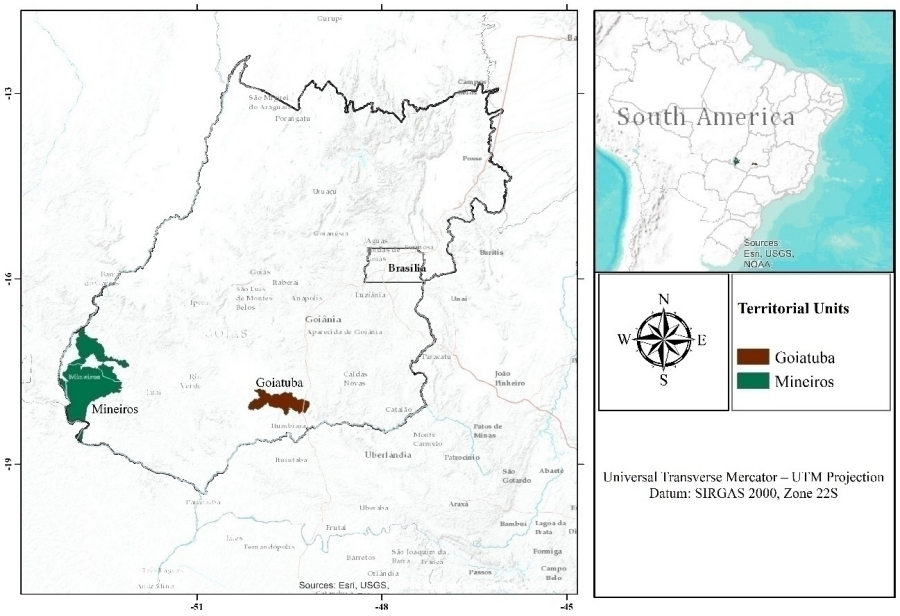

Figure 1 - Location of the municipalities of Mineiros and Goiatuba. Source: adapted from the IBGE (2022b)

Figure 2 illustrates the variations in harvested area and sugarcane yield in Mineiros and Goiatuba between 2000 and 2020.

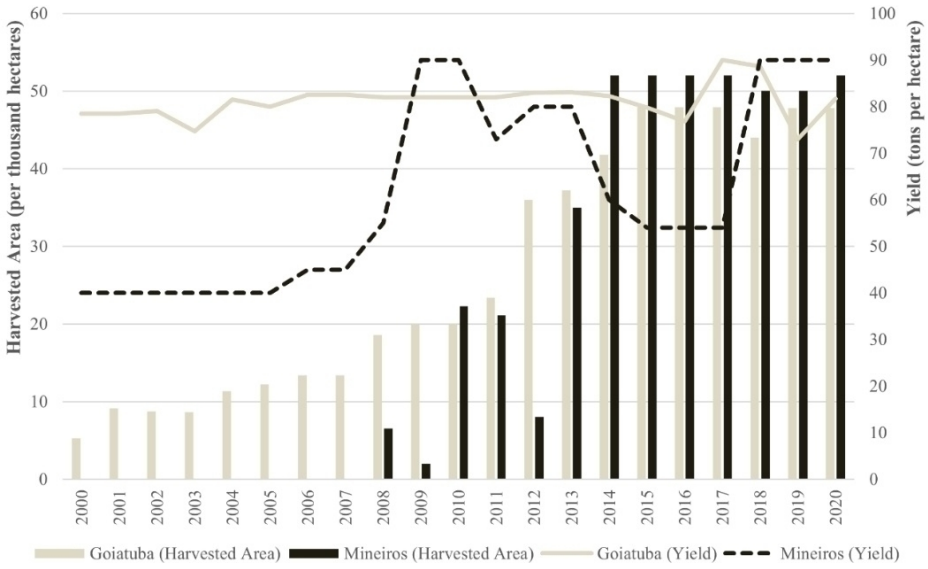

Figure 2 - Mineiros and Goiatuba: variations in the harvested areas and sugarcane yields (2000-2020). Source: produces based on IBGE (2022c)

Although Goiatuba is in an older sugarcane region, due to the cultivation areas around the Goiasa Mill, both municipalities expanded their cultivation in the 2010s. In Goiatuba, this increase began in 2007 and intensified in 2011 after the inauguration of the Bom Sucesso Mill. In Mineiros, the area with sugarcane became more significant only after 2010, with the inauguration of the Morro Vermelho Mill. The municipality has presented moments of growth (2010 and 2011) and decline (2012) but managed to achieve stability from 2013 onwards.Regarding the sugarcane yield, Goiatuba presented few variations, remaining in the range of 80 t/ha, even though the area under cultivation was extended. The increase in 2017 and 2018, to a range of 90 t/ha, and the drop in 2019 to 70 t/ha, may be explained by seasonal

events, which did not change the stability pattern. Mineiros has different behavior. The low yield between 2000 and 2008 is not very representative for our analysis, explained by the small area with sugarcane. The most significant variations occurred from 2010 onwards. The positive yield between 2010 and 2013, which averaged 80 t/ha, may be explained by gains from the first cuts of sugarcane. From 2014 to 2017, the average yield was only 55 t/ha, which places Mineiros well below the national (74 t/ha) and the State of Goiás (77 t/ha) average during the same period (IBGE, 2022c).

Understanding the yield distinctions in these two municipalities requires a study of the natural conditions. There is little difference concerning climate between Goiatuba and Mineiros since both may be classified as tropical climates with dry winters. Mineiros in a region of average annual rainfall above 1,801 mm, and Goiatuba is in a region of 1,601 mm to 1,800 mm per year. The altitude of the two municipalities ranges between 600 m to 800 m, and the biotemperature between 22.1° and 23.0° C. The main distinctions between the two municipalities are in the soil types. The supply of soil alters the system of sugarcane management since its respective constituents and behavior undergo changes essential for germination, growth, and harvest, such as compaction levels, availability of water, root support system, and base saturation (PRADO, 2016), among others, such as erodibility.

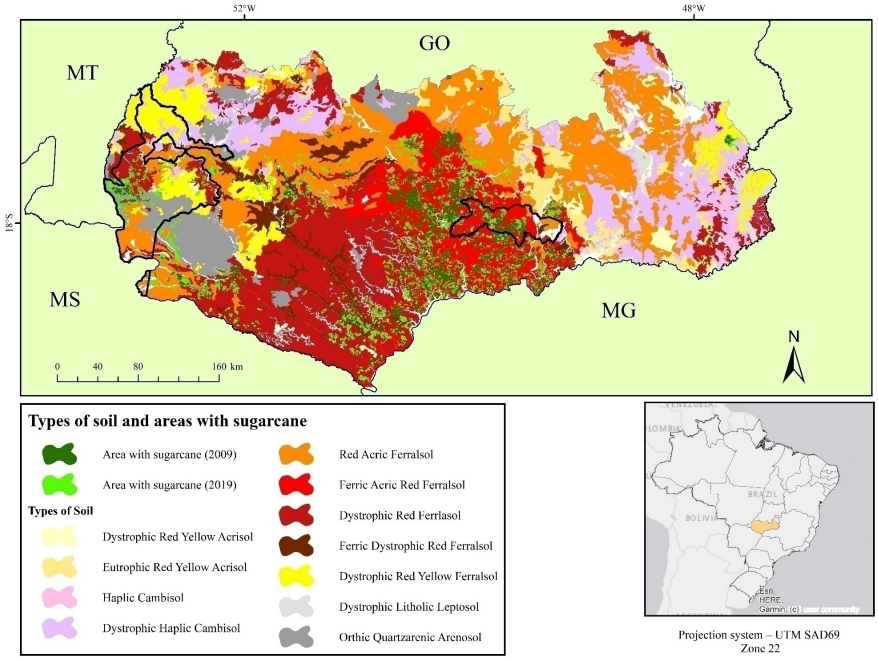

Figure 3 - Mesoregion of South Goáis highlighting Mineiros and Goiatuba: soils of the area with sugarcane. Source: adapted from the Soil Map (SIEG, 2022) and the Area with sugarcane from Canasat (AGUIAR, 2022)

Figure 3 illustrates the area with sugarcane in 2009 and 2019, in the geographic mesoregion of South Goiás, according to soil type. A concentration of activity may be observed in Ferric Acric Red Ferralsol areas, where expansion took place prior to 2009, and Dystrophic Red Ferralsol, with a more internal expansion from 2009 onwards. While in Goiatuba, expansion occurred in more homogeneous environments (dominated by Ferric Acric Red Ferralsol), guaranteed by moving into areas occupied by grain (BARBALHO; SILVA; CASTRO, 2013), in Mineiros, sugarcane was introduced into more diverse environments (Trindade et al., 2018). A significant part of this expansion occurred in Orthic Quartzarenic Arenosols, derived from the Botucatu Formation, which has a high sand content and erodibility (ALMEIDA; LAGOS; CASTRO, 2018). Other soils occupied in Mineiros are Aluminum Ferric and Dystrophic Red Ferralsols.

As a result, as observed in Figure 4, in Mineiros, sugarcane is located on soils with medium, high, and very high erodibility, while Goiatuba is located in a region where practically all the soils have very low erodibility. Comparing the maps in Figures 3 and 4, it is possible to verify the preferential location

of sugarcane in areas with lower erodibility, such as in Goiatuba, and thus deduce its greater aptitude for cultivation.

It is important, however, not to overestimate the influence of natural conditions and fall into a deterministic conception. Referring back to Figure 2, it may be noted that, between 2018 and 2020, the yields in Mineiros increased, obtaining an average of 90 t/ha, a value that was not only higher than Goiatuba, but also than the Brazilian average (75 t/ha) and of the state of Goiás (80 t/ha). However, we argue that to reach this yield pattern, the producers in Mineiros had to deal with particular conditions that ultimately resulted in different combinations of natural and social elements. The point is to investigate how these different combinations affect competitiveness and knowledge production.

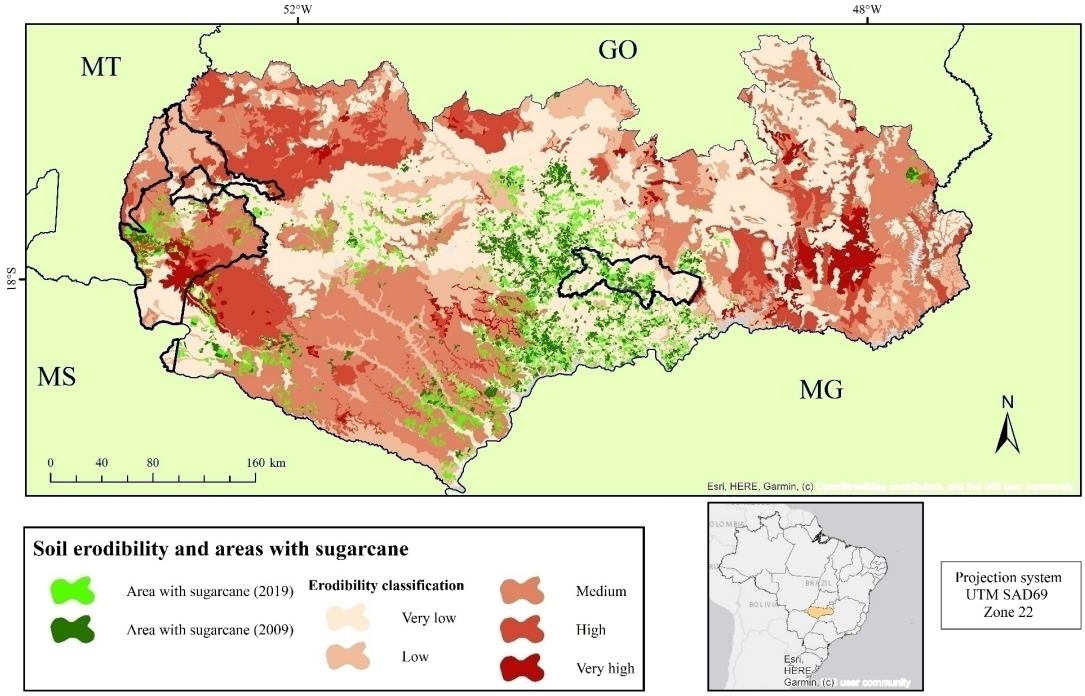

Figure 4 - Mesoregion of South Goiás highlighting Mineiros and Goiatuba: soils per levels of erodibility. Source: adapted from the Erodibility Map (EMBRAPA, 2022) and Area with sugarcane from Canasat (AGUIAR, 2022)

NATURE, COMPETITIVENESS, AND INNOVATION

The concept of competitiveness as a localized attribute derives from the fact that the economic success of companies is associated with the interconnection and gains resulting from the geographical proximity between agents, such as firms, specialized suppliers, service providers, and universities. According to Porter (2000), this articulation in clusters creates competitive advantages through an increase in firms' productivity; an increase in the ability of agents to innovate; and the growth of a new local business, thereby expanding the cluster. In agreement with Santos (2021), the foundations of competitiveness are based on unique geographic conditions in each fraction of space (place, productive region, territory) for each productive branch. Competitiveness, therefore, is a geographical and not simply an economic attribute (SANTOS, 2021). Different geographic compartments offer different competitive capacities, for the same product or branch, due to the combination of natural characteristics with specialized technical objects. It refers to a more complex process than the mere accumulation of wealth, which involves changes in the material (logistics, companies, technological infrastructure, and nature) and the regions' immaterial (knowledge and creativity) conditions (CASTILLO, 2015; HUGGINS et al., 2014).

Regional competitiveness is not exclusive to manufacturing regions but also applies to those focused on intensive natural resource-based activities. According to Walker (2001), natural resources are not only gifts of nature but also endogenous factors of economic progress, much like technology. Agricultural and mineral products face competitive pressures from the global economy and depend on a complex network of interactions among agents. Large-scale agriculture involves integrating the production of chemical inputs, consulting and maintenance services for equipment, agricultural research and extension services, workforce training services, producers of machinery used in planting and harvesting, and industrial processing (ELIAS, 2011; WALKER, 2004). Competitiveness in natural resources-based regions is therefore a dynamic competitive advantage contemplating the interdependence between inherited attributes (nature) and constructed attributes (social).

In sugarcane production, soil, and climatic conditions are decisive factors for sugarcane yields and regional competitiveness. One of the effects of production in unfavorable environments, when comparing Mineiros and Goiatuba, is in the expenditure of the agricultural sector. As presented in Table 1, in Mineiros, fertilizers, and soil correctives represent 20.8% of the total expenses of temporary crops[2], while in Goiatuba this rate represents 14.4% in 2017. Concerning expenses proportional to the establishments that used fertilizers and corrective measures, Mineiros presented an expenditure of 159,000 US$ per establishment and Goiatuba of 85,400 US$ per establishment. A similar effect is observed in the use of pesticides. In Mineiros, pesticides corresponded to 18.5% of the total expenditure; in Goiatuba, it accounted for 11.5%. Per establishment, it represents an expenditure of 151,500 US$ in Mineiros and 71,600 US$ in Goiatuba. The unfavorable natural conditions of Mineiros (compared to Goiatuba), in addition to increasing production costs, also implied a greater dependence on the foreign market, since a significant portion of fertilizers and pesticides is imported. Only the expenditure with salaries is higher in Goiatuba, which is explained by the fact that it is a region with a more significant economic density and labor supply, thereby increasing the cost of labor.

Type of expenditure	% of the total expenditure		Expenditure per establishment* (in thousand US$)	
	Goiatuba	Mineiros	Goiatuba	Mineiros
Contracting services	3.1	2.9	71.9	115.3
Salaries	20.8	14.7	166.4	116.6
Fertilizers and correctives	14.4	20.8	85.0	159.0
Seeds and seedlings	8.4	8.7	48.4	77.3
Pesticides	11.5	18.5	71.6	151.5
Other expenses	41.8	34.5	45.6	48.8
Total	**100.0**	**100.0**	**570.8**	**820.1**

Table 1 - Mineiros and Goiatuba: the expenditure of temporary crops (2017). Source: IBGE (2022a). Values converted from Brazilian reais to United States dollars based on IPEA

* Refers only to the local establishments that made use of the service in question

Therefore, natural conditions, by affecting production costs on a local scale, create heterogeneous environments for competitiveness. The discontinuity of sugarcane in southern Goiás (Figures 3 and 4) illustrates this phenomenon. Most of the sugarcane plantations are in the central-south region of the state, close to Goiatuba, where there are also soybean plantations in rotation with maize, i.e., in a region with more favorable environments, as previously explained. The southwest portion of Goiás, where the municipality of Mineiros is located, in which production environments are less favorable and the transport structure less efficient, is less competitive for sugarcane production, making the mills located there much more vulnerable to price fluctuations of ethanol and sugar on the international markets.

The combination of unfavorable natural conditions and inefficient companies is an inhibiting factor for the region's competitive capacity. The adaptive effort, necessary to raise yield levels, as in the

adoption of advanced management of sugarcane, will be a medium and long-term effort. Such a project involves risks since the results are not very predictable. In addition, the volatility of the prices of primary or semi-manufactured products on international markets may affect profitability, change expectations and reduce agricultural investments. For regions with unfavorable natural environments to become competitive, joint action by companies will be necessary, plus the mobilization of capital, human and material resources for innovation, as well as the State, by providing credit policies and funding for scientific research.

The knowledge base theory emphasizes how innovation and knowledge production are influenced by the regional environment (GRILLITSCH; MARTIN; SRHOLEC, 2017). As Boschma (2018) demonstrated, this literature derives from studies on regional innovation systems. In the beginning, it was presented as an instrument for differentiating the type of knowledge produced in each region, and, in a second phase, in which we situate this approach, as a more dynamic, combinatorial conception between different types of knowledge (MANNICHE; MOODYSSON; TESTA, 2017).

The proposal considers three forms of knowledge: analytical (science-based), synthetic (engineering-based), and symbolic (arts-based) (ASHEIM, 2007; ASHEIM; BOSCHMA; COOKE, 2011). We focus on the first two, directly involved in the productive sphere, to maintain the study's focus on the association between the natural dimension and regional production.

Analytical knowledge is obtained through models, the use of basic science, and a rational process (ASHEIM, 2007), as in the technological trajectory for the creation of new varieties, with the development of areas such as genetics, biochemistry, and botany (ROSENBERG, 1976). Synthetic knowledge, in turn, is defined as creating particularized knowledge based on practice, observation, testing, and field experience (ASHEIM, 2007). In agriculture, this concerns the daily learning on the farm and the experience created within the local context (ANLLO; BISANG; KATZ, 2015). In short, the analytical base represents techniques exogenous to the natural ecosystem produced in laboratories and universities. The synthetic base is an endogenous technique to the region's ecosystem. It is built on geographical proximity that does not operate through the distance between economic actors to facilitate the exchange of tacit knowledge (BOSCHMA, 2005), but rather on physical proximity to nature for the creation of consistent knowledge, with the specifics of the environment (ANDERSEN; WICKEN, 2021).

Innovation process in agriculture – even if it involves incremental innovations (FURTADO; SCANDIFFIO; CORTEZ, 2011) – is essentially based on analytical knowledge, while the diffusion depends on synthetic knowledge. If farmers only have a synthetic base, they cannot advance in production processes that use genetics or phytosanitary, for example (ANLLO et al., 2015). At the same time, the agricultural production system cannot spread only using general principles without adhering to any adaptation (ROSENBERG, 1976).

Analytical knowledge in sugarcane constitutes the necessary knowledge to develop new varieties adapted to different climatic and soil conditions based on genetic improvement (FURTADO; SCANDIFFIO; CORTEZ, 2011). The main agents in Brazil are the Centro de Tecnologia Canavieira [Sugarcane Technology Center] (CTC), located in Piracicaba, in the state of São Paulo; the Instituto Agronômico de Campinas (IAC), whose sugarcane segment is located in Ribeirão Preto, also in São Paulo; and the Interuniversitária para o Desenvolvimento do Setor Sucroenergético [Interuniversity Network for the Development of the Sugar-Energy Sector] (RIDESA), which comprises a network of federal universities distributed across the country. Synthetic knowledge, in turn, represents the knowledge of the local ecosystem. Sugarcane plants remain in the soil for a more extended time, compared to soybean or maize, for example, so that sugarcane: i) is particularly vulnerable to the temperature and climatic conditions; ii) is exposed to pests and weeds for a longer period; iii) develops deeper roots, making the plant more vulnerable to an influx of deeper soil horizons. Unfavorable environments increase the complexity of this production process and demand more investments in synthetic knowledge.

As a way of measuring the production of analytical and synthetic knowledge, we adopted the procedure developed by Martin (2012), based on occupational data. “Occupation statistics are most suitable for capturing the knowledge base of an economic system, as they reflect the set of activities or tasks that employees are paid to perform, and thereby the type of knowledge they actually apply at their

place of work" (MARTIN, 2012, p. 1574). Martin (2012) delineates specific occupational groups that exhibit a heightened affinity with the different knowledge bases. Considering his proposal but focusing on occupations related to agriculture and life science knowledge, we used data from the Annual Social Information Report (Rais) and the division of jobs established in the Brazilian Classification of Occupations. A three-digit classification was employed to identify subgroups pertinent to agricultural and life sciences, while a four-digit classification was utilized to pinpoint specific occupations.

The analytical knowledge was measured by the set of occupations, at three digits, "Agronomists and related" (222); "Biologists and related scientists" (221); and, at four digits, "Researchers in agricultural sciences" (2034). The synthetic knowledge was measured by the set of occupations, at three digits, "Farm crop production technicians" (321), "Biological technicians" (320); and, at four digits, "Topographic and hydrographic survey technicians" (3123). Table 2 displays the findings for the years 2008 and 2020, detailing the total number of jobs associated with analytical and synthetic knowledge in Mineiros and Goiatuba. Additionally, it provides the relative proportion of jobs linked to the sugarcane area for each year.

Year	Number of Professionals				Number of Professionals / sugarcane area (in 1.000 ha)			
	Goiatuba		Mineiros		Goiatuba		Mineiros	
	AK	SK	AK	SK	AK	SK	AK	SK
2008	7	18	10	35	0.376	0.968	1.530	5.356
2009	9	23	17	45	0.450	1.150	8.500	22.500
2010	10	23	23	54	0.500	1.150	1.033	2.426
2011	12	25	34	35	0.513	1.070	1.611	1.659
2012	8	9	29	39	0.222	0.250	3.625	4.875
2013	3	11	32	60	0.081	0.296	0.914	1.714
2014	4	15	29	78	0.096	0.359	0.558	1.500
2015	7	24	33	73	0.146	0.501	0.635	1.404
2016	9	93	38	74	0.188	1.942	0.731	1.423
2017	9	83	36	65	0.188	1.733	0.692	1.250
2018	11	19	39	75	0.250	0.432	0.780	1.500
2019	20	22	36	79	0.418	0.460	0.720	1.580
2020	23	19	37	74	0.481	0.397	0.712	1.423

Table 2 - Mineiros and Goiatuba: synthetic and analytical knowledge base (2008 and 2020). Source: produced based on Rais (2022) and IBGE (2022c)

* AK – Analytical Knowledge; SK – Synthetic knowledge

Goiatuba illustrates a case in which there was an increase in the area harvested with sugarcane (Figure 2) with no significant changes in the local knowledge base. There are occasional variations, such as an increase in analytical knowledge in 2019 and 2020 and an increase in synthetic knowledge in 2015 and 2016. Concerning professionals per area with sugarcane, there were more than 0.5 employees per thousand hectares only during two years in the analytical knowledge, and in synthetic knowledge, there was one employee per thousand hectares on five occasions. This may be explained by the fact that the productive units of Goiatuba encountered environments that generated high levels of sugarcane yields without the need for profound adaptations. Under these conditions, agents were not forced to expand knowledge production and hire qualified professionals.

In Mineiros, on the other hand, sugarcane expansion was only profitable through creating more detailed knowledge. It is important to highlight the higher number of professionals linked to synthetic knowledge compared to Goiatuba during practically all periods and the growth after 2013, followed by relative stability until 2020. Each year, there was more than one professional for any given thousand-hectare sugarcane unit, especially in 2008, 2009, 2010, and 2012, when the activity was initiated in the municipality. These results are linked to the local capacity of training this workforce. The Atvos group (until then, ETH Bioenergia) worked with the municipal government of Mineiros to create a unit of the National Industrial Apprenticeship System (known as SENAI), aiming to provide mill workers with technical qualifications at their place of work (SENAI, 2022). A course of higher education was also created at the Universidade Estadual de Goiás (UEG) in Mineiros to train technologists in sugar and ethanol production with the aim of, among others, developing skills to deal with technologies applied to the sector (UEG, 2022).

Regarding analytical knowledge, Mineiros faces the same challenge as Goiatuba in terms of training professionals in this field and therefore relies on attracting talent from elsewhere. However, Mineiros has a larger pool of professionals specializing in analytical knowledge, even though the number of hectares of sugarcane harvested has decreased since 2013, following the initial period of expansion. Despite this, the proportion of analytical professionals to sugarcane hectares remained above 0.5 per thousand hectares throughout the series. This suggests a deliberate effort to maintain a local workforce that is well-versed in analytical knowledge and can combine it with the learning acquired through cultivating the land in the region.

CONCLUSION

In conclusion, we return to the question that has guided this article: how does nature affect regional competitiveness and innovation?

To address this issue, we need a theoretical framework that acknowledges the active role of nature in regionalization, which cannot be easily transformed to align with economic rationality. French authors from the first half of the twentieth century positioned the conceptualization of region within these terms. In the present day, the combinations are shaped by broader phenomena, such as regional integration into a global spatial division of labor. In the case of the sugarcane areas in southern Goiás, they conform to the political, economic, and sociocultural guidelines of planetary urbanization, making them emblematic cases for examining how nature is transformed to suit interests that are far removed from the local reality.

Nature is a factor of competitiveness due to the variations in crop yields. Even if it is possible to change the natural conditions with investments in technology, this is a procedure that involves increased costs and a reduction in the profitability of production. Such a situation may have repercussions on the entire regional combination since a firm, by taking on higher production costs, becomes more vulnerable to the variation of input prices on the international markets. As a result, it is generally the locations that are less competitive in natural terms, such as Mineiros, that are mainly affected in times of crisis.

When it comes to innovation, it's widely recognized that each environment requires a specific set of knowledge. However, we argue that hostile environments demand a higher level of agent engagement with the local ecosystem to effectively dominate it and transform it into a profitable cultivation environment. This led to sugarcane producers from Goiatuba and Mineiros occupying different positions in the knowledge networks. The successful spread of sugarcane cultivation in Mineiros was dependent on a learning process that involved adapting the activity to the local environment. This created a synthetic base that was tailored to overcome the challenges posed by cultivating sugarcane in soils with poor fertility and high erodibility.

Integrating nature into regional studies is crucial not only from a society-nature perspective, as seen in environmental debates, but also from a nature-society standpoint, which can provide valuable insights into competitiveness and innovation. Specifically, in the case of natural resources-based regions, policy strategies must be underpinned by a theoretical framework that recognizes the pedological, climatic, and geomorphological dimensions of the region. Moreover, as the production in Mineiros is reliant on a fragile natural system, it warrants different treatment in regional policies than

Goiatuba. Mineiros' economic system is more vulnerable during crises, and it should be viewed as a priority region to develop a knowledge base for sugarcane production in unfavorable natural conditions.

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