

A Geo-historical Analysis of Expanding Soybean Frontiers in the Brazilian Cerrado

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ABSTRACT

Until the 1970s, the Brazilian Cerrado was considered an unsuitable agricultural territory. Logistic and infrastructural issues, combined with soil acidity, made the Cerrado a marginal biome for crop production. However, since the Brazilian Agricultural Research Corporation (Embrapa) was created in 1973, the Cerrado has become a national and international hotspot for the food industry. Such a transformation turned this savannah biome into a landmark for the tropical expansion of commodity frontiers, especially in soy production. This research seeks to analyze data on the historical development of soy production volumes and productivity in the Cerrado, considering the complex interrelations between commodity frontier dynamics and its interface within different Brazilian biomes. Comparing data from the Cerrado and other biomes, our results indicate a rapid expansion of the soybean frontier in most Brazilian biogeographic regions. Moreover, the article demonstrates how the growth of soy farming in the Brazilian Cerrado is also affecting other biomes such as the Amazon, influencing local and national policies of agrarian expansion and environmental conservation.

Keywords: cerrado; soybean; agricultural frontier; biomes; Embrapa.

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In 2010, *The Economist* published an article about the revolution of Brazilian agriculture, pointing at the positive impact of modern agricultural technologies in transforming the country's inland territories.⁴ The text paid particular attention to the tropical savannahs of the Cerrado and its rapid transformation into one of the country's most productive regions, considered an otherworldly process, a real agrarian "miracle." The newspaper ironically attributed this miraculous revolution to three main factors: "Embrapa, Embrapa and Embrapa." Such an assessment was not a lone voice. Over the last decade, several scientific studies have attempted to make sense of this transformation, looking at the conjunction of variables that allowed this revolution to come into place. The Cerrado's swift agricultural change has led to engaging comparisons with countries invested in the historical process known as the Green Revolution. This Rockefeller-sponsored agricultural program led to the improvement of several unproductive lands all over the globe through the creation of mechanization packages and extension networks.⁵ While the Green Revolution crucially impacted food production in countries such as India, Mexico and the Philippines, its impact in Brazil has often been overlooked, although some Rockefeller-sponsored experiments took place in the Brazilian Cerrado between the early 1950s and 1970s.⁶ Yet, since the 1970s, Brazil's agricultural production volume, especially in the context of grain and commodity production in the Cerrado, constitutes a valid case study to reconsider the historical role of Brazil in the Green Revolution. Particularly relevant was the Brazilian Agricultural Research Corporation (Embrapa), the leading national institution promoting agronomic development in the challenging Cerrado ecosystem.⁷ Complementary discussions have attempted to describe the Cerrado's agricultural miracle. They have analyzed variables such as a global market-oriented agricultural model; state subsidies; cutting-edge food production technologies such as machinery,

⁴ *The Economist*, *Brazilian agriculture - The miracle of the Cerrado*, 2010. <https://www.economist.com/briefing/2010/08/26/the-miracle-of-the-cerrado>.

⁵ John R. McNeill and Peter Engelke, *The Great Acceleration: An Environmental History of the Anthropocene since 1945* (Cambridge MA: Belknap Press, 2014); R. Douglas Hurt, *The Green Revolution in the Global South: Science, Politics and Unintended Consequences* (Tuscaloosa: University of Alabama Press, 2020).

⁶ Claiton Márcio da Silva and Claudio de Majo, "The Making of a Pastureland Biome: American Scientists, Miracle Grasses and the Transformation of the Brazilian Cerrado." *Environment and History Fast Track* (first online 2020) <https://doi.org/10.3197/096734020X15900760737338>.

⁷ Amélio Dall'Agnol, *Embrapa soja no contexto do desenvolvimento da soja no Brasil: histórico e contribuições* (Brasília: Embrapa Soja, 2016); Ryan Nehring, "Yield of Dreams: Marching West and the Politics of Scientific Knowledge in the Brazilian Agricultural Research Corporation (Embrapa)." *Geoforum* 77 (2016): 206-217; Ryan Nehring, "The Brazilian Green Revolution." *Political Geography* 95 (2022): 102574.

artificial fertilizers, and pesticides; innovations in agro-environmental knowledge; improved cultivation techniques; and the genetic engineering of seeds and crops.⁸

This article analyses the agri-food revolution that has invested the Cerrado for the last fifty years, with particular attention to the complex spatial dynamics of soy production and its role in the dramatic land cover and land-use transformations. In contrast to previous scholarship, the purpose of this study is not to produce an institutional historical reconstruction of Embrapa or other state agencies' role but to understand local agri-food revolution in relation to production and productivity datasets. In so doing, this research seeks to contribute to the environmental history of the Cerrado, providing an analysis of the Brazilian agricultural frontier that considers the impact of the political, economic, and socio-environmental processes that shaped the complex relationships between national biogeographic formations.⁹ In particular, variables of production and productivity allow understanding of soy production in the broader context of agricultural frontier expansion. The historical dynamics of soy frontier expansion analyzed in this study consider the complex interrelations between agrarian and environmental policies in Brazilian biomes. This geographical category has dominated debates on biogeographic formations since the 1980s, consolidating towards the early 2000s with the official release of the first maps. While the term dominates in Brazilian debates, this word is often replaced with bioregion in other scholarly contexts.¹⁰ Brazilian biomes are classified as Atlantic Rainforest, Pampa, Pantanal, Cerrado, Caatinga and Amazon. Such a biogeographic approach constitutes the primary reference for understanding the socioeconomic and ecological implications of the Cerrado's soy farming expansion and

⁸ The three main concepts in academic literature describing the Brazilian's agricultural miracle are *modernização conservadora* (conservative modernization), *agricultura científica globalizada* (globalized scientific agriculture) and *scientific food production*. About these three terms see (in order), Guilherme Costa Delgado, A questão agrária e o agronegócio no Brasil," in *Combatendo a desigualdade social: o MST e a reforma agrária no Brasil*, ed. Miguel Carter, 81–112 (São Paulo: UNESP, 2010); Samuel Federico, "Expansão da Fronteira Agrícola e Emergência de uma Agricultura Científica Globalizada no Território Brasileiro." *Revista Geográfica de America Central* 2 (2011): 1-18; Roger Scruton, *Green Philosophy: How to Think Seriously About the Planet: The Case for an Environmental Conservatism*. New York: Oxford University Press, 2014. Specifically, about soybean innovations in Brazil see Linus Franke, F.M. Greco, M.Y. Noordam, et al. "The institutional and legal environment for GM soy in Brazil." *Plant Research International* 298, Research Report, Wageningen, 2009; Carlos Otavio Zamberlan, Claudia Maria Sonaglio, João Fernando Zamberlan, "Pesquisa, inovação e aprendizagem: a expansão da soja nos Cerrados e a contribuição da Embrapa." *Estudos do CEPE* 29 (2009): 5-29.

⁹ Sandro Dutra e Silva, "Challenging the Environmental History of the Cerrado: Science, Biodiversity and Politics on the Brazilian Agricultural Frontier." *Historia Ambiental Latinoamericana Y Caribeña (HALAC)* 10, no. 1 (2020): 82-116.

¹⁰ The mapping of Brazilian biomes was the result of a 2003 cooperation between the Brazilian Institute of Geography and Statistics (IBGE) and Ministry of Environment. Published in 2004, it became the main reference tool for the formulation of environmental public policies in Brazil. See Instituto Brasileiro de Geografia e Estatística (IBGE), *Biomass e Sistema Costeiro-Marinho do Brasil: Compatível Com a Escala 1:250 000/IBGE*. Coordenação de Recursos Naturais e Estudos Ambientais. Série Relatórios Metodológicos 45 (Rio de Janeiro: IBGE, 2019).

its influence on other biomes from 1974 to 2019. While recent research efforts have mapped the emergence of soybean monocultures in the Cerrado over the last two decades, this contribution aims at re-constructing the geographical expansion of soybean monocultures since their first inception in 1974.

Moreover, this research adds valuable insights into the deforestation process brought by the Cerrado's agricultural expansion and its implications for present and future conservation policies. Considering the relationship between the plantation area, the technological resources employed, and the different environmental impacts in each biogeographic region, we attempt to understand the influence of the Cerrado's soy frontier on other biomes, especially the Amazon. Overall, this essay is primarily informed by the will to assess the role played by the Cerrado in consolidating the Brazilian soy frontier, with particular attention to the harvested area and the shifting patterns of soy production and productivity. A complementary task lies in assessing the pressures that the Cerrado's expanding soy frontier has exercised on local native vegetation and its pressure on other bioregions.

SOY FRONTIER IN THE BRAZILIAN CERRADO AND BEYOND

The expansion of the Cerrado's agrarian frontier stems from processes of scientific knowledge production based on research on biogeographic formations and their relation to global food production trends. Looking at current agri-food production trends, one could today define the Cerrado case as an example of "commodity frontier" par excellence, involving both internal and international actors operating at different intensity levels on domestic and foreign markets, with significant socioeconomic and environmental impacts.¹¹ As a national soy production hotspot, the Cerrado and the other soy-producing regions of the Latin American Southern Cone have become broadly renowned as *Soylandia*. This term indicates the "immense region" where soy farming dominates industrial production and influences significant socioeconomic aspects of everyday life, political decision-making processes and environmental policies.¹² Sustained by ambitious economic agendas and neo-Malthusian assumptions

¹¹ Ernst Langthaler, "The soy paradox: the Western nutrition transition revisited 1950-2010." *Global Environment* 11, no. 1 (2018): 79-104; "Broadening and Deepening: Soy Expansions in a World-Historical Perspective. *Historia Ambiental Latinoamericana Y Caribeña (HALAC)* 10, no. 1 (2020): 244-277.

¹² Susanna Hecht and Charles Mann, "How Brazil Outfarmed the American Farmer." *Fortune* 157, no. 1 (2008): 94.

on international food security and the need to “feed the world”, Soylandia poses as one of the main emblems of agrarian modernization during the twentieth century, representing a successful example of a tropicalized commodity. As a term, Soylandia holds symbolic power, conveying a nostalgic “Fordist” sense of “order and progress,” ideally in line with the Brazilian national motto still featuring on the country’s national flag.¹³ By homogenizing tropical agricultural landscapes, Soylandia stands as the symbol of a global narrative of growth and progress. On the other hand, as a symbol of global technoscientific progress, such a concept mystifies specific territorial features characterizing tropical biogeographic regions’ rich and complex ecosystems.¹⁴ Just as important as this, this term possesses a profound self-deprecatory connotation, reproducing hierarchical and ethnocentric assumptions that deepen the Latin America urban-rural divide and disregard the complex historical trajectory of soybean farming in the continent.¹⁵

The introduction of soybeans in Latin America is indeed a complex process at the intersections of botanic and agronomic research in several parts of Brazil simultaneously.¹⁶ The current international scenario of soy monoculture in Latin America’s Southern Cone only emerged between the 1970s and 1990s, first with genetically modified soybeans and later with transgenic crops.¹⁷ The need to look at the intersections of these complex historical processes and the massive socio-environmental impacts of soybean farming in the Latin American Southern Cone has led environmental historians to adopt the term *Soyacene* as an attempt to “critically address the historical role of soybean production – and the Southern Cone – in the context of the Great Acceleration.”¹⁸

As previously mentioned, Brazil’s primary soybean frontier today is the Cerrado, a biome considered for a long time as a low fertility territory, barely suitable for

¹³ Gustavo Oliveira and Susanna Hecht, “Sacred groves, sacrifice zones and soy production: globalization, intensification and neo-nature in South America.” *The Journal of Peasant Studies* 43, no. 2 (2016): 252.

¹⁴ Oliveira and Hecht, “Sacred groves.”

¹⁵ Claiton Márcio da Silva and Claudio de Majo “Towards the Soyacene: Narratives for an Environmental History of Soy in Latin America’s Southern Cone.” *Historia Ambiental Latinoamericana Y Caribeña (HALAC)* 11, no. 1 (2021): 329-356; “Genealogy of the Soyacene: The Tropical Bonanza of Soya Bean Farming During the Great Acceleration.” *International Review of Environmental History* 7, no. 2 (2021): 65-96.

¹⁶ This historical process was crucially driven by Polish immigrant communities in southern Brazil, who began to adopt soy as a complement to coffee for domestic consumption and for raising animals. See Rhuán Targino Zaleski Trindade, “A soja e os colonos poloneses no sul do Brasil: o caso de Ceslau Biezanko e outros personagens (1930-1934).” *História Unisinos* 22, no. 2 (2018): 254-263.

¹⁷ Silvio Crestana and Ivan Sergio Freire de Sousa, “Agricultura tropical no Brasil,” in *Agricultura Tropical. Quatro décadas de inovações tecnológicas, institucionais e políticas, Vol. 1 Produção e produtividade agrícola*, ed. Ana Christina Sagebin Albuquerque Aliomar and Gabriel da Silva, 41-63 (Brasília: Embrapa, 2008).

¹⁸ Silva and de Majo “Towards the Soyacene,” 332.

agriculture. Local soils' high oxisols concentration deprived them of essential nutrients and created acidic grounds with high levels of aluminum.¹⁹ Despite these significant issues, the Cerrado's agronomic development began towards the end of the 1930s, accompanied by the railway expansion in the state of Goiás.²⁰ The historical expansion of the local agricultural frontier took place in one of the least representative areas of this biome – its tropical forest, known at the time as *Mato Grosso de Goiás*.²¹ It mainly consisted of a slash-and-burn agricultural model, a topic widely researched by Brazilian environmental history.²² However, such deforestation practices only took advantage of eminently fertile lands.

Such a scenario permeated the Cerrado until the end of the 1950s when the grain production policy promoted after World War II and the creation of the Federal District of Brasilia in central Brazil encouraged the exploration of the forests of Mato Grosso de Goiás.²³ This era witnessed colonization processes – led by foreign and national actors – towards the areas known as *Cerrado stricto sensu*, the tropical savannahs. Multiple documents and reports described the difficulties of both Brazilian and foreign farmers in dealing with soil acidity, low fertility, and local climatic patterns.²⁴ While such issues initially decelerated processes of agricultural modernization, they fostered developmental ideas and policies aimed at modernizing the region through food

¹⁹ Karita de Jesus Boaventura, Claiton Marcio da Silva and Sandro Dutra e Silva, "A fronteira agrícola nos cerrados: o papel institucional da EMBRAPA para as pesquisas agronômicas sobre a baixa fertilidade do solo (1975-1995)." *História Agrária: Revista de Agricultura e História Rural* (forthcoming in 2022); Claiton Márcio da Silva, "Between Fenix and Ceres: The Great Acceleration and the Agricultural Frontier in the Brazilian Cerrado." *Varia Historia* 34, no. 65 (2018): 409-444; José Felipe Ribeiro and Bruno Machado Teles Walter, "Fitofisionomias do bioma Cerrado," in *Cerrado, Ambiente e Flora*, ed. Sueli Matiko Sano and Semíramis Pedrosa de Almeida, 89-166 (Planaltina: Embrapa Cerrado, 1998); George Eiten, "Delimitation of the Cerrado Concept." *Vegetatio* 36, no. 3 (1978): 169-178; Paulo S. Oliveira and Robert J. Marquis, "Introduction: Development of Research in the Cerrados," in *The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna*, ed. Paulo S. Oliveira and Robert J. Marquis, 1-10 (New York: Columbia University Press, 2002); Mário Guimarães Ferri, "Contribuição Ao Conhecimento da Ecologia Do Cerrado e Da Caatinga. Estudo Comparativo Da Economia D'água de Sua Vegetação." *Boletim Da Faculdade de Filosofia, Ciências e Letras, Universidade de São Paulo. Botânica* 12 (1955): 7-170; Mário Guimarães Ferri and Eugenio Warming, *Lagoa Santa e a Vegetação de Cerrados Brasileiros* (Belo Horizonte: Itatiaia, 1973).

²⁰ Robert Leighton Carmin, *Anápolis, Brazil: Regional Capital of an Agricultural Frontier* (Chicago: The University of Chicago, Department of Geography, 1953); Sandro Dutra e Silva, *No Oeste a Terra e o Céu: A Expansão Da Fronteira Agrícola No Brasil Central* (Rio de Janeiro: Mauad X, 2017); Sandro Dutra e Silva and Stephen Bell, "Colonização agrária no Brasil Central: fontes inéditas sobre as pesquisas de campo de Henry Bruman em Goiás, na década de 1950." *Topoi* 19, no. 37 (2019): 198-225.

²¹ Speridão Faissol, *Vegetação e Solos No Sudeste Do Planalto Central* (Rio de Janeiro: Edição do Instituto Brasileiro de Geografia e Estatística, 1953); Waibel, Leo, "Vegetation and Land Use in the Planalto Central of Brazil." *Geographical Review* 38, no. 4 (1948): 529-54; Preston E. James, "Trends in Brazilian Agricultural Development." *Geographical Review* 43, no. 3 (1953): 301-328.

²² Warren Dean, *With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest*. Berkeley, Los Angeles: University of California Press, 1995; James, "Trends in Brazilian Agricultural Development."; Pádua, José Augusto, *Um sopro de destruição: pensamento político e crítica ambiental no Brasil escravista (1786-1888)* (Rio de Janeiro: Jorge Zahar Editor, 2004); Diogo de Carvalho Cabral, *Na presença da Floresta: Mata Atlântica e história colonial* (Rio de Janeiro: Garamond, 2014).

²³ Sandro Dutra e Silva, *No Oeste*; "Challenging the Environmental History of the Cerrado: Science, Biodiversity and Politics on the Brazilian Agricultural Frontier." *Historia Ambiental Latinoamericana Y Caribeña (HALAC)* 10, no. 1 (2020): 82-116.

²⁴ Sandro Dutra e Silva and Stephen Bell, "Colonização agrária"; Sandro Dutra e Silva, "Promised land: americanos na expansão da fronteira em Anápolis, Goiás (1940-1950)," in *As ciências na história das relações Brasil-EUA*, ed. Magali Romero Sá, Dominichi Miranda de Sá, André Felipe Cândido da Silva, 325-340. Rio de Janeiro: Mauad X: FAPERJ, 2020.

production. As Sandro Dutra e Silva pointed out, the environmental history of the Cerrado follows processes of national-territorial division in different biogeographic regions, marked by two categories that characterize these natural formations: forests (e.g., tropical forests and rainforest) and fields (e.g. grasslands and tropical savannahs).²⁵ Such a context helps to understand the role of environmental policies and the asymmetric treatment experienced by different bioregions while reinforcing fields' historical vocation for agricultural use. Proponents of environmental protection in Brazil also played along with this distinction, as the tropical savannahs became the main breathing spaces for ambitious developmental policies leading to deforestation.²⁶ The Rockefeller Foundation also played a central role since the 1950s by promoting bilateral treaties with the Brazilian government to research soil fertility, crops, and grasslands.²⁷

These initial collaborations were followed by official partnership agreements between the Brazilian government and the US Agency of International Development (USAID) during the 1960s, fostering cutting-edge crop growing techniques and introducing agricultural machinery.²⁸ This process culminated in the formation of agronomists who specialized in farming technologies, which would later form the core of the Embrapa, created in 1973. In other words, unlike other countries, the Brazilian Green Revolution was not characterized by the direct American inception of knowledge and technologies but by continuous scientific collaboration, academic formation and intergovernmental negotiations. The combination of joint research programs and developmental policies transformed the Cerrado into one of the world's most productive regions. In this context, soybean farming programs were created since 1975, propelled by the creation of Embrapa's soy division in Londrina, state of Paraná (*Embrapa Soja*), partially financed by private companies such as Swift, Anderson Clayton and Samrig, as well as the *Centro Brasileiro de Pesquisa Agropecuária dos Cerrados (Embrapa Cerrados)*.²⁹ The first postgraduate university courses in agricultural

²⁵ Sandro Dutra e Silva, "Promised land: americanos na expansão da fronteira em Anápolis, Goiás (1940-1950)," in *As ciências na história das relações Brasil-EUA*, ed. Magali Romero Sá, Dominichi Miranda de Sá, André Felipe Cândido da Silva, 325-340. Rio de Janeiro: Mauad X: FAPERJ, 2020..

²⁶ Dutra e Silva, "Promised land"; Alberto J. Sampaio, *Phytogeografia Do Brasil* (São Paulo: Companhia Editora Nacional, 1938).

²⁷ Silva and de Majo, "The Making of a Pastureland Biome"; Silva, "Between Fenix and Ceres"; Nehring, "Yield of Dreams."

²⁸ Raoni Rajão and Ricardo B. Duque, "Between hybridity and purity: technoscientific and ethnic myths of Brazil." *Science, Technology & Human Values* 39, no. 6 (2014): 844–874; Carlos Nayro Coelho, "A agricultura, os acordos de liberalização do comércio e a Alca." *Revista de Política Agrícola* 10, no. 4 (2001): 53-68; Alfredo Lopes and Luiz Guimarães Guilherme, "A Career Perspective on Soil Management in the Cerrado Region of Brazil." *Advances in Agronomy* 137 (2016): 1-72.

²⁹ Dall'Agnol, *Embrapa soja*; OEC, 2020a.

development were also created at the University of São Paulo (Escola Superior de Agricultura Luiz de Queiroz, ESALQ/USP) and the Federal Universities of Viçosa, Lavras and Paraná.³⁰ Increased international demand for soy and vegetable oils and the internal reduction of broiler meat that increased demand for soy bran also stimulated these processes.³¹ The combination of these factors was responsible for the first migrations of soybean plantations from southern Brazil's temperate, subtropical climate to the Cerrado's tropical climate.

Soy farming in the Cerrado further intensified between the late 1970s and early 1980s, boosted by public and private investments such as the Japanese-Brazilian Cooperation Program for the Cerrados Development (PRODECER). Moreover, low land prices stimulated southern Brazilian farmers' internal migrations, and mechanized soil fertilization processes relying on limestone applications reduced acidity.³² The combination of these factors favored the creation of the first soy breed specifically selected for the Cerrado – the so-called *Doko* – a somewhat rustic yet highly lucrative crop. Interbreeding and genetic selection inaugurated a new era of public-private partnerships between the Embrapa and other foundations specialized in seed production, culminating in modern transgenic biotechnologies. As a result, during the last thirty years, about 50 different soy breeds have been launched, playing an essential role in the development and sustainability of agriculture in the Cerrado.³³ In this context, Emgopa 313 was one of the cultivars with the greatest adaptive and commercial success in the region's expansion of soybean areas. This cultivar was mainly the result of initiatives promoted by the Goiás state government, which in 1973 created the Goiás Agricultural Research Institute (IPEAGO), which later changed its name to Goiás Agricultural Research Corporation (Emgopa). Working in partnership with Embrapa, Emgopa adapted key breeds to expand soybean farming in the region.³⁴

³⁰ Dall'Agnol, *Embrapa soja*.

³¹ Marcelo Hiroshi Hirakuri and Joelsio José Lazzarotto, *O agronegócio da soja nos contextos mundial e brasileiro* (Londrina: Embrapa Soja, Documentos 349, 2014); Dall'Agnol, *Embrapa soja*.

³² Hirakuri and Lazzarotto, *O agronegócio*; Dall'Agnol, *Embrapa soja*.

³³ Empresa Brasileira de Pesquisa Agropecuária (Embrapa), *História da Soja*, 2020. Accessed 17 February 2021 <<https://www.embrapa.br/en/soja/cultivos/soja1/historia>>.

³⁴ Antonio Carnielli, Nilso Luiz Zuffo, Wilson Heidi Higashi, *Soja: caracterização das cultivares recomendadas para Mato Grosso e Mato Grosso do Sul* (Dourados: Embrapa-CPAO, 1996); Roberto Kazuhiko Zito et. al, *Cultivares de soja: macrorregiões 3, 4 e 5 Goiás e Região Central do Brasil* (Londrina: Embrapa Soja, 2017); Goiás (State of), *Lei nº 7.690 de 19 de setembro de 1973*, Accessed 5 August, 2022; <<https://legisla.casacivil.go.gov.br/api/v2/pesquisa/legislacoes/88712/pdf>>; and *Lei nº 7.767 de 19 de setembro de 1973*, Accessed 5 August, 2022 <<https://legisla.casacivil.go.gov.br/api/v2/pesquisa/legislacoes/88785/pdf>>.

Thus, agronomic development in the Cerrado resulted from national policies relying on investments, financing, and partnerships that resulted in an extraordinary boost to research and development of technologies for the agricultural sector, especially from the 1960s and 1970s onwards. Besides financial investments, the Brazilian government also elaborated a set of rural financing and capitalization policies. Among the various policy programs, it is worth highlighting the National Rural Credit System (SNCR), institutionalized in 1965 by Law 4.829.³⁵ Building on this legal framework, a series of financing packages linked to the soybean production chain were implemented in the following years. For example, between the 1970s and 1980s, significant financial resources were allocated to creating Constitutional Funds, with particular emphasis on the Midwest Constitutional Fund (FCO).³⁶ In the 1990s, the Brazilian market economy became increasingly internationalized. In this context, the SNCR financed the integration between industry and agriculture by improving soils and agricultural practices with new technologies and strengthening farmers' cooperatives. Noteworthy were the activities of the National Bank for Economic and Social Development (BNDES), the Program to Encourage the Use of Soil Correctives (Prosolo), and the Revitalization Program for Agricultural Production Cooperatives (Recoop). In the first decades of the twenty-first century, Brazilian agriculture consolidated itself as an essential player in the global grain and commodities market. This period, therefore, was marked by the expansion of foreign trade, especially in the Asian market (mainly China). Just as significant were rural credit initiatives such as the Program for the Incentive and Modernization of Storage Units in Rural Properties (Proazem), the Program for the Modernization of Agricultural Tractors and Associated Implements and Harvesters Fleet (Moderfrota) and the Program for the Capitalization of Agricultural Production Cooperatives (Procap-Agro).³⁷

As a result, since the 1970s, the Cerrado became one of Latin America's main agrarian frontiers, massively increasing productivity, expanding its cultivated surface and trespassing on other biomes.³⁸ In this context, soy played a central role in the

³⁵ Brasil (Federal Republic of), *Lei nº 4.829 de 5 de novembro de 1965*. Accessed 5 August, 2022 <http://www.planalto.gov.br/ccivil_03/leis/l4829.htm>.

³⁶ Brasil (Federal Republic of), *Lei 7.827, de 27 de setembro de 1989*. Accessed 5 August 2022 <http://www.planalto.gov.br/ccivil_03/leis/l7827.htm>

³⁷ Simone Yuri Ramos and Geraldo Bueno Martha Júnior, *Evolução da política de crédito rural brasileira* (Planaltina DF: Embrapa Cerrados, 2010).

³⁸ Mariana Soares Domingues and Célio Bermann, "O arco de desflorestamento na Amazônia: da pecuária à soja." *Ambiente & Sociedade* 15, no. 2 (2012): 1-22.

national economic incorporation of the Cerrado, increasing from 944.138,00 tons in 1974 to more than 56.950.787,00 in 2019.³⁹ This process went hand in hand with the expansion of the meat industry (bovine, swine and poultry), as soy became the main source of animal feed.⁴⁰ Currently, soy is the primary commodity produced in Brazil, accounting for 28.6 billion dollars, turning the country into the world's leading producer and exporter in 2020.⁴¹ Furthermore, states within the Cerrado, such as Mato Grosso and Goiás, occupy first and fourth place on national production charts, respectively.⁴² In the former, soy production constitutes 41 per cent of the total exports, while in the latter, 23.2 per cent.⁴³ While these numbers might lead to the conclusion that soy production has reached its limits in the region, according to modern agribusinesses, the Cerrado presents the suitable characteristics and know-how to continue improving its agriculture potential, becoming one of the world's main agrarian barns in the following decades.⁴⁴

AREA OF STUDY

As previously mentioned, this research primarily focuses on the Cerrado, the second-largest Brazilian bioregion, with an estimated area of about 2 million Km² (Map 1). This biogeographic formation comprises different physiognomic and floristic compositions, such as grasslands, prairies, bushed fields, and tropical forests.⁴⁵ Regarding landscape transformation and land use, the Cerrado has been one of the most affected biomes by the expansion of the agricultural frontier, with only 57 per cent of its original surface still intact by 2018. Moreover, data from the Amazon Environmental Research Institute (IPAM) points out that between 2000 and 2015, deforestation in the Cerrado was more intense than in the Amazon, with a total loss of

³⁹ Instituto Brasileiro de Geografia e Estatística (IBGE), *Produção Agrícola Municipal*, 2019. Accessed 25 January 2021, <<https://sidra.ibge.gov.br/pesquisa/pam/tabelas>>.

⁴⁰ Arnaldo Carneiro Filho and Karine Costa, *A expansão da soja no Cerrado. Caminhos para a ocupação territorial, uso do solo e produção sustentável* (São Paulo: Agroicone/ INPUT, 2016); Bonato; Bonato, 1987.

⁴¹ Observatory of Economic Complexity (OEC), *Brazil (BRA) Exports, Imports, and Trade Partners*, 2020. Accessed 21 November 2020, <<https://oec.world/en/profile/country/bra>>.

⁴² Empresa Brasileira de Pesquisa Agropecuária (Embrapa), *Soja em números (safra 2019/2020)*, 2020. Accessed 12 November 2020, <<https://www.embrapa.br/soja/cultivos/soja1/dados-economicos>>.

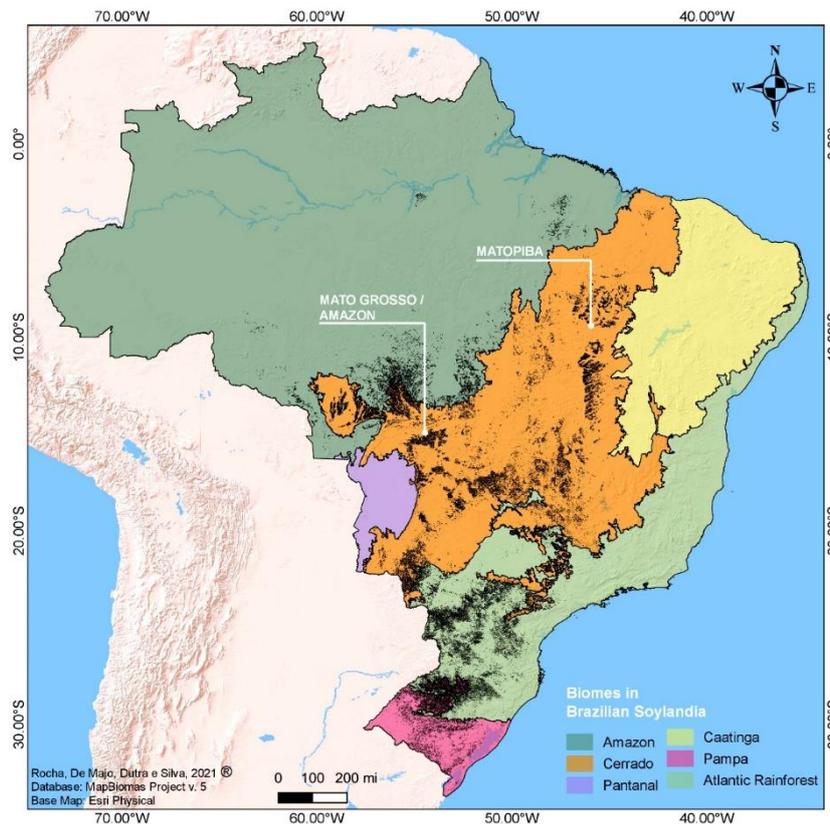
⁴³ Observatory of Economic Complexity (OEC), *Mato Grosso*, 2020. Accessed 21 November 2020 <https://oec.world/en/profile/subnational_bra_state/mato-grosso>; *Goiás*, 2020. Accessed 21 November 2020 <https://oec.world/en/profile/subnational_bra_state/goias>.

⁴⁴ Carneiro Filho and Costa, *A expansão da soja*.

⁴⁵ George Eiten, "The Cerrado Vegetation of Brazil." *The Botanical Review* 38, no. 2 (1972): 201-341; Paulo S. Oliveira and Robert J. Marquis, "Introduction," 9.

236.000 km² of its native surface.⁴⁶ The bioregion's most threatened areas are those that registered the most significant soy frontier expansion, such as the so-called MATOPIBA – a region located at the intersection between the states of Maranhão, Tocantins, Piauí, and Bahia and northern Mato Grosso, the latter at the crossroads between the Cerrado and the Amazon (see Map 1).

Map 01. Soybean farming expansion in Brazilian biomes.



In both instances, environmental hazards have moved beyond the Cerrado's biogeographic borders, directly affecting the Amazon region. Analyzing the expansion of the soy frontier from the perspective of biogeographic regions can help understand the scientific processes and historical route that led soy farming to expand from southern to central Brazil and currently further pushing northward.

⁴⁶ Edson Eyji Sano, Roberto Rosa, Jorge Luís Silva Brito and Laerte Guimarães Ferreira, *Mapeamento de Cobertura Vegetal do Bioma Cerrado: Estatísticas e Resultados*, Planaltina: Embrapa Cerrado 2007; Carvalho, André Fernando Araújo de "Supressão da Vegetação Nativa Para o Bioma Cerrado à Partir de 2000 (Raster), Divisão de Processamento de Imagens -DPI/OBT/INPE, 2019. Accessed 17 February 2021 <<http://terrabrasilis.dpi.inpe.br/geonetwork/srv/api/records/333db098-86ec-4447-a8b8-067ae94a2329>>; Bernardo Strassburg, Thomas Brooks, Rafael Feltran-Barbieri et al., "Moment of Truth for the Cerrado Hotspot," *Nature Ecology & Evolution* 1, no. 4 (2017): 1-3.

DATA COLLECTION

Data on the harvested area, production and average productivity were structured by cross-checking information from three databases produced by the Brazilian Institute of Geography and Statistics (IBGE): (i) Municipal Agricultural Production (PAM) between 1974 and 2019; (ii) Brazilian Biomes and Coastal-Maritime Systems (scale 1:250 000, Lista Município Bioma 250 mil.xls); (iii) Environmental Information Database (BDIA).⁴⁷ Datasets were constructed by classifying the dominant biome in each municipality. This allowed the creation of a spreadsheet with the indication of the category “biome”. This classification was extracted from IBGE’s Environmental Information Base, in which 118 municipalities were identified, with territories comprised within the Cerrado, the Amazon, or both.⁴⁸ After establishing the municipalities’ percentage of biogeographic components, those whose attribution and clipping criteria considered the Cerrado dominant were selected. Moreover, IBGE’s System of Automatic Recuperation (SIDRA) allowed parameterizing research on Municipal Agricultural Production (PAM) in every Brazilian municipality. The research was based on temporary farming classes, with the following variables: soy grains, harvested area, produced quantity, and average returns (IBGE, 2019b).

To further explain, PAM provides statistical information on 64 agricultural products (31 temporary crops and 33 permanent ones). Moreover, it is integrated into the Systematic Survey of Agricultural Production (LSPA), a monthly assessment consisting of questionnaires compiled by State Supervisors of Agricultural Research in collaboration with the IBGE. Besides, the data incorporates other technical representations from agricultural research committees belonging to either public or private institutions, both at the state, regional and municipal levels (e.g., Coordinating Groups for Agricultural Statistics “GCEA”, Regional Commissions for Agricultural Statistics “COREA” and Municipal Commissions for Agricultural Statistics “COMEIA”). In this context, this research uses data from soy harvests between 1974 and 2019

⁴⁷ See Instituto Brasileiro de Geografia e Estatística (IBGE), *Produção Agrícola Municipal*, 2019. Accessed 25 January 2021, <<https://sidra.ibge.gov.br/pesquisa/pam/tabelas>>; and BDIA - Banco de Dados de Informações Ambientais, 2020. Accessed 27 November 2020 <<https://bdiaweb.ibge.gov.br/>>.

⁴⁸ The complete base with all biomes (Amazon, Cerrado, Pantanal, Atlantic Forest, Pampa and Caatinga) totals 5,570 municipalities. The border polygons between the Cerrado and Amazon biomes amount to 118 municipalities. However, as the Cerrado borders other biomes besides the Amazon, the municipalities with this type of occurrence were considered according to the polygon of the dominant biome. The result was 1,370 Cerrado-dominant municipalities.

concerning municipal units with a minimal extension of 1 hectare and a harvest rate of at least one ton. Furthermore, the Aggregated data bank allows digital publication from IBGE's System of Automatic Recuperation (SIDRA), printed publications and the Multidimensional Bank of Statistics (BME).

The extracted data sets are used to classify different biomes with municipal-based geographical breakdown levels, following PAM's data sets. In this research, the Cerrado and the Amazon are listed as such, while the others as "other biomes."⁴⁹ Our data classified each biome as a unique and continuous whole without transition areas between different biogeographic regions in cartographic representations. In this context, each contact area was added to one of the confronted biomes, following a dominant typology criterion.⁵⁰ Furthermore, border areas between the Cerrado and other biomes were classified according to the dominant percentage. Such a classification allowed to create datasets with high accuracy levels to effectively estimate soy level production in different biomes between 1974 and 2019 and to understand the soy frontier expansion in the Amazon through the Cerrado corridor. To sum up, the data extracted from the combination of Brazilian Biomes and Coastal-Maritime Systems (scale 1:250 000, Lista Município Bioma 250 mil.xls) and BDIA allowed to classify 5.570 municipalities, 1.370 of which belong to the Cerrado (48 out of 112 bordering the Amazon were classified as Cerrado according to our dominant percentage criterion), while 502 belong to the Amazon (the remaining 3.698 to "other biomes").

It is important to emphasize that data estimation on soy harvests between 1974 and 2019 was particularly challenging, given the limitations on biome data classification, for the following reasons: (i) the lack of a benchmark data set for the survey; (ii) the lack of a biome classification criterion on soy farming data; (iii) the only estimation method identified for the municipal-biome attribution was through IBGE's xls data archive; (iv) the lack of biome-related attributions in border municipalities, making data on soy harvest less accurate. In this context, the online platform *Mapbiomas*, producing annual mappings on land cover and utilization through a pixel-by-pixel classification of

⁴⁹ Instituto Brasileiro de Geografia e Estatística (IBGE), *Conheça o Brasil – Território – Biomas Brasileiros*, 2021. Accessed 25 January 2021, <<https://educa.ibge.gov.br/jovens/conheca-o-brasil/territorio/18307-biomas-brasileiros.html>>.

⁵⁰ Instituto Brasileiro de Geografia e Estatística (IBGE), *Comissão nacional de classificação – Biomas brasileiros*, 2021. Accessed 27 November 2021, <<https://cnae.ibge.gov.br/en/component/content/article.html?catid=0&id=1465>>.

Landsat's satellite images processed by Google Earth Engine's machine learning algorithms, aggregated important information in the discussion of our results.⁵¹ While it would have been ideal to solely build on these maps to analyze the expansion of the soy frontier within the desired period (1974-2019), temporal limitations within Mapbiomas' soil harvest datasets, only starting in 2000, side-lined such an endeavour. On the other hand, using Mapbiomas' data allowed elemental analyses on expanding soy farming to new frontiers such as MATOPIBA and the Amazon biome.

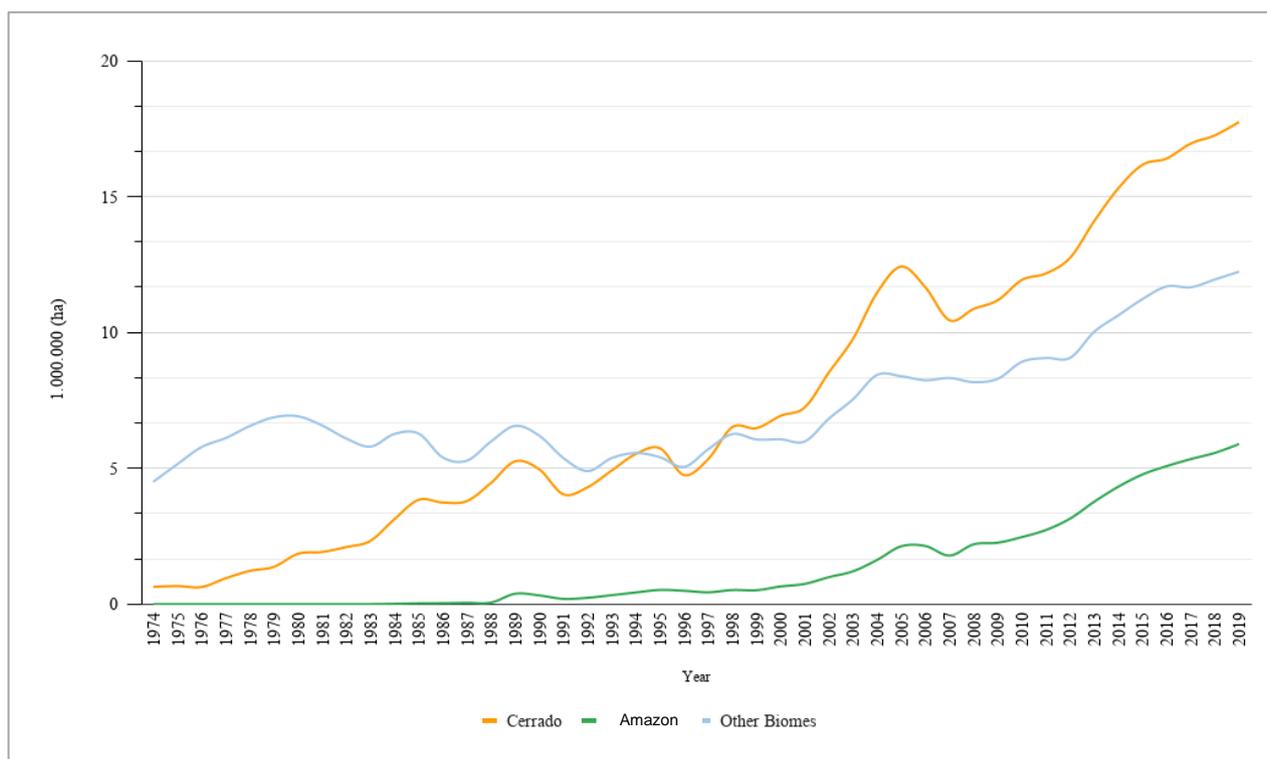
FRONTIER EXPANSION IN BORDER REGIONS

Data analysis demonstrated that the soy frontier in the Cerrado experienced significant expansion between 1974 and 2019 (figure 1). In 1974, indicators of the harvested area totaled 638.120,00 hectares, a figure increased to 17.745.717,00 hectares in 2019, pointing to an approximate growth of 2.781 per cent. The initial period of soy farming experiments (1974-1989) indicated an expansion of 4.622.541,00 hectares, while during the 1990s, the digit increased to 1.517.983,00. In the following decades, these numbers further increased, respectively, by 4.254.873,00 hectares between 2000 and 2009; and by 5.811.520,00 hectares between 2010 and 2019. Therefore, by comparing the volume of harvested soy in these periods, it is possible to notice a steep expansion of soy farming since the beginning of the twenty-first century, with significant environmental pressure on the Cerrado's native forests and in the direction of other biomes (e.g., Amazon, Pantanal, and Caatinga). Moreover, looking at the patterns of soil utilization, it appears evident that the soy frontier has exercised the most pressure in terms of environmental transformations compared to other crops.⁵² The soybean frontier's expansion between 2008 and 2014 was directly linked to approximately 20 per cent of deforestation in the Cerrado.⁵³

⁵¹ Rede Mapbiomas. *Uso e cobertura do solo*, 2019. Accessed 27 November 2020, <<https://plataforma.brasil.mapbiomas.org/>>.

⁵² Liana Oighenstein Anderson, Rojas, Eddy Hoover Mendoza and Yosio Edemir Shimabukuro, "Avanço da soja sobre os ecossistemas cerrado e floresta no Estado do Mato Grosso." *Simpósio Brasileiro de Sensoriamento Remoto*, 11 (2003): 19-25.

⁵³ Lucy S. Nepstad, James S. Gerber, Jason D. Hill et al., "Pathways for recent Cerrado soybean expansion: extending the soy moratorium and implementing integrated crop livestock systems with soybeans." *Environmental Research Letters* 14, no. 4 (2019): 044029.

Figure 1. Soybean frontier expansion in Brazilian biomes (1974-2019) / Harvested area indicated in millions of hectares (ha).

Data Source: Produção Agrícola Municipal – PAM/IBGE 1975-2019 (modified). Lista Município Bioma – IBGE 2019 (modified) Banco de Dados de Informações Ambientais – BDIA/IBGE 2020 (modified).

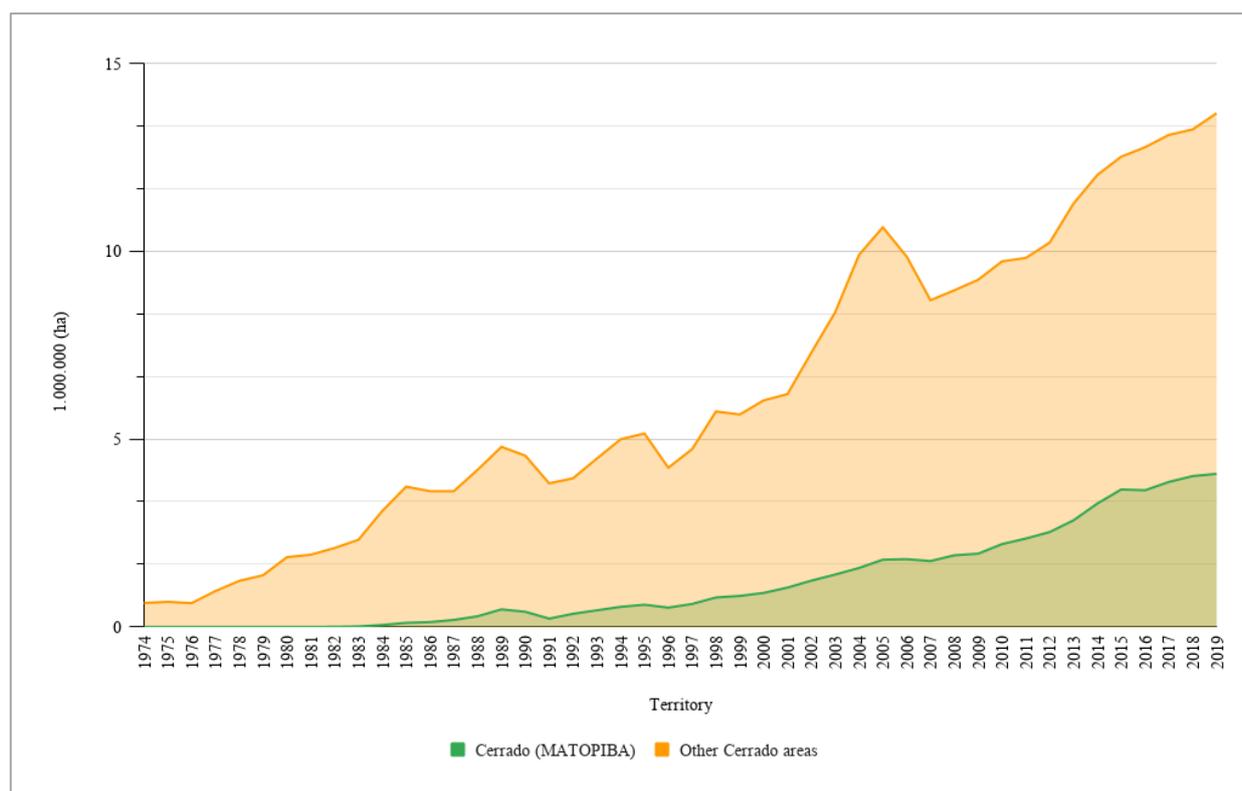
Particularly relevant is the expansion of soy to the region known as MATOPIBA.⁵⁴ In this region, the Cerrado is the dominant biome, covering an area of 234.400,65 km², about 93.89 per cent of its surface. This territory also includes transition areas between different biogeographic regions, approximately 7.765,51 km² between the Cerrado and the Caatinga; and 6.838,77 km² between the Cerrado and the Amazon.⁵⁵ According to our estimates (figure 2), in Cerrado-dominated border areas, harvested hectares increased from 100 in 1974 to 4.074.209 in 2019. In 2009, MATOPIBA's participation in the Cerrado's total harvested area was about 21.10%, reaching 29.80% in 2019. The region's participation peak was registered in 2018 when it produced 30.32% of the Cerrado's total soybean yields. When analyzing the soy frontier expansion from the perspective of MATOPIBA, the pressure of this crop on

⁵⁴ United States Department of Agriculture (USDA), *Crop Explorer – Production Briefs – Brazil*, 2014. Accessed 6 February 2021, <https://ipad.fas.usda.gov/cropeexplorer/pecad_stories.aspx?regionid=br&ftype=prodbriefs>; Aline Soterroni, Fernando Ramos, Aline Mosnier, et al. "Expanding the soy moratorium to Brazil's Cerrado." *Science Advances* 5, no. 7 (2019): eaav7336; De Miranda, Evaristo Eduardo, Luciola Alves Magalhães and Carlos Alberto De Carvalho, *Proposta de Delimitação Territorial do MATOPIBA*. Campinas: Embrapa Territorial-Outras publicações técnicas (INFOTECA-E), 2014.

⁵⁵ Rafael Mignoti, Mayra A. Brasco, Wilson A. Holler, Elio Lovisi Filho and Claudio A. Spadotto, "Matopiba: caracterização das áreas com grande produção de culturas anuais." *Embrapa Gestão Territorial-Nota Técnica/Nota Científica (ALICE)*, 2014.

patterns of soil utilization and consequently on the native ecosystem appears evident. Embrapa studies indicate that between 1974 and 1989, soy farming incorporated 467.829 hectares of native forest. In the following decades, soy plantations' incorporation of native forest areas increased by 422.319 between 1990 and 1999, 1.044.624 between 2000 and 2009, and 1.869.656 between 2010 and 2019. Moreover, between 2008 and 2011, MATOPIBA accounted for the highest percentages of deforestation in the Cerrado.⁵⁶ Despite this disturbing data, MATOPIBA continues to constitute the last Brazilian agricultural frontier, with 26 million hectares (35 per cent of its overall surface) classified as a territory with high agricultural potential. Such an index projects a future scenario of intensive farming in which soy monoculture is likely to play a significant role.⁵⁷

Figure 2. MATOPIBA's participation in the soybean harvested area of the Cerrado (1974-2019) / Harvested area in millions of hectares (ha).



Data Source: Produção Agrícola Municipal – PAM/IBGE 1975-2019 (modified). Lista Município Bioma – IBGE 2019 (modified) Banco de Dados de Informações Ambientais – BDIA/IBGE 2020 (modified).

Between 2005 and 2019, MATOPIBA registered an increase in deforestation index of 9.016.221 hectares – about 3.040.570 in Tocantins, 2.724.104 in Maranhão,

⁵⁶ Édson Luis Bolfe, Daniel De Victória, Elisio Contini et al. "Matopiba em crescimento agrícola. Aspectos territoriais e socioeconômicos." *Revista de política agrícola* 25, no. 4 (2016): 38-62.

⁵⁷ Bolfe et al., "Matopiba em crescimento agrícola."

2.015.452 in Bahia and 1.236.095 in Piauí, respectively.⁵⁸ Moreover, a study published in 2016 demonstrated that the main index of agrarian expansion regarded native forests, with the estimated destruction of 1.3 million hectares between 2007 and 2014.⁵⁹ Another research presented by Embrapa showed that between 2006 and 2012, the soybean farming frontier expanded predominantly in previously anthropized territories.⁶⁰ Finally, a more recent study from 2020 detected stark deforestation peaks between 1986, 1991 and 2012.⁶¹ Moreover, it concluded that the Amazon Soy Moratorium established in 2006 to prohibit the advancement of soybean monocultures indirectly contributed to the acceleration of deforestation rates in the areas of MATOPIBA classified as Cerrado, with an increase of 41 per cent between 2007 and 2016 compared to the previous decade (1996-2005).⁶² On the other hand, it also maintained that the Amazon Soy Moratorium could not be considered the only factor of increased deforestation.⁶³ Other complex variables are related to the intricate relation between expansion dynamics of the Cerrado's agrarian frontier and other processes, such as the availability of territories apt for mechanization, the abundance of hydrological resources for irrigation and low aggregate land value. According to Embrapa's GEO MATOPIBA database, between 2013 and 2018, R\$ 40.957.158.902,83 was allocated as rural credit for investments, funding, and commercialization.⁶⁴ Among these R\$ 18.718.705.803,31 was allocated to Bahia; R\$ 7.643.515.974,73 to Maranhão; R\$ 6.047.165.296,26 to Piauí; and R\$ 8.547.771.828,53 to Tocantins. In addition, it is worth mentioning other initiatives such as the federal Decree (nº 8.447, 6 May 2015) that

⁵⁸ Instituto Nacional de Pesquisas Espaciais (INPE), TerraBrasilis – PRODES (Desmatamento), 2020. Accessed 9 February 2021 <<http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/cerrado/increments>>.

⁵⁹ Carneiro Filho and Costa, *A expansão da soja*.

⁶⁰ Lorensini, Carolina Lobello; Daniel De Castro Victoria, Luiz Eduardo Vicente and Renan Pfister Maçorano, "Mapeamento e identificação da época de desmatamento das áreas de expansão da agricultura no MATOPIBA." *Anais XVII Simpósio Brasileiro de Sensoriamento Remoto - SBSR, João Pessoa-PB, Brasil*: 3542-3548, 2015.

⁶¹ Alana Almeida de Souza, Lênio Soares Galvão, Thales Sehn Korting and Juan Doblaz Prieto, "Dynamics of savanna clearing and land degradation in the newest agricultural frontier in Brazil," *GIScience & Remote Sensing* 57, no. 7 (2020): 965-984.

⁶² About the soy moratorium see Amaral, Daniel Furlan, Joaquim Bento de Souza Ferreira Filho, André Luis Squarize Chagas, Marcos Adami, "Expansion of soybean farming into deforested areas in the Amazon biome: the role and impacts of the Soy Moratorium." *Sustainability Science* 16 (2021): 1295-1312. About the increase in deforestation rates in the Cerrado see Nikolas Kuschnig, Jesús Crespo Cuaresma, Tamás Krisztin, and Stefan Giljum. "Spatial Spillover Effects from Agriculture Drive Deforestation in Mato Grosso, Brazil." *Scientific Reports* 11, no. 1 (2021): 21804.

⁶³ Stephanie Spera, "Agricultural Intensification Can Preserve the Brazilian Cerrado: Applying Lessons from Mato Grosso and Goiás to Brazil's Last Agricultural Frontier." *Tropical Conservation Science* 10 (2017): 1-7; Souza et al., "Dynamics of savanna clearing."

⁶⁴ Empresa Brasileira de Pesquisa Agropecuária (Embrapa), *GeoMatopiba: Inteligência Territorial Estratégica para o Matopiba – Crédito Rural*, 2020. Accessed 9 February 2021, <<https://www.embrapa.br/geomatopiba/sistemas/credito-rural>>.

launched the MATOPIBA Agricultural Development Plan and the creation of a guiding steering committee.⁶⁵

As previously indicated, the expansion of the soy frontier consisted of a complex dynamic of biogeographic relations, subjected to different variables. In this context, it is possible to notice that in 1974 about 87.59 per cent of the total production was concentrated in other biomes, with few exceptions in the Cerrado and the Amazon (figure 3). The increased value of soy on global markets since 1970 propelled the northward expansion of its agricultural frontier. In southern Brazil, where soy farming originates, producers faced issues with expanding cultivations given high land prices. In this context, the Cerrado became a valuable alternative, especially since the end of the 1970s, given the increased availability of cheap flatlands suitable for mechanized agriculture. This trend favored a great migratory exodus of southern farmers to central Brazil.⁶⁶

A second important factor were the technological innovations that favored the “conquest” of nature, as problems related to soy productivity were solved.⁶⁷ This process presented impressive results since the second decade of 1980, when the Cerrado hosted 43.08% of Brazil’s farmed area. Since 2000, this number has further increased to 50.77%. This same scenario presents another significant historical transformation, showing a substantial reduction in the participation of the Atlantic Rainforest in Brazilian food production, mainly comprised in the states of Rio Grande do Sul and Paraná. It is worth noting that this biome’s reduced participation did not mean a reduction in the plantation area, which experienced a growing trend at a much slower pace than the Cerrado and the Amazon. Comparing the three biomes’ classes under scrutiny, between 1974 and 2019, the Cerrado expanded at an average rate of 6.07%, and the Amazon at 15.02%, against the 1.53% of “other biomes.”

The year 2005 saw the Cerrado’s highest participation in terms of harvested soy (54.15%). By 2019 this indicator still amounted to 49.46%, with an average of 50.94% between 2000 and 2019 (a 0.02% average variance). The massive expansion of soy farming in the Cerrado significantly affected the biome’s vegetation landscape, with

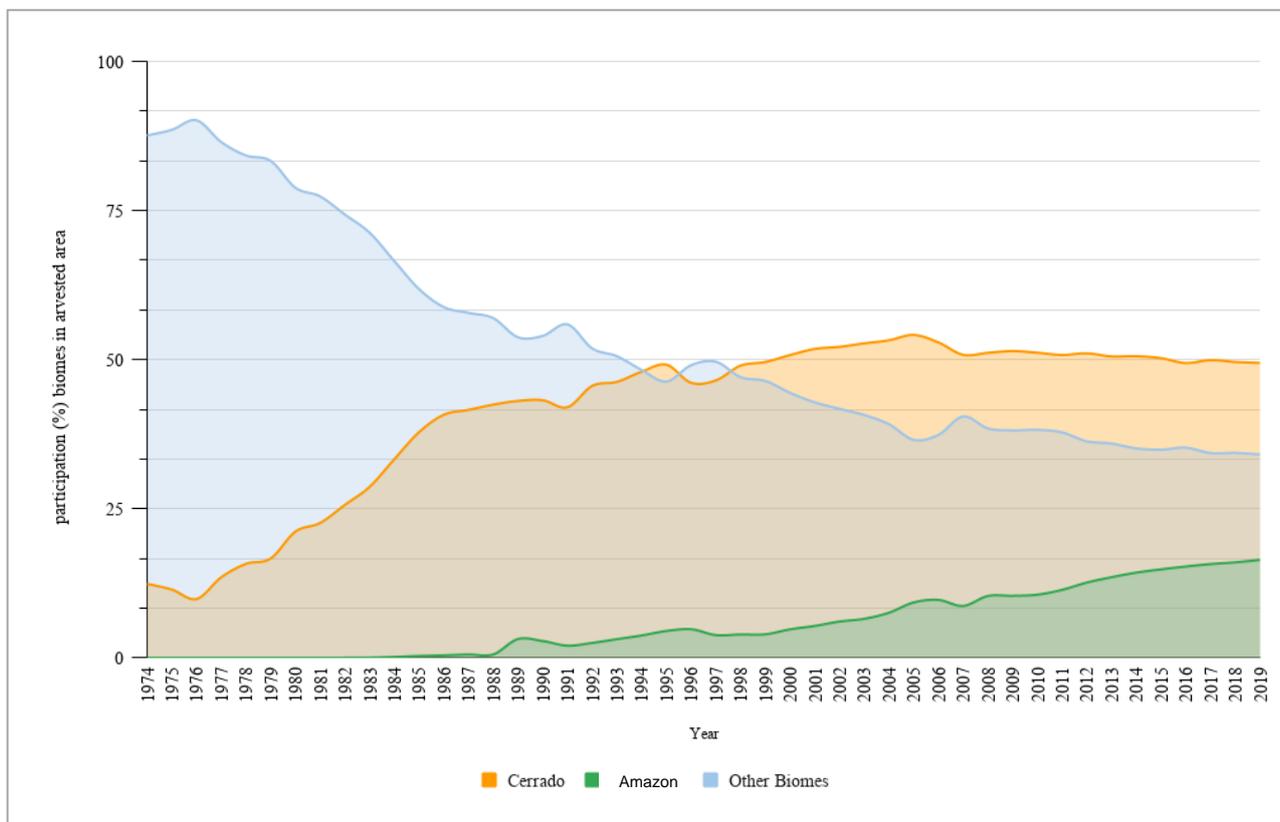
⁶⁵ Diário Oficial da União, *Plano de Desenvolvimento Agropecuário do Matopiba e a criação de seu Comitê Gestor (Decreto nº 8.447)* 1, no. 2 (2015). Accessed 9 February 2021, <<https://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=07/05/2015&jornal=1&pagina=2&totalArquivos=96>>.

⁶⁶ Dall’Agnol, *Embrapa soja*.

⁶⁷ Nehring, “Yield of Dreams.”

relevant transformations mostly concerning already anthropized areas, with the sole exception of Mato Grosso and MATOPIBA (see Map 1). In the state of Mato Grosso, the advancement of the soy frontier mainly involved native vegetation, significantly affecting deforestation rates on the Amazon borders. Between 2000 and 2007, soy expansion in the local native area amounted to 88%, later decreasing to 68% between 2007 and 2014.⁶⁸

Figure 3. Brazilian biomes' historical participation in soybean production by percentage of their harvested area (1974-2019) / Harvested area in millions of hectares (ha).



Data Source: Produção Agrícola Municipal – PAM/IBGE 1975-2019 (modified). Lista Município Bioma – IBGE 2019 (modified) Banco de Dados de Informações Ambientais – BDIA/IBGE 2020 (modified).

MATOPIBA and Mato Grosso are the two regions where increasing soybean farming exercises pressure at the Amazon borders. As shown by the data displayed below (figure 4), since 2005, the soy farming frontier has expanded more significantly in the Amazon biome, with a 9.30 per cent participation in the total production index. This process was a direct consequence of the already-mentioned 2006 Soy Moratorium, leading to the expansion of the soy frontier in Mato Grosso's border

⁶⁸ Carneiro Filho and Costa, *A expansão da soja*.

regions between the Amazon and the Cerrado (see Map 1).⁶⁹ Although between 2005 and 2013, the international community celebrated a 70 per cent decrease in deforestation rates in the Amazon, these numbers obfuscated the unprecedented destruction of 88 million hectares (Mha) in the Cerrado.⁷⁰ In other words, by prohibiting deforestation, the Amazon Soy Moratorium incentivized the expansion of soy farming in already deforested areas.⁷¹ Another specific frontier dynamic deriving from the Soy Moratorium that has often been overlooked was the westward shifting of cattle farming, as the increase of soy farming in the Cerrado progressively pushed this non-prohibited sector towards the Amazon's cheaper forested lands. Therefore, although soy farming might have strictly followed the Moratorium terms, it indirectly impacted deforestation rates in the Amazon by pushing the cattle frontier towards pristine forest areas and contributing to the arsons that invested both Mato Grosso and the Amazon between 2019 and 2020.⁷² While the Soy Moratorium demonstrated the potentially positive impact of private agreements between governmental actors and producers, the asymmetry between environmental policies and agricultural expansion data reflects the centrality of biogeographic relations in formulating land-use legislation and conservation.⁷³ For example, the need to preserve local biodiversity and indigenous territories demonstrates the importance of elaborating agreements like the Amazon Soy Moratorium in the Cerrado. Such measures could potentially avoid the loss of 3.6 million hectares of native vegetation, only reducing the total area of soy cultivation by 2 per cent until 2050. This could also contain the advancement of soy in the Amazon, considering the growing pressures to increase production in the region, despite the alleged commitment of private firms to environmental conservation.⁷⁴

⁶⁹ Holly Gibbs, Lisa L. Rausch, Jacob Munger et al. "Brazil's Soy Moratorium." *Science* 347, no. 6220 (2015): 377-378; Douglas Morton, Ruth DeFries, Yosio Shimabukuro et al. "Cropland Expansion Changes Deforestation Dynamics in the Southern Brazilian Amazon." *Proceedings of the National Academy of Sciences* 103, no. 39 (2006): 14637-14641; Marcia Macedo, Ruth DeFries, Douglas Morton, Claudia Stickler, Gillan Galford and Yosio Shimabukuro, "Decoupling of Deforestation and Soy Production in the Southern Amazon during the late 2000s." *Proceedings of the National Academy of Sciences* 109, no. 4 (2012): 1341-1346.

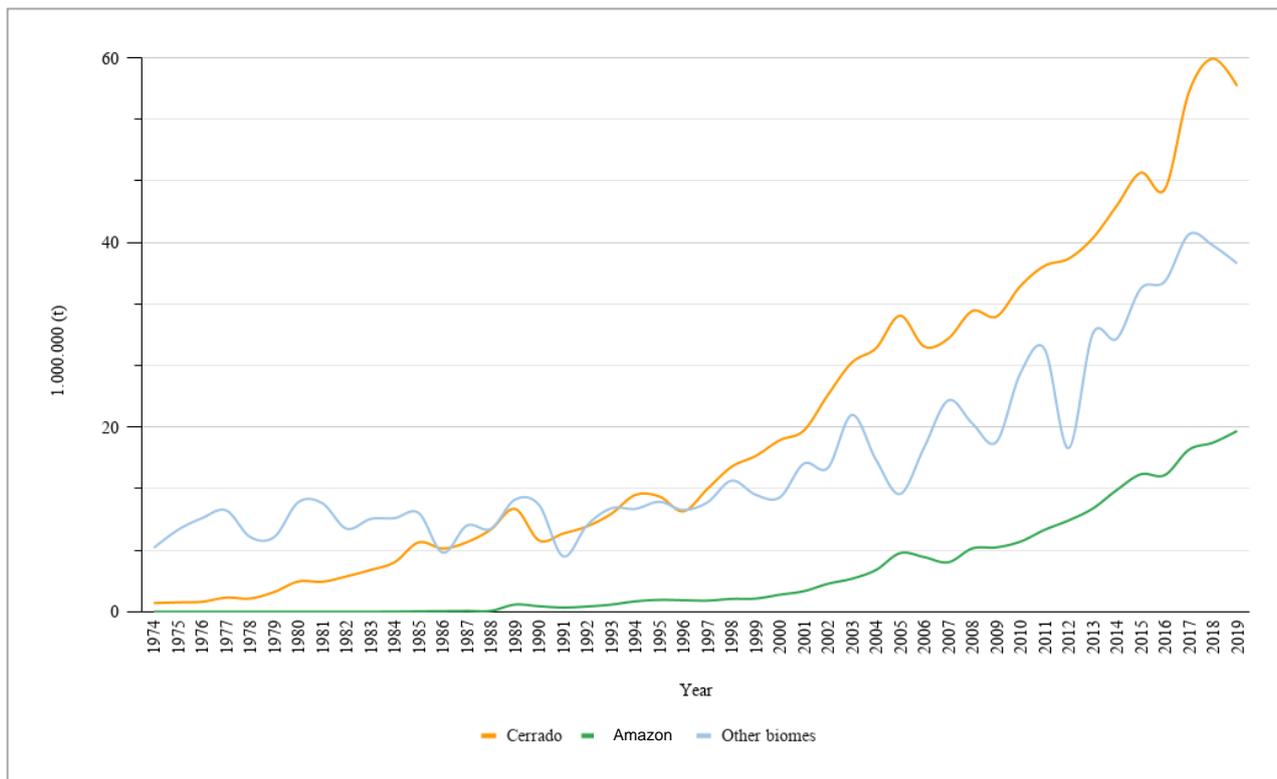
⁷⁰ This figure accounts for almost half of the biome's total surface, estimated around 200 Mha (see Strassburg et al., "Moment of Truth.")

⁷¹ Gibbs et al., "Brazil's Soy Moratorium."

⁷² Raoni Rajão, Britaldo Silveira Soares-Filho, Felipe Nunes et al., "The rotten apples of Brazil's agribusiness Brazil's inability to tackle illegal deforestation puts the future of its agribusiness at risk." *Science* 369, no. 6501 (2020): 246-248.

⁷³ Robert Heilmayr, Lisa L. Rausch, Jacob Munger, Holly K. Gibbs, "Brazil's Amazon Soy Moratorium reduced deforestation." *Nature Food* 1, no. 12 (2020): 801-810.

⁷⁴ Aline Soterroni, Fernando Ramos, Aline Mosnier, et al. "Expanding the soy moratorium to Brazil's Cerrado." *Science Advances* 5, no. 7 (2019): eaav7336.

Figure 4. Soybean production in Brazilian biomes in tons (1974-2019).

Data Source: Produção Agrícola Municipal – PAM/IBGE 1975-2019 (modified). Lista Município Bioma – IBGE 2019 (modified) Banco de Dados de Informações Ambientais – BDIA/IBGE 2020 (modified).

SOY COMMODITY MARKET-DRIVEN FRONTIER

The main factor currently influencing the expansion of the soy frontier is the commodity's increased relevance in international markets. In 2006 soy represented about 4.05% of Brazilian exports, with a total of U\$ 5.8 billion. By 2018 it became the main commodity in Brazil, responsible for 13.7 per cent of the total exports, generating revenues of U\$ 33.2 billion.⁷⁵ Another critical variable is the significant increase of pesticides, a relevant theme for the environmental history of the Cerrado.⁷⁶ Among the pesticides adopted in Brazil, about 60% are applied to transgenic crops. In the 2013/2014 harvest, more than 180 million liters of glyphosate were commercialized for genetically modified crops such as soy, corn, and cotton. The action of biotechnology

⁷⁵ OEC, *Brazil (BRA) Exports*.

⁷⁶ Denise Evangelista Teixeira, Vitor Santos Duarte, Hamilton Barbos Napolitano and Sandro Dutra e Silva, "A expansão da fronteira agrícola e a utilização do dicloro-difenil-tricloroetano (DDT) em Goiás (1940-1980)." *Revista Inclusiones* 6, no. 4 (2019): 280-300.

giants such as Monsanto, Bayer, DuPont, Syngenta, BASF, and Dow limit local farmers' autonomy, guaranteeing control of the international food industry.⁷⁷

The combination of cheap and vast farmable areas, ineffective land laws and governmental incentives have turned the Cerrado into a transnational soy farmers' frontier, attracting foreign investors, such as ranchers from the American Mid-West and Chinese entrepreneurs interested in the lucrative soy business.⁷⁸ China currently ranks as the primary buyer of Brazil's soybean commodities in the global market. In 2018 Chinese demand corresponded to 82.3 per cent of Brazilian soybean exports, with a total value of about US\$ 27,3 billion.⁷⁹ International pressure for Brazilian agrarian regulation has been aggressive, as witnessed by the Law Project n. 2.963 from 2019, aiming to limit foreign investors' capacity to purchase rural lands to 25% of the total area of a given municipality.⁸⁰

Regarding the historical advancement of soy production, our data documents the success of the Cerrado's agricultural model. For example, the estimates presented in figure 4 demonstrate that soy production increased from 944.138,00 tons in 1974 (about 11.99% of the national output) to 56.950.787,00 in 2019 (49.84% of national production). This data reinforces the values presented in figures 1 and 3 about the expansion of the harvested area. Regarding production, our data indicate that soy cultivation registered a steep increase since the second half of the 1980s (7.523.732,00 tons only in 1985). In general, figure 4 demonstrates that the volume of soy production in the Cerrado grew significantly over the last decades without experiencing significant downfalls.

⁷⁷ Issberner, Liz-Rejane; Léna, Philippe (ed.), *Brazil in the Anthropocene: Conflicts between predatory development and environmental policies* (New York: Routledge, 2018).

⁷⁸ Andrew Lehne Ofstehage, "Farming is easy, becoming Brazilian is hard: North American soy farmers' social values of production, work and land in Soylandia." *The Journal of Peasant Studies* 43, no. 2 (2016): 442-460; "From US Farm Crisis to the Cerrado Soy Frontier: Financializing Farming and Exporting Farmers," in *Land Justice. Re-imagining Land, Food, and the Commons in the United States*, ed. Justine M. Williams and Eric Holt-Gimenez, 174-189 (Oakland, CA: Food First Books/Institute for Food and Development Policy, 2017); "Financialization of work, value, and social organization among transnational soy farmers in the Brazilian Cerrado." *Economic Anthropology* 5, no. 2 (2018a): 274-285; "Farming out of place: Transnational family farmers, flexible farming, and the rupture of rural life in Bahia, Brazil." *American Ethnologist* 45, no. 3 (2018): 317-329; Lorena Izá Pereira and Lucas Pauli, "O processo de estrangeirização da terra e expansão do agronegócio na região do MATOPIBA." *CAMPO-TERRITÓRIO: revista de geografia agrária* 11, no. 23 (2016): 196-224.

⁷⁹ OEC, *Brazil (BRA) Exports*.

⁸⁰ Agência Brasil, *Senado aprova venda de terras para estrangeiros*, 2020. Accessed 6 February 2021, <<https://agenciabrasil.etc.com.br/politica/noticia/2020-12/senado-aprova-venda-de-terras-para-estrangeiros>>; Almeida, Maria Cecília Ladeira de. *Considerations on the draft law nº 2.963, from 2019 – Acquisition of rural property in Brazil, by non-Brazilians*. Animal Business Brasil. Sociedade Nacional de Agricultura. Seção: Suplemento Internacional, 2021. Accessed 3 February 2021, <<https://animalbusiness.com.br/colunas/suplemento-internacional/considerations-on-the-draft-law-n-o-2-963-from-2019-acquisition-of-rural-property-in-brazil-by-non-brazilians/>>.

On the other hand, the “other biomes” – mainly represented by the Atlantic Rainforest – experienced upward trends, although with several adverse fluctuations over the last years.⁸¹ In the Cerrado, the most significant production outage was registered in 1990, with a negative variation of just 3.413.276,00 tons compared to 1989. In contrast, the major growth index was recorded in 2017, with a positive variation of 10.509.987,00 tons compared to the previous year. Conversely, the major production volume was registered in 2018, with soy production reaching 59.922.069,00 tons.

The combination of datasets on production volume and harvested area demonstrates the dynamics of the soy frontier in terms of its geographic enlargement and the grain’s expressive ton indexes. Another relevant variable concerns productivity indexes. Without productivity improvements, soy farming would not present itself as an economically viable alternative, especially considering the relation between production and market costs. Figure 5 provides a historical estimation of average productivity gains in each biome. In 1975 the Cerrado’s average yields totaled 1.438,00 kg per hectare, a digit elevated to the impressive amount of 2.100,00 kg/ha in 1994 and reaching 3.060,00 kg/ha by 2019. When comparing such numbers with the Amazon, one could notice a slight edge of this biome in average productivity levels, despite a low index in 1974 (1.200,00 kg/ha). However, in 1994, average yields surpassed the Cerrado with 2.244,00 kg/ha, reaching 3.200,00 kg/ha in 2019. As far as “other biomes” are concerned, average yields in 1974 exceeded the Cerrado and the Amazon with 1.500,00 kg/ha. Such an advantage can be explained by the initial stage of Embrapa’s research endeavors and the lack of substantial insights on soil quality, climate, and other critical auxiliary variables for agronomic development. In the following years, such improvements figured in every biome, with average yields estimated at around 1.980,00 kg/ha in 1994 and 3.100,00 kg/ha in 2019. Finally, by comparing the productivity gain peaks of different biomes, it is possible to observe a 2017 record yield of 3.470 kg/ha for “other biomes.” However, while “other biomes” demonstrate a historical peak in

⁸¹ The main negative trend was registered between 2011 to 2012, with a total drop of 10.768.643,00 tons. Two of Brazil’s major soybean producer states, Rio Grande do Sul and Paraná, are in the Atlantic Rainforest. Note that there is a relationship between Figure 4 and Figure 5 (production versus productivity). The production oscillations evidenced are related to the productivity drop which is more pronounced in 2004 and 2012. Both in 2004 and 2012 production reduction was due to the lack of rainfall. In Rio Grande do Sul, productivity reduced by about 48.4 per cent and Paraná, at the time the second largest soybean producer in Brazil, only participated with 16.6 per cent in the national soy production effort. See Canal Rural, “IBGE revê para baixo a produção da safra 2012 de soja,” 05/06/2012. Accessed 29 July 2022, <<https://www.canalrural.com.br/noticias/ibge-reve-para-baixo-producao-safra-2012-soja-37732/>>.

productivity gains, the Cerrado and the Amazon present a much lower negative variation degree in productivity. Overall, the productivity gains displayed in figure 5 serve as valid indicators to register the scientific advancement that favored the Cerrado's swift agronomic development, particularly impressive considering the substantial skepticism until the late 1960s.

Figure 5. Average soybean yield in the Cerrado kg/ha (1974-2019).



Data Source: Produção Agrícola Municipal – PAM/IBGE 1975-2019 (modified). Lista Município Bioma – IBGE 2019 (modified) Banco de Dados de Informações Ambientais – BDIA/IBGE 2020 (modified).

FINAL CONSIDERATIONS

A pessimistic perspective concerning the Great Acceleration has estimated that current production tendencies are insufficient to satisfy the future global demand for soy, also in concurrence with the increase of dietary regimes based on animal proteins.⁸² Meanwhile, the progressive shifting of rural markets towards technoscientific solutions aimed at satisfying global demand for food could constitute a significant risk factor in terms of food security and natural conservation.⁸³

⁸² Walter Willett, Johan Rockström, Brent Loken et al., "Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems." *The Lancet Commissions*. 393, no. 10170 (2019): 447-492.

⁸³ Scruton, *Green Philosophy*.

Unfortunately, such issues have not always been adequately considered when estimating the economic revenues of agricultural frontiers. This constitutes an excellent example of the Brazilian agricultural revolution in the Cerrado, especially concerning the complex historical processes that led to the expansion of the country's agricultural frontier in supposedly inadequate territories. Until the last decade, normative efforts substantially overlooked the Cerrado and other non-forested native ecological formations. Instead, aesthetic notions of landscape influenced conservation and land-use policies, drawing a concise distinction between forests and grasslands formations, such as the Brazilian tropical savannah.⁸⁴

From an eminently agronomic perspective, the history of the Cerrado's agrarian frontier constitutes a successful example of how to economically profit from a savannah ecosystem, whose non-forested ecological formation formed a perfect setting for the inception of industrial agriculture. Furthermore, the conquest of nature appears evident when looking at the indicators that point to new global transformations in food production, combining the possibility of multiple harvests, cost reduction, mechanization facility, and adaptation of seasonal rain patterns, soil acidity and plague control as well as better land utilization. In this sense, our data on soy production points to the Cerrado as a new global breadbasket with great potential in both production and productivity. For example, soy production in the Cerrado reached 70.399.981 tons between 1974 and 1989, 117.999.839 between 1990 and 1989, 272.219.950 between 2000 and 2009 and 461.969.430 between 2010 and 2019. According to these estimates, the Cerrado accounts for 49.18 per cent of the country's total soy production, 922.589.200,00 tons out of a total 1.875.855.459,00.

Considering the country's complex biogeographic relations, our results show that Cerrado's increased participation in the total amount of soy production is not the result of a production decrease in other biomes, which also continues to expand. Instead, the average increase of the harvested area – and consequently of production rates – in each biome between 1974 and 2019 is the result of different time-space relations, respectively 9% in the Cerrado, 15% in the Amazon and 1.60% in “other

⁸⁴ Dutra e Silva, Sandro, “Environmental History of the Cerrado.” *Oxford Research Encyclopedia of Latin American History* (forthcoming in 2022). About recent efforts to defend non-forested bioregions such as the Cerrado see *The Cerrado Manifesto* (<https://cerradostatement.fairr.org/>) and *Campanha Nacional em Defesa do Cerrado* (<https://campanhacerrado.org.br/>).

biomes.” In this context, the Amazon’s rapid growth rates stand out, despite its relatively modest participation in national production rates (10.33%). Overall, it appears evident that the soy frontier is still expanding in every Brazilian biome. Meanwhile, the Cerrado has registered the highest numbers, hosting almost half of the total harvested area (49.46%) and total production (49.84%) by 2019. Keeping in mind the complexity of biogeographic formations and their composite relations, the Cerrado’s soy farming expansion demonstrates a progressive advancement toward the Amazon. In this context, historical studies need to consider frontier dynamics in light of their biogeographic context.⁸⁵ This research has shown a substantially lacking tendency towards restricting or interrupting the expansion of soy farming in the Cerrado. The effects of these transformations are particularly problematic if biogeographic formations are merely analyzed in relation to their landscape and not in their complex ecological entanglements. While our analysis has primarily assessed land cover, land-use changes and the impact of the soybean frontier on natural forest covers, future studies could draw from these findings to analyze other aspects that our research has partly omitted. Potentially engrossing future research lines include the impact of expanding soybean monocultures on traditional farming practices and shifting patterns of water utilization. Moreover, satellite-based remote sensing tools might be employed to assess the patterns of illegal land dispossession to the expense of local farming communities.

The Cerrado, therefore, is an endangered biome since the Brazilian environmental legislation continues to consider it as a strategic region for agribusiness development. Historically, Brazilian environmental movements have privileged forests for environmental protection campaigns, looking at the Cerrado as an agronomic alternative for conservation. Despite initiatives such as the Proposal for Amendment to the Constitution (PEC) 504 of 2010 – which aims to change paragraph 4 of article 225 of the Federal Constitution to include the Cerrado and Caatinga among the national biomes heritage – the Cerrado continues to embody a commodities breadbasket par excellence. As soybean expands throughout the biome, especially in areas such as

⁸⁵ Dutra e Silva, “Challenging.” Primary Sources

MATOPIBA, the consequences of the destruction of this natural environment increasingly affect adjacent bioregions.

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Uma Análise Geográfica e Histórica da Expansão da Fronteira da Soja no Cerrado Brasileiro

RESUMO

Até a década de 1970, o Cerrado brasileiro era considerado um território impróprio para o desenvolvimento agrônômico. Questões logísticas e de infraestrutura, aliadas à acidez do solo, tornaram o Cerrado um bioma marginal para a produção agrícola. No entanto, desde a criação da Empresa Brasileira de Pesquisa Agropecuária (Embrapa) em 1973, o Cerrado tem se transformado em um hotspot nacional e internacional para a produção de grãos e commodities. Dentre os principais produtos responsáveis pelo potencial agrícola do Cerrado destacamos o papel da soja, considerando as complexas inter-relações entre a dinâmica da fronteira de commodities e sua interface nos diferentes biomas brasileiros. Comparando dados do Cerrado e de outros biomas, nossos resultados indicam uma rápida expansão da fronteira da soja na maioria das regiões biogeográficas brasileiras. Além disso, demonstra como o crescimento da soja no Cerrado brasileiro também está afetando outros biomas como a Amazônia, influenciando as políticas locais e nacionais de expansão agrária e conservação ambiental.

Palavras-chave: cerrado; soja; fronteira agrícola; biomas; Embrapa.

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