

BRAZILIAN INDUSTRIAL-SCALE AGRICULTURE: A
LONGITUDINAL GEOSPATIAL ANALYSIS OF SOY BEAN
PRODUCTION IN MATO GROSSO

by

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A THESIS

Presented to the Department of Environmental Studies
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Arts

May 2025

An Abstract of the Thesis of

Nathan Gregory King for the degree of Bachelor of Arts
in the Department of Environmental Studies to be taken May 2025

Title: Brazilian Industrial-Scale Agriculture: A Longitudinal Geospatial Analysis of Soybean
Production in Mato Grosso

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In July 2006, following mounting domestic and international pressure, two major Brazilian associations of soybean corporations announced a new agreement deemed the Soy Moratorium (SoyM). Under the agreement, members of these organizations would not purchase—and, thus, not process or sell to global or domestic markets—any soybeans produced on land deforested from the Legal Amazon after July 2008. In the following years, Amazon Rainforest deforestation rates dropped significantly. Yet, despite this, soybean cultivation in Mato Grosso, Brazil (MT) continued to expand, seeing a near doubling in total land planted from 2005 to 2023. International researchers and the Brazilian government alike agreed that there has been compliance with the SoyM. If this is true, then where is soybean cultivation occurring? And why has Mato Grosso, of all places, become the hotspot for soybean expansion? In this study, I perform a longitudinal geospatial analysis on microregion scale soybean data in Mato Grosso, Brazil between the years of 2006 and 2022. Using Municipal Agriculture Production (PAM) data, I find regions with significant expansion in Mato Grosso during the study period. I also provide theory and compile available literature to determine why Mato Grosso has experienced such a rapid agricultural transformation.

Acknowledgements

Thank you to my advisor, Dr. David Meek, for your invaluable guidance, critique, and mentorship throughout this long process. Thank you for jumping on board on day one and continuing through to the end. Your guidance through this process has shaped and reshaped my understanding of what research is and can be. Thank you for always speaking with intention.

Thank you to Dr. Jean Faye, who willingly joined this project at the drop of a hat. I am incredibly grateful for your flexibility and interest in my work.

To my dear friend and advisor, Bjørn Kristensen, for your keen ability to broaden my contemplative mind. I am now more considerate of our human and non-human friends than previously imagined. Thank you for your writing and organizational advice, and for your kind words.

With great warmth, I extend gratitude to my advisor, Dr. Yalda Asmatey, for your unconditional embrace of the good and your dedication to justice. Your faith in my person is nothing shy of inspiring.

To my partner in love, Mia Owen, for your sensibility and patience. Thank you for supporting me while I dedicated myself to this project. I admire your ability to pace yourself. Thank you for asking me to take a break. *Para siempre, mi amore.*

To my parents, for your most excellent contributions to my life and education, and for arriving into each day with such love and dedication. *Sí, claro.* To my brothers, for your switching of hats. I appreciate your enthusiasm and continual interest in whatever it is I want to share so intently with you. May we be bozy for as long as we live. *Soy gardísimo.* And to my friends, peers, instructors, coworkers, and employers, thank you for the brush stroke you each have contributed to the painting of my person. I am indebted to each of you.

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List of Abbreviations

ABIOVE	Associação Brasileira das Indústrias de Óleos Vegetais [The Brazilian Vegetable Oil Industries Association]
ANEC	Associação Nacional de Exportadores de Cereais [The National Grain Exporters Association]
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária [Brazilian Agricultural Research Corporation]
IBGE	Instituto Brasileiro de Geografia e Estatística [Brazilian Institute of Geography and Statistics]
GMOs	Genetically Modified Organisms
MST	Brazilian Landless Workers Movement
MT	Mato Grosso
NPK	Nitrogen (N), phosphate (P), and potassium (K)
PAM	Produção Agrícola Municipal [Municipal Agriculture Production]
SIDRA	Sistema IBGE de Recuperação Automática [Automatic Recovery System of the IBGE]
SoyM	Soy Moratorium
U.S.	United States of America

Introduction

In July 2006, two major Brazilian associations of soybean corporations, the Brazilian Vegetable Oil Industries Association (ABIOVE) and the National Grain Exporters Association (ANEC), announced a new agreement deemed the Soy Moratorium (SoyM). Under the agreement, members of these organizations would not purchase—and, thus, not process or sell to global or domestic markets—any soybeans produced on land deforested from the Legal Amazon rainforest after July 2008. The majority of analyses conducted after the SoyM have found a high level of compliance with this agreement (Klein and Luna). Yet, somehow, Brazil has continued to increase both its soybean production and the amount of land planted in soybeans in the decades following the SoyM (IBGE).

The state of Mato Grosso, Brazil (MT) has seen the most rapid expansion of land planted in soybeans out of any Brazilian state. Since 2005, MT has nearly doubled the amount of land planted in soybeans, from 6.21 million hectares (or 6.67% of the state's total area) to 11.98 million hectares (or 13.3% of the state's total area) in 2023 (IBGE). According to both the Brazilian government and international researchers, this post-SoyM expansion is not occurring on deforested land. If this is true, then where in Mato Grosso is soybean cultivation expanding? And why has Mato Grosso become the hotspot for soybean expansion?

To address these questions, I begin with a literature review that compiles the history of Brazilian agriculture with practices in use today. I include an explanation for the selection of soybeans over other crops for Brazilian agriculture, including the adaptation of soybeans to the tropical climate of MT and the subsequent widespread application of pesticides and herbicides. I then conduct a longitudinal geospatial analysis of soybean cultivation, highlighting regions with significant expansion. I conclude with suggestions for the furthering of this research.

Literature Review

I begin this section by providing background knowledge on Brazil. I discuss Brazilian agricultural history and the history of agricultural transformation. I then introduce the agricultural history of Mato Grosso. I explain the selection of the soybean as the primary crop in Mato Grosso, and provide detailed reasoning for the selection of soybeans over other crops. I conclude with a brief comment on the global soybean market.

Brazil

Geography, Climate, and Society

Brazil is the fifth largest nation in the world by land area and the seventh largest by population. Brazil covers 8,515,700 km² of area, making it roughly the same size as the contiguous United States (8,080,464 km²). Brazil has the largest area of arable land out of any nation in the world. See **Figure 1**. As of 2024, the Brazilian population was around 212.4 million people, making it roughly 60% the size of the population of the United States, which sits at around 340 million people (IBGE; U.S. Census).

Brazil contains six distinct terrestrial biomes: the “Amazon (tropical rainforest), Caatinga (semi-arid vegetation), Cerrado (savanna-like vegetation), Pantanal (wetlands), Atlantic Forest (system of forests and ecosystems under the influence of the Atlantic Ocean) and Pampa (grasslands)” (Ellwanger et al.). The majority of Brazil experiences a tropical climate. The Amazon Rainforest is known internationally for its high biodiversity and status as a major carbon stock¹ (Morton et al.). Brazil has varied geomorphologic structures which include highlands, mountain ranges, basins, and complex river networks, among others.

¹ Carbon stock refers to a regions ability to capture and store carbon dioxide.



Figure 1. Brazil overlaid on a map of the United States. Drawn to scale.

Brazilian society currently experiences structural issues pertaining to race inequality, gender inequality, medical availability, violence, political corruption, public education, and wealth inequality. While Brazil is not a poor country—neither in economic prosperity nor natural resources—wealth is not evenly distributed, resulting in a high rate of poverty. Brazil has one of the highest indices for social inequality in the world (Ellwanger et al.).

Welcome to Brazilian Agriculture

In the 1950s, traditional, small-scale agricultural was the dominant practice across Brazil, with regional variety determining the size of farm and type of crops grown.² Excess crops were sold at local markets and only select few crops were exported to global markets. This resulted in little wealth entering the agricultural sector from outside of Brazil. Due to the poor agrarian system and relatively weak economy during this time, malnutrition and related post-neonatal death rates were high across the country. Brazil relied on the importation of agricultural goods to support its population (Klein and Luna).

² Regional variability is and was high (Klein and Luna).

Over the last seventy years, Brazil has radically transformed its agricultural sector. Today, Brazil is the world's leading exporter of soybeans, maize, sugar, orange juice, meat, coffee, tobacco, and ethanol, among others. Brazil is the largest net exporter of agricultural goods in the world (Klein and Luna).³ This transformation is considered by some to be one of the most significant developments in modern history (Klein and Luna). In the following section, I will introduce the key developments that allowed for Brazil's agricultural transformation.

The military government that took control of Brazil in 1964 viewed the agricultural sector as the primary impediment to the development of the country. Through their "conservative modernization" reform program, they poured government resources into updating the agriculture sector. They saw to the mechanization of farming by providing modern equipment to farmers. Equipment was imported from the global market. The government realized that simply using global-north agricultural techniques and machinery in Brazil would not work due to the vastly different ecoregions and climate of Brazil (Klein and Luna).

To combat this, the government formed the Brazilian Agricultural Research Corporation (*Empresa Brasileira de Pesquisa Agropecuária*; hereafter, Embrapa) in 1973, an organization tasked with revolutionizing the agricultural system. The organization's early research focused on adapting global-north agricultural technology and techniques to the differing demands of tropical farming (Embrapa). Their goal was to increase domestic food security, reduce poverty, and grow the Brazilian economy. Government programs funded research both at private institutions (like Embrapa) and at public Brazilian universities. This program survived the 1985 military coup d'état and is still in operation today (Klein and Luna).

³ In other words, Brazil turns the largest relative profit on exports versus imports to the global market.

Through their research, Embrapa developed and adapted a number of technical and mechanical advancements that aligned with Brazilian climates and ecoregions. Of these, Direct Planting Agriculture (often referred to as no-till), double-cropping, and the application of synthetic fertilizers and pesticides were three of the most significant.

No-till farming, when compared to till-based agriculture, is more time and energy efficient, leaves the soil intact, reduces evaporation, increases soil health, and allows for better water infiltration. Brazil led the global movement in no-till farming as one of the first nations to widely adopt the strategy. Double-cropping is a technique of planting a crop in the on-season and off-season on the same field. Double-cropping using soybeans (on-season) and corn (off-season) became popular in Brazil, particularly in drier regions. This technique led to higher production and productivity (Klein and Luna). Synthetic fertilizers and pesticides became increasingly widespread in Brazil in the decades following the recommendation for their usage from Embrapa. These chemical compounds increase the productivity of plants by reducing competition and providing additional nutrients.⁴ Today, synthetic fertilizers and pesticides are applied to the vast majority of cultivated fields (Klein and Luna).

Deforestation has also been a major driver in agricultural transformation. Large-scale deforestation primarily occurred in the Amazon Rainforest and Atlantic Forest. Approximately two-thirds of the Amazon forest is in Brazil, where it is referred to as the Brazilian Legal Amazon. Over the last 50 years, the Brazilian Amazon has lost about one-fifth of its forest cover. During much of this period, the Brazilian government incentivized the cutting down of trees to spread agricultural land, increase population, and stimulate the economy. Due to these incentives, each year from 1996 to 2005, an estimated 19,500 km² of forested land was converted

⁴ They also have serious downsides, which I will discuss later.

into agriculturally productive land (Tremblay et al.). This incentivization is no longer practiced today⁵ (Klein and Luna).

Agricultural Transformation and Urbanization

Agricultural land-use transformation brought with it a rapidly increasing population and a disproportionate rate of urbanization. In the 1940s, only 31.2% of Brazil's population lived in urban areas. The rural population then accounted for 68.8% of Brazil's total population (IBGE; Martine and McGranahan). By contrast, urban areas today house approximately 88.4% of Brazil's population,⁶ leaving approximately 12.6% of the population living in rural areas (IBGE).⁷ See **Figure 2**. Brazil now has a higher rate of urbanization than the United States and nations in the European Union (Konchinski).

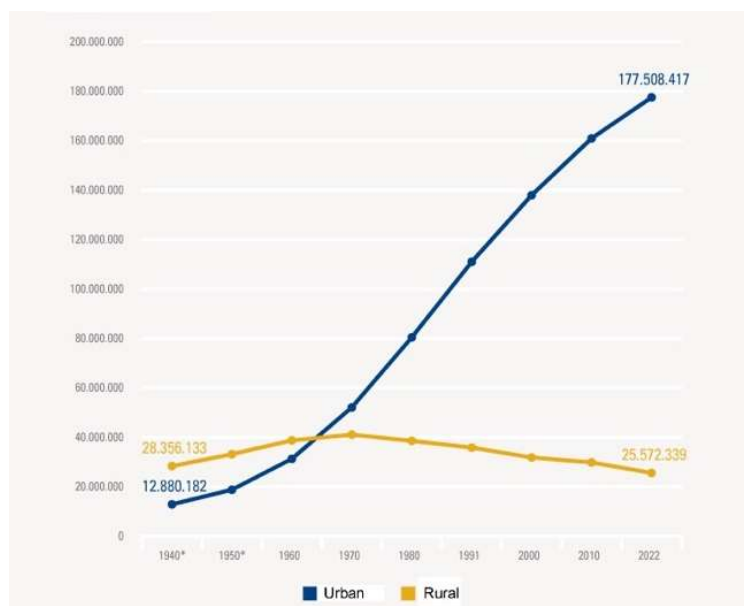


Figure 2. Urban and rural population in Brazil from 1940 to 2022 (IBGE).

Urbanization began to accelerate during the 1964 to 1985 military regime when farmers were forcibly removed from their land to allow rural elite to own larger farms. Rural Brazilians

⁵

⁶ Brazil's urban population is approximately 177.5 million people as of 2025 (IBGE).

⁷ For reference, the United States population is split 80.0% urban and 20.0% rural, with 272.1 million and 68.0 million living in urban and rural areas, respectively (Barrett).

were encouraged to move to urban spaces due to a combination of inadequate medical and educational availability, infertile soil, strict social order, and very little economic mobility (Dawsey). Despite the motivations for moving to urban centers, many urban Brazilians continue to suffer from poor education and quality of life.⁸ As more rural Brazilian's moved to urban centers in search of a better life, the already existing socioeconomic gap grew larger.

To push back against the forced evictions, farmers responded by joining together to enact agrarian reform groups. The Brazilian Landless Workers Movement (MST) is a predominant agrarian reform group that occupies unproductive land until they win land rights (Meek et al.).

Mato Grosso

The state of Mato Grosso is located in central western Brazil. It is the third largest state by area, with a total of 903,357 km². The state is home to three major ecoregions. The northern part of the state is dominated by the Amazon ecoregion, known for being the world's largest rainforest and harboring roughly 20% of known plant and animal species (Klein and Luna); to the south lies the Pantanal ecoregion, a well-preserved continental wetland covering 160,000 km² in Brazil, Bolivia, and Paraguay (Ribiero and Pereira); to the southwest stretches the Cerrado ecoregion, a biologically diverse tropical savanna (Bonanomi et al.).⁹ See **Figure 3**. The climate is predominantly tropical, with a rainy season that lasts from September to April.

MT is currently the leading producer of soybeans out of any Brazilian state.¹⁰ In 2023, for example, the state produced roughly 27.4% of Brazil's total soybean exports (in tonnes), despite

⁸ The state has been making it extremely difficult for those living rurally to receive education. Since 1995, the state closed 142,401 rural schools which accounted for 65% of all previously open rural schools (Meek et al.)

⁹ The Cerrado region is considered to be the most biologically diverse savanna in the world (Bonanomi et al.; Klein and Luna).

¹⁰ MT produced 44.4 million tons of soybeans in 2023; Paraná produced the second largest quantity of soybeans with 21.5 million tons (IBGE).

only occupying 3.5% of Brazil's total land area. MT is also the leading producer of maize and cotton (IBGE). It produces a number of other commodity crops, but maintains a less significant portion of the overall Brazilian exports.

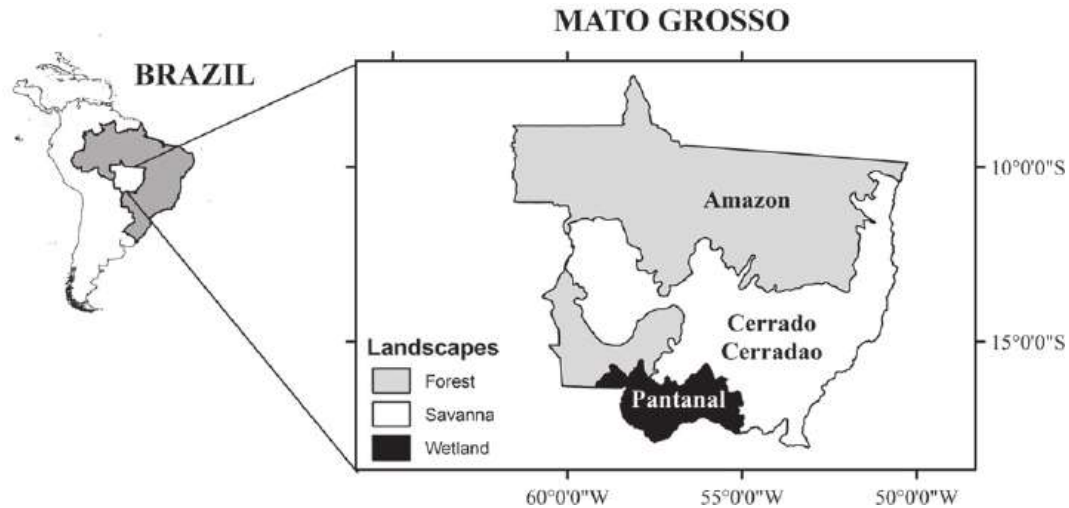


Figure 3. Map of ecological regions in Mato Grosso (Lathuilliere et al.).

Agricultural History

The agricultural history of Mato Grosso, while loosely paralleling that of Brazil, also has significant divergence from the trend. In the 1970s, when much of Brazil began seeing serious agricultural transformation, MT lagged behind. This was largely due the small relative population (~600,000 residents compared to the ~3.5 million residents today) and lack of transportation infrastructure (IBGE). The state was covered in dense Cerrado vegetation in the south and the near-impassable (for commercial means) Amazon Rainforest in the north. At the time, there was no easy way to travel in MT and, thus, no easy manner of exporting goods to state, national, or international markets.

To add to the transportation concerns, the commodity crop seeds that were in use in the southern states at the time did not respond well to Mato Grossian soil. The soil of MT, particularly in the Cerrado, is acidic, metal-heavy, and nutrient-poor, rendering commodity crops unproductive (Garrett and Rausch; Embrapa).

Despite the initial failings of agriculture in Mato Grosso, Embrapa and the Brazilian government saw the potential of turning MT into an agricultural powerhouse. They believed that if the technical, mechanical, and transportation issues were to be resolved, MT offered a highly arable and minorly populated stretch of land, with gentle topography and high physical remoteness (Cabral; Klein and Luna).

Embrapa began working intensively in the 1970s and 1980s to bring technical and mechanical developments to the region. They offered competitive salaries, trained their researchers at top U.S. and Brazilian universities, and set to work to develop soybean cultivars that could be grown in the tropical climate offered by the Cerrado. The success of the soybean over other commodity crops at adapting to the Cerrado has been largely chalked up to its biological nitrogen fixing ability and the research of Johanna Döbereiner, who is credited with developing the first successful tropical soybean cultivar (Cabral).

With Cerrado-ready seeds at their fingertips, the Brazilian government saw to the migration of experienced soybean farmers from southern states to Mato Grosso. The federal military government provided subsidies and aid to farmers, providing financial aid at extremely reasonable rates for operation costs (Klein and Luna; Cabral). The migration that occurred in the 1980s would double the population of Mato Grosso. The 1990s would see a similar doubling of population, with the total population crossing 2.5 million people around the year 2000 (IBGE).

Two major global developments that occurred in the following years would further explode the expansion occurring in Mato Grosso. First, Monsanto released a genetically modified variety of soybeans that was resistant to a glyphosate pesticide in 1996. While this original varietal was, like most soybean varietals, unsuccessful in Mato Grosso, Embrapa and Monsanto collaborated to develop a glyphosate-resistant soybean varietal that took to Mato

Grossian soil. The second development was the entering of China into the World Trade Organization in 2001. China would begin buying the majority of Brazil's soybean exports (Klein and Luna). This economically incentivized the further development in the Cerrado and the agricultural expansion into the Amazon Rainforest.

The expansion and transformation that began in the 1970s and 1980s continued at full force through the 1990s and into the early 2000s. Deforestation and linked agricultural expansion continued at increasing rates. When land experienced deforestation, the immediate land-use type was principally cattle ranching. Soybean cultivation would often follow roughly 2-5 years after cattle were first introduced to the land. Between the 2000 and 2005, soybeans accounted for 12% of the primary land use following deforestation, with the remaining 88% majorly dominated by cattle ranching (Defries et al.).

In the early 2000s, Mato Grosso and other southern Amazon states gained international and domestic attention due to their extremely rapid rates of deforestation. Organizations called for the Brazilian government to step in and put an end to the rapid deforestation that defined the last three decades of agricultural expansion. Through a civil, industrial, and governmental agreement, a new agreement deemed the Soy Moratorium (SoyM) was announced. Under the agreement, members of soybean organizations ABIOVE and ANEC would no longer purchase any soybeans produced on land deforested from the Legal Amazon rainforest after July 2008.

The majority of analyses conducted after the SoyM have found a high level of compliance with this agreement (Klein and Luna).

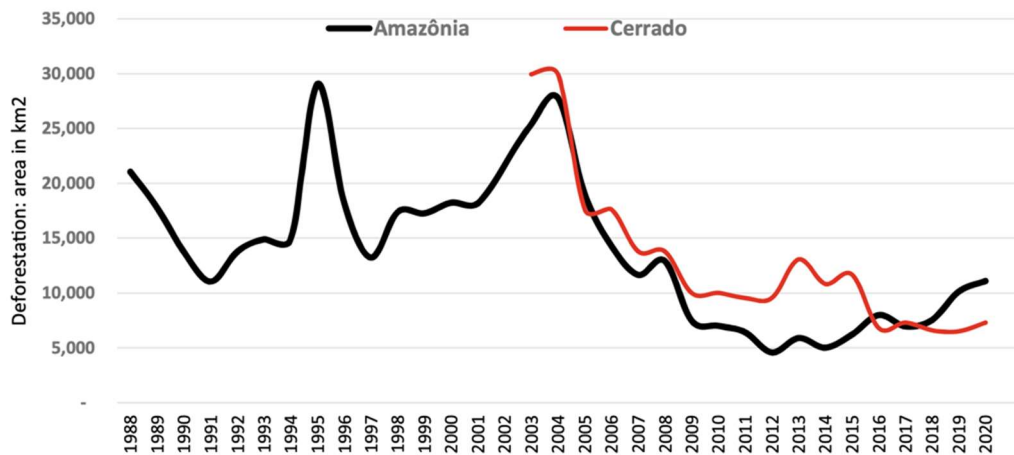


Figure 4. Deforestation annually in the Amazon and Cerrado ecoregions (Klein and Luna).

Note the reduction in Amazon deforestation following the SoyM in 2006.

The Cost of Agricultural Expansion

The SoyM has received criticism for only protecting land-use change in the Amazon biome. The Cerrado ecoregion, while also containing forested land and high biodiversity, has largely gone unobserved by the international community (Bonanomi et al.). Native vegetation conversion in the Cerrado has some researchers suggesting that the SoyM should be expanded to the Cerrado ecoregion, to further reduce the long-lasting ecological damages of agricultural expansion (Soterroni et al.). Additionally, some studies have found that soybean production on post-SoyM deforested land has continued in Mato Grosso, indicating that the SoyM may not be as successful as is purported by the Brazilian government and researchers (Nunes et al.; Klein and Luna; Binswanger).

The Brazilian government focused all efforts on expansion and global exportation of commodity crops. They saw the lucrative potential of deforestation and land-use change, and

they realized these changes rapidly. The land-use change transformation of Mato Grosso brought with it a rising concern and attention from both domestic and international communities.

Between 2000 and 2006, international governments and NGOs became increasingly aware of the massive, rapid deforestation occurring in the Amazon Rainforest. During this time, Mato Grosso saw a 43% increase in net area cropped (Arvor et al.).

The now agricultural land was previously occupied by humans, plants, and animals. Humans living in Mato Grosso were evicted from their land holdings and forced to vacate. Indigenous groups were disproportionately affected by these evictions (Garrett and Rausch). Plants and animals also have and will be experiencing removal from land. Due to the extreme biodiversity of the Cerrado and Amazon Rainforest, the undocumented extinction of species is extremely likely. Species extinctions often take many generations, implying that the future extinction of species currently at risk is highly likely. While estimates vary, there is the possibility of hundreds or thousands of undiscovered plant and animal species living in the Cerrado and Amazon Rainforest in Mato Grosso. Their extinctions could easily go unnoticed as agriculture continues to expand (Klink and Machado; Klein and Luna).

The Soybean

Throughout Brazil's agricultural transformation, the importance of one product shines above the rest: the soybean. Soybeans (*Glycine max*) are a type of edible legume (Messina). Native to East-Asia, soybeans have been central to the sustenance and development of human life since before written record. While the date of the earliest soybean cultivation is highly debated amongst agricultural anthropologists, it is widely agreed upon that humans have had a close relationship with the plant for at least five thousand years (Lee et al.).

Soybeans were first grown in Brazil in 1882 at the Agronomic Institute of Campinas. The institute has records of giving samples of soybeans to local farmers. The first wave of soybean cultivation began in 1908 with the arrival of Japanese immigrants. Soybean exports were first recorded in 1937, with the state of Rio Grande do Sul exporting 6,420 kg. Between 1954 and 1969, soybean production increased by a factor of ten, reaching 1 million tonnes. In 1973, due to a drought in the U.S., the United States government placed an export embargo on soybeans and other crops. This resulted in a global shortage of soybeans and a strong desire for a reliable source of soybeans. This would lead the European and Asian markets to the discovery of Brazil as a soybean producer. By 1975, Brazilian production increased again by a factor of ten (since 1969), reaching 10 million tonnes produced. Over the following decades, production continues to increase, with production reaching 25 million tonnes in 1994. In 2002, international and domestic scientific communities begin reviewing soybean cultivation as a cause of Amazon deforestation. This investigation eventually led to the 2006 SoyM, as previously mentioned (Shurtleff and Aoyagi).

Compared to other legumes, soybeans are more digestible and prove to be a high quality protein source for animals (including humans) They have been shown to lower blood pressure and lower the incidence of heart attack and stroke (Rotundo et al).¹¹ Soybeans can be consumed in their raw state but are most often processed before human consumption. Common processed products include tofu and soy milk. Soybeans are also often fermented before consumption, creating products such as soy sauce, tempeh, nattō, and fermented bean paste¹² (Rotundo et al.).

¹¹ Research is only beginning to indicate the correlation of soybeans and the reduction of stroke, heart attack, and lowered blood pressure. Variability between study groups has been seen and more research is necessary to determine a more certain correlation.

¹² Miso paste is a common example of fermented bean paste.

Nitrogen, Synthetic Fertilizers, and Soybeans

Plants need nitrogen to grow. While nitrogen is the most abundant gas in Earth's atmosphere by volume (making up ~78% of the atmosphere by volume), plants cannot use it in its atmospheric form (N_2). Dinitrogen (N_2) forms a strong triple bond, making it inert, unreactive, and, thus, not available to plants. There are three known ways to convert dinitrogen into forms that plants can consume. The first is performed by an enzyme housed in bacteria belonging to the genus *Rhizobium*. This bacteria can transform N_2 into ammonium (NH_4). During the nitrification process,¹³ ammonium (NH_4) is converted to nitrate (NO_3), a bioavailable form of nitrogen (Kabange et al.). This biological process is not yet well understood and is difficult to artificially replicate (Nishibayashi et al.). Soybeans have the ability to fix nitrogen into the soil through this very symbiotic relationship. In the case of soybeans, a common *Rhizobium* to appear is *Bradyrhizobium japonicum* (Slaton et al.).

The second method is through naturally occurring plasma-driven oxidation of dinitrogen (N_2) during thunderstorms. Simply put, lightning provides sufficient energy to break the strong triple bond of N_2 (Kabange et al.). The third and highly agriculturally relevant method is known as the Haber-Bosch process. Developed in the early 1900s, the Haber-Bosch method is detailed here:

Industrially, ammonia is produced from N_2 and H_2 by the Haber–Bosch process under relatively harsh conditions (350~550C, 150~350 atm) to activate N_2 on the solid catalyst surface. It was proposed that the reaction is initiated by dissociative absorption of N_2 and H_2 on low valent multiple iron metal sites to form metal hydrides and nitrides, followed by reversible hydrogenation of the nitride species to provide NH_3 . Both the biological and the Haber–Bosch processes are thought to take place through the cooperation of multiple metal sites bearing hydride ligands (Nishibayashi et al.).

¹³ The nitrification process occurs in the soil. For a detailed explanation, see “Nitrogen Fixation” (Nishibayashi et al.).

The application of nitrogen-rich fertilizers has become common practice in industrial-scale agriculture. This increase is concurrent with the reliance on “improved” or “high-yield” crop varieties which are particularly demanding of nutrients. Nitrogen is applied through fertilizers, including composts, animal feces, liquid organic fertilizers, and synthetic fertilizers. Common nitrogen-rich synthetic fertilizers used at the industrial scale include urea ($\text{CO}(\text{NH}_2)_2$) and carbamide ($\text{CH}_4\text{N}_2\text{O}$). Diammonium phosphate ($(\text{NH}_4)_2\text{HPO}_4$) is a common nitrogen and phosphate dual-purpose fertilizer. Nitrogen fertilizers are the most commonly applied type of fertilizer (Kabange et al.).

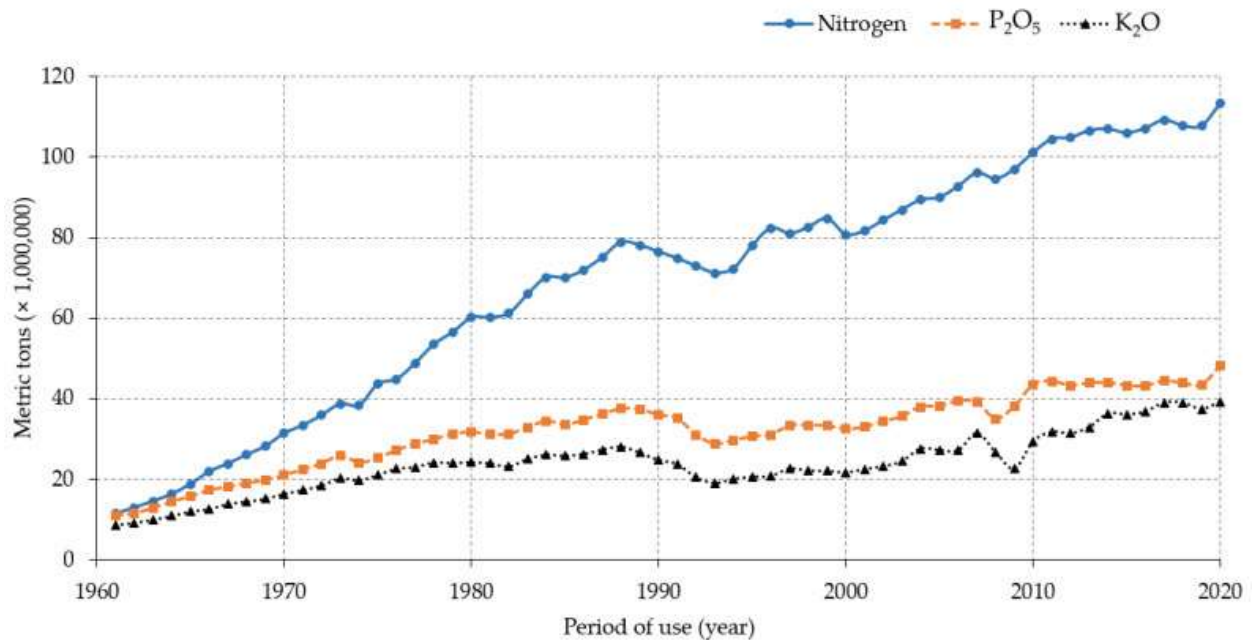


Figure 5. Annual pattern of globally applied fertilizers on industrial-scale farms from 1961 to 2020 (Kabange et al.).

Nitrogen, phosphate, and potassium, commonly referred to as NPK, have taken center stage as the three primary ingredients for synthetic fertilization of agricultural crops. Some researchers today believe that nitrogen and phosphate are of more importance than potassium (Carmo and Ferreira et al.). The focus on these three elements as essential to plant growth has found its way to Mato Grosso, where the application of synthetic fertilizers is common practice

on industrial-scale farms (Klein and Luna). In conjunction with agricultural expansion, the application of NPK fertilizers has been increasing over the last 60 years. See **Figure 5**.

Discussion around synthetic fertilizers often focuses on increased yields and productivity. While these short-term benefits can be achieved, research on the long-term affects of prolonged synthetic fertilizer application show that fertilizers alter ecosystems across trophic levels and create toxic environments. In the case of nitrogen-rich fertilizers, widespread application has been shown to result in water eutrophication, contamination of groundwater, emission of nitrous oxide (an ozone depleting substance), air pollution, nitrogen leaching, soil acidification and degradation, and an overall reduction in the suitability of crop production and animal well-being in surrounding areas (Anas et al.).

Fertilizers are often intentionally applied in abundance, leaving excess fertilizer on the field. The next rain event will remove fertilizers, moving them to local groundwater supplies and nearby rivers, causing pH alteration and supporting algal blooms (Pan et al.). Humans are unintentionally selecting for plant species that can benefit the most from excess, bioavailable nitrogen. Species that benefit from excess nitrogen often choke out local species, threatening endangered species and causing species extinctions (Klein and Luna).

Soybeans' natural ability to fix nitrogen has made them an ideal agricultural plant, seeing as they do not need nitrogen-rich fertilizers. This can save farmers significant amounts of labor, equipment, and expense (Carmo and Ferreira et al.). Soybeans have also been long favored by Brazilian farmers as a double-crop or intercrop.¹⁴¹⁵ Historically, soybeans were often planted in

¹⁴ Intercrops are species planted in between rows of primary crops. They are used to reduce erosion and evaporation, increase productivity, and, in the case of soybeans, fix nitrogen (Bogužas et al.).

¹⁵ Modern farmers are by no means the first to discover the benefits of planting legumes. In the Americas, for example, people were using legumes' nitrogen-fixing abilities to bolster their other crops long before Europeans arrived. Native Americans planted legumes with corn and squash, in a technique referred to as the Three Sisters.

off-season or off-year positions, with primary crops like maize (*Zea mays*) or wheat (*Triticum aestivum*) planted in the on-season position (Klein and Luna).

Pesticides, Herbicides, and Genetically Modified Soybeans

To grow soybeans at an industrial-scale in a tropical climate, Embrapa determined that farmers needed to apply pesticides.¹⁶ Soybean cultivars developed through collaboration between Monsanto and Embrapa to be Roundup Ready have been crucial to the expansion of soybean cultivation in Brazil. These cultivars are Genetically Modified Organisms (GMOs). They are designed to be resistant to herbicides containing glyphosate, a compound that kills broadleaf plants.¹⁷ In the decades following the initial development in the late 1990s, Embrapa and Monsanto have regularly developed updated versions of these soybean seeds (Klein and Luna).

Genetically modified crops have been considered to have similar nutritional and elemental value as their non-genetically modified counterpart. Genetically modified soybeans were initially thought to not cause harm to humans and other animals. A growing body of literature heavily indicates that these assumptions are not the case (Bøhn et al.).

Genetically modified soybeans are significantly inferior in terms of the quality of the actual bean when compared to organic farming practices. Genetically modified soybeans were shown to have lower protein contents as well as higher levels of linoleic acid and palmitic acid.¹⁸

One of the key roles of the legumes in the Three Sisters is to provide an available nitrogen source to the other sisters (Kimmerer).

¹⁶ Insecticides and herbicides are examples of subcategories of pesticides. They are used interchangeably in this paper but do refer to different compounds.

¹⁷ Glyphosate has been shown to bond with the plant itself, resulting in high levels of the toxic compound in both the plant body and in the seeds (Bøhn et al.). Other ingredients in glyphosate-based herbicides also contribute significantly to the overall toxicity of the products. Toxic chemicals present in products include polyoxyethylene amine and polyethoxylated tallowamine (Moore et al.).

¹⁸ While appearing in all soybeans and essential for animal diets, an unbalanced intake of linoleic and palmitic acid is emerging as an indicator for obesity development (Bøhn et al.).

Although further research needs to be performed, studies are indicating that organic soybeans have higher levels of nutrients (Bøhn et al.).

Working with herbicides and other pesticides also introduces a risk of acute poisoning to the individual. The literature demonstrates a correlation between people working with pesticides and health concerns:

It is widely believed that exposure to pesticides is linked to various health disorders, such as respiratory and reproductive disorders, endocrine disruption, Hodgkin and non-Hodgkin lymphomas, Parkinson's disease, and various types of tumors such as breast, brain and prostate, lung, liver, lymphoid tissue, uterus, and thyroid.¹⁹ In Brazil, most of them have been linked to acute and chronic intoxications due to repetitive exposure to very toxic substances (Panis et al.).

These damages were believed to only raise a concern to farm workers. Recently, some within the scientific community are beginning to believe that toxins appear in food at levels that could affect humans and other animals (Paganelli et al.; Bøhn et al.). The consumption of glyphosates and other toxins present in genetically modified food products show particular concern to humans and other animals during their development stages. At this stage, consumption of genetically modified foods that contain toxins can significantly alter or impede neural development (Paganelli et al.; Bøhn et al.).

Brazilian Soybeans in the Global Market

The majority—at least 80%—of soybeans grown globally are fed to livestock. Roughly 95% of soybean meal feeds livestock (Lwin et al.). From this, it is expected that countries importing raw grain from Brazil are crushing the majority of the soybeans into meal to feed livestock. Brazil continues to produce more soybean meal each year, correlating with increased

¹⁹ Exposure to pesticides has also been shown to cause damage to the central nervous system and malformations in the body and brain (Recena et al.).

animal protein exports (Klein and Luna). In 2023, for example, 34% of soybeans grown in Brazil were crushed and processed into soybean oil and soybean meal. Once processed, 23% of the oil and 52% of the meal was exported. 61% of the remaining 66% of grain was exported to the global market (Klein and Luna).

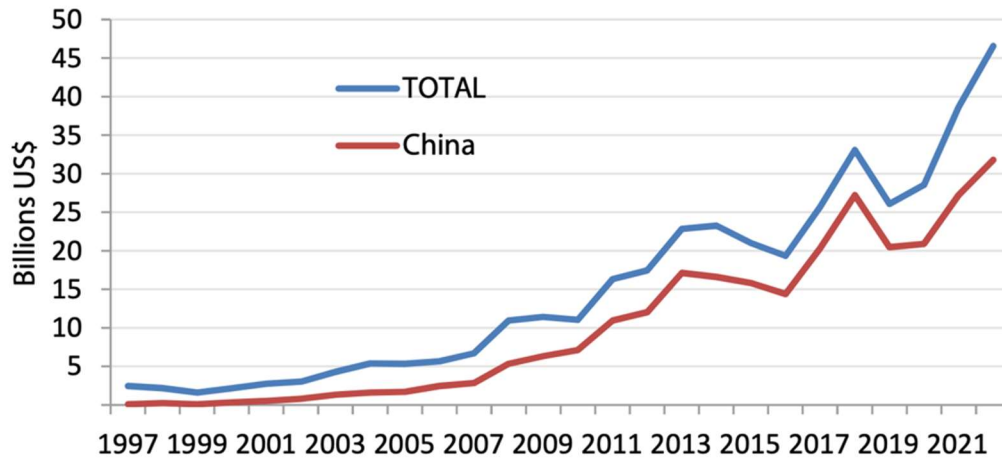


Figure 6. Brazilian exports and Chinese imports of Brazilian soybeans (Klein and Luna).

Today, the majority of Brazilian exports are imported by China. From 1997 to 2009, China’s allotted purchase of Brazilian soy exports increased from 4% to ~50%, respectively. In the decade and a half since then, China has consistently purchased 70% to 80% of Brazilian soybeans that enter the global market (Klein and Luna). As discussed, total Brazilian production has been increasing at a rapid rate over this entire period (IBGE). Chinese importation has continued to increase in tandem with Brazilian exportation rates (Klein and Luna).

Materials and Methods

Materials

Data Collection and Extent

Data was drawn from the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*; hereafter, IBGE).²⁰ The data is publicly and freely downloadable from their website and through the SIDRA data portal. The IBGE is an entity under Brazil's federal Ministry of Economy (*Ministério da Economia*) tasked with the documentation and dissemination of geographic and statistical data for the nation of Brazil. The IBGE conducts census surveys, collects agricultural data, produces geographic and environmental information, and coordinates statistical services for the government and people of Brazil (IBGE).

The specific agriculture data used in this study was produced by the biannual survey²¹ titled the Municipal Agriculture Production (*Produção Agrícola Municipal*; hereafter, PAM). The PAM provides soybean data at the municipality scale on the following: planted area (*área plantada*), harvested area (*área colhida*), quantity produced (*quantidade produzida*), average output (*rendimento médio*), and economic value (*valor*). These categories did not change across the study years. PAM collection methodology varies both municipality to municipality and year to year, and thus is not easily summarizable here. A detailed explanation of their methodology is publicly available on the IBGE website.

²⁰ The IBGE's mission and scope do not directly align with any one department within the United States government. Instead, the IBGE's domestic goals are similar to a conglomeration and restructuring of the United States Geological Survey (USGS), United States Department of Agriculture (USDA), U.S. Department of Labor, and the U.S. Department of Commerce.

²¹ The survey is conducted twice a year.

While the PAM is collected and reported on the municipal scale, reports also include data on the microregion, mesoregion, and state scales. As of 2023, the PAM for MT reported data for 141 municipalities, 22 microregions, and 5 mesoregions, totaling 903,357 km². Mesoregions and microregions have larger spatial extents and consist of a conglomerate of municipalities. To determine meso- and microregion values, the PAM sums the values of all municipalities within their borders.

The number of municipalities and their spatial extents did not stay consistent across the study period. In 2005, MT consisted of 111 municipalities (IBGE). By 2023, MT consisted of 141 municipalities (IBGE).²² The size of the state did not change across this period, only the number of municipalities within. For this reason, the analyses here were conducted on the microregion scale, where spatial extents were maintained across the study period.

Methods

I joined 16 years of data into four groups, each associated with a federal election cycle. These were as follows: 2006 to 2009, 2010 to 2013, 2014 to 2017, and 2018 to 2021.²³ Henceforth, these groups will be referred to as Period 1, Period 2, Period 3, and Period 4 with respect to sequential order. To facilitate the join, I calculated the relative mean for each microregion using the following formula:

$$\text{relative land planted} = \frac{\text{land area planted in soybeans}}{\text{total land area}}$$

Relative values were then employed to calculate the difference from the first period to the last (Δ) and the percent increase of planted land. Delta values demonstrate the regional change

²² As of today in 2025, MT consists of 142 municipalities, having established the municipality of Boa Esperança do Norte in 2023. Previously, it was a district in Sorriso (IBGE, 2025).

²³ The growing season in Brazil does not line up with the calendar year (like it does in the northern hemisphere); instead, dates refer to the end of the growing season. For example, the year 2005 in the data refers to the September 2004 to March 2005 growing season.

relative to the total area of the microregion. The following formula was used (where Period 4 is the 2018 to 2021 date range and Period 1 is the 2006 to 2009 date range):

$$\Delta = \textit{period 4}_{\textit{relative land planted}} - \textit{period 1}_{\textit{relative land planted}}$$

The percent increase, or relative land planted change, demonstrates the regional change relative to the original regional amount of land planted. To calculate this, the following formula was used:

$$\textit{percent increase} = \left(\frac{\textit{period 4}_{\textit{relative land planted}}}{\textit{period 1}_{\textit{relative land planted}}} - 1 \right) * 100$$

The value produced by the percent increase calculation demonstrates the change relative to the original.

Results

Every region saw an increase in the total amount of land planted across the 16 year study. The amount of change varied significantly across regions. The centrally located microregions saw similar delta values across the study period, with each adding somewhere between 8 and 10% of total land planted in soybeans. These regions are as follows: Sinop, Alto Teles Pires, Paranatinga, Canarana, and Arinos. See **Figure 7**.

Primavera do Leste and Alto Teres Pires consistently had the greatest relative amount of land planted in soybeans out of any microregion. That said, Primavera do Leste saw a much greater increase with a delta value of 16.91% compared to Alto Teres Pires' value of 9.40%.

The percent relative increase calculation captures a different aspect of the change across this period. 14 out of the 22 regions experienced more than a 100% increase. Alto Araguaia saw a 4,487% increase in relative land planted, going from 0.11% of total land planted in soybeans to 4.85%. Rosário Oeste went from 0.08% of relative land planted to 1.31% in for a 1,543% increase. Colíder saw a similar change, going from 0.30% to 5.09% relative land planted for a 1,590% increase. See **Figure 8**. The majority of regions that saw great increase via the difference metric did not see a great increase via the relative percent increase metric. Further results are available in **Table 1**.

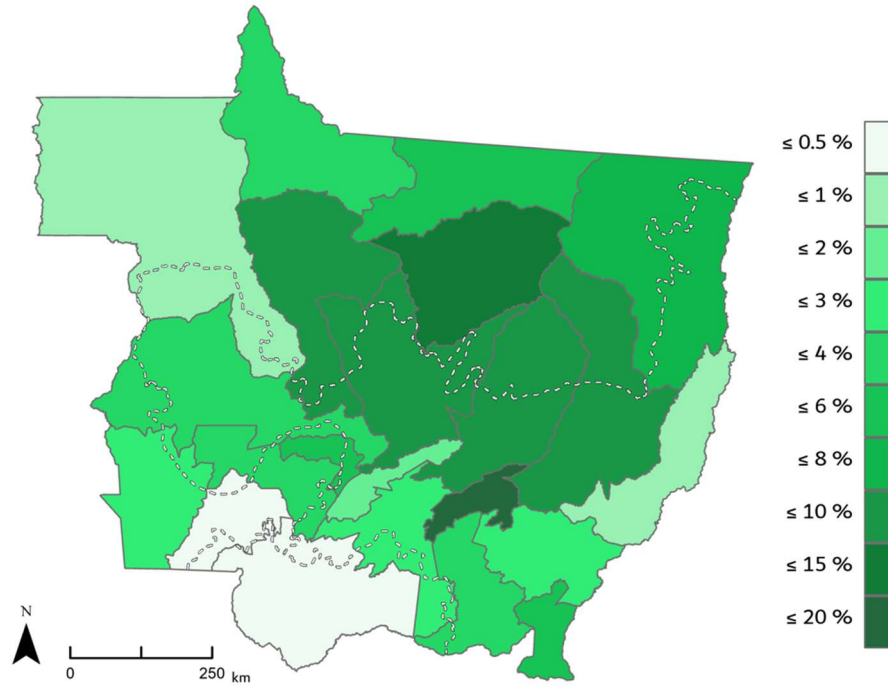


Figure 7. Difference change (Δ) from period 1 to period 4 in Mato Grossian microregions.

Ecoregion boundaries drawn here with dotted lines. Refer to **Figure 3** for details.

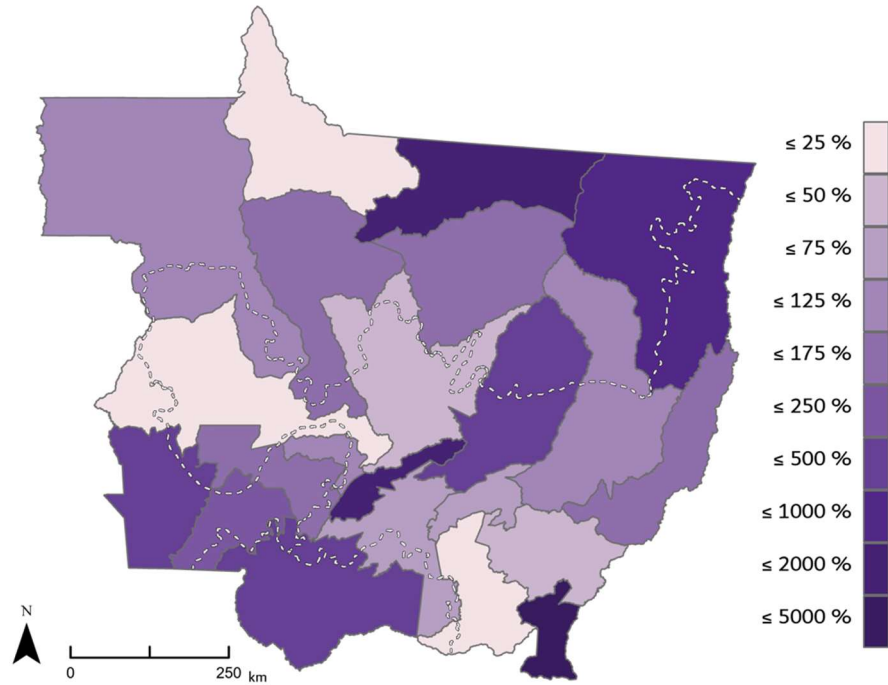


Figure 8. Relative percent increase from period 1 to period 4 in Mato Grossian microregions

Ecoregion boundaries drawn here with dotted lines. Refer to **Figure 3** for details.

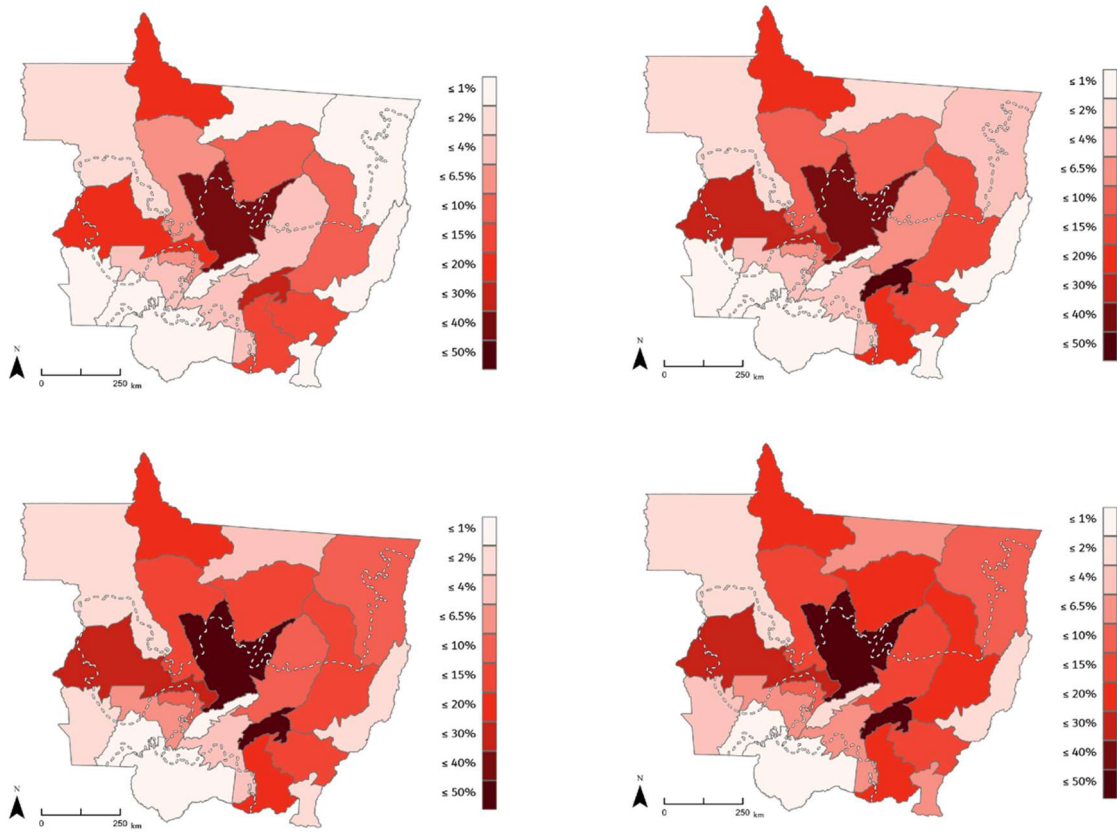


Figure 9. Relative land planted in soybeans for Period 1 (top left), Period 2 (top right), Period 3 (bottom left), and Period 4 (bottom right).

Ecoregion boundaries drawn here with dotted lines. Refer to **Figure 3** for details.

	<i>Period 1</i>	<i>Period 2</i>	<i>Period 3</i>	<i>Period 4</i>	<i>Difference</i>	<i>Relative</i>
<i>Alta Floresta</i>	15.55	15.65	19.21	19.21	3.66	23.55
<i>Alto Araguaia</i>	0.11	0.14	1.46	4.85	4.74	4487.77
<i>Alto Guaporé</i>	0.54	0.65	1.52	2.63	2.09	383.48
<i>Alto Pantanal</i>	0.07	0.07	0.20	0.36	0.29	422.70
<i>Alto Paraguai</i>	4.15	6.25	8.85	9.29	5.13	123.57
<i>Alto Teles Pires</i>	33.48	37.26	42.28	42.88	9.40	28.07
<i>Arinos</i>	4.89	7.63	11.57	13.08	8.20	167.75
<i>Aripuanã</i>	1.07	1.37	1.84	1.99	0.92	86.50
<i>Canara</i>	7.22	10.24	14.18	15.68	8.45	116.99
<i>Colíder</i>	0.30	1.13	3.27	5.09	4.79	1589.85
<i>Cuiabá</i>	3.14	3.47	3.87	5.23	2.10	66.84
<i>Jaura</i>	0.20	0.12	0.39	0.64	0.44	220.01
<i>Médio Araguaia</i>	0.57	0.60	1.30	1.45	0.87	151.85
<i>Norte Araguaia</i>	1.03	2.62	7.32	8.91	7.88	761.45
<i>Paranatinga</i>	2.35	4.57	8.63	10.47	8.12	346.07
<i>Parecis</i>	19.76	20.77	22.56	23.14	3.39	17.15
<i>Primavera do Leste</i>	30.44	40.55	46.06	47.35	16.91	55.56
<i>Rondonópolis</i>	13.65	15.34	15.76	16.64	2.99	21.93
<i>Rosário Oeste</i>	0.08	0.31	0.97	1.31	1.23	1543.91
<i>Sinop</i>	6.70	9.69	14.45	17.15	10.44	155.86
<i>Tangará da Serra</i>	2.32	2.66	4.30	5.75	3.43	147.77
<i>Tesouro</i>	10.27	11.66	12.77	13.07	2.81	27.32

Table 1. Relative land planted values per microregion for each period as well as difference and relative change values.

Delta change (Δ) from the first to last period (Difference) and relative change from the first to last period (Relative). Values in the Period 1, 2, 3, and 4 columns represent the percentage of the total land planted in soybeans averaged across the 4 year period (relative land planted). The difference column represents the change in the relative land planted in soybeans from Period 1 to Period 4. The increase column represents the relative change in land planted in soybeans from Period 1 to Period 4. Microregions are organized alphabetically.

Discussion

Every microregion in Mato Grosso saw expansion of soybean agriculture across the 16 year study period. Microregions in the center of the state saw the most rapid land-use conversion, with the difference in relative land planted in soybeans falling in the 8 to 10.5% range. The results of my study clearly demonstrate that land is continuing to be converted to soybean agriculture in Mato Grosso, particularly in microregions that contain both the Cerrado and Amazon ecoregions.

The study groups data into four year periods that correlate with federal elections in Brazil. Federal elections in Brazil have been shown to have serious domestic and global ramifications related to soybeans. Environmental law in Brazil and its enforcement—particularly in the Mato Grossian Amazon—have shifted dramatically with changing administrations (Bonanomi et al.). This has resulted in dramatic changes in the rates of legal and illegal deforestation along with the paralleling expansion of agricultural land.

I did not find a correlation between federal administration and the amount of land planted in soybeans, nor in the change of amount of land planted in soybeans. This is likely due to the limitations of my study methods and the environmentally protective federal governments who were in power during the majority of the study period (Barbosa et al.). The effects of the anti-environmental policy enacted by the 2018-2021 administration will likely be reflected in the data in coming years, but did not appear in my dataset.

Now, to return to the initial question of this study, why has soybean expansion occurred so rapidly in Mato Grosso, Brazil? What is motivating this transition? Brazil has been heavily incentivized by the global market to produce soybeans. Every year, Brazil produces more soybeans and every year, nations around the world hungrily purchase Brazilian exports. The

question is then, why do other nations want foreign soybeans? Why can't they grow soybeans themselves? What is the end product of soybeans grown in Brazil? If soybeans are extremely climatically adaptable, why are they primarily produced in Brazil? And in Brazil, why Mato Grosso? I will answer these questions in the following three sections.

The Hidden Costs of Soybean Agriculture

Nations want foreign soybeans because they're cheap to purchase, but expensive to grow. The price set for soybeans in the global market does not account for the ecological and societal damages incurred by large-scale soybean agriculture. Growing soybeans has an operational cost that is covered by the price in the global market. What isn't accounted for in that price are the long-term effects of chemical pesticide and herbicide run-off, smoke from slash-and-burn agriculture fires, lower education rates, rising urbanization rates, land-right claims, or the myriad of the other problems that are motivated by the expansion of large-scale agriculture. When a nation purchases soybeans from Brazil, they receive the product, soybeans, in the short-term and do not have to deal with any of the long-term damages. In the short-term, Brazil sees economic gains at domestically unprecedented levels. In the long-term, though, Brazil will eventually come to face the repercussions of the tunnel-vision rapid agricultural expansion that has defined the last 50 years.

Other nations can grow soybeans; they are choosing not to. At least, not at a large scale. Brazil has shown willingness to produce soybeans for the world. They are willing to suffer the domestic damages that come with large-scale production. So long as another nation will produce soybeans and sell them to the global market at an expense ratio that does not take into account the domestic damages, other nations will continue to rely on Brazil for their soybeans.

Soybeans as Feed: Global Meat Consumption

Global meat consumption is the major driver for the purchasing of soybeans from the global market. The majority (80%) of soybeans produced around the world are fed to livestock. Meat consumption has been increasing globally over the last 70 years and with it, the demand for a reliable food source for livestock has too. That said, consumption has not been expanding equally in all countries, but is instead concentrated in countries with growing middle- and upper-class populations, like China. Meat consumption has long been associated with affluence, and is seen as an indicator of well-being and class.

This raises questions about the efficacy of feeding the growing global population with meat products. Feeding livestock human-grade food is highly inefficient in terms of energy, water, and ecological damages. Some ~15% of all livestock and aquaculture feed is human-grade quality (Sandström et al.). If the cropland and grazing land dedicated to producing meat was instead made productive for food for direct human consumption, researchers estimate that we could produce ~70% more calories, feeding ~4 billion more people (Rust et al.; Eshel et al.). The growing demand for meat products is and will continue to be reflected back on energy and water consumption, as well as biodiversity loss, deforestation, green house emission, global warming, and the social, physical, and economic well-being of individuals (Rust et al.; Eshel et al.).

Research and individuals concerned with the expansion of global meat consumption and related food studies may benefit from the consideration of soybean production in Mato Grosso.

Epistemic Remoteness

The global demand for meat also brings to surface the relation between epistemic remoteness and the ecological damages occurring in Mato Grosso. Epistemic remoteness is a term levied by environmental philosophers (among others) to refer to consumers' inability to

gain knowledge about the damages of their consumption decisions due to the distance between their position and the position of the formulation of the product. It is believed that consumers closer to the ecological harms being committed by their consumption and production decisions are much more likely to make decisions that reflect their ethical positions (Plumwood, 2002).

This said, individuals may not have developed or considered their ethical position towards meat consumption, and thus would not adjust their practices given information. This brings forward the more complicated conversation around feeding our growing population through environmentally considerate and sustainable means. The individual consumer is not best held responsible for the environmental damages of their actions when governments, researchers, and corporations are extremely aware of the damage and choosing to continue to support these systems. Rising meat consumption, and the subsequent environmental damage, is a global, systemic concern, one that must be met with cooperation and awareness at the individual, corporate, and governmental scales. The work of environmental philosophers can be levied to understand how soybean expansion in Mato Grosso has been supported despite its grave environmental implications. This philosophic study could help environmentalists and governments avoid allowing similar damages from occurring in the future.

Why Mato Grosso?

I've discussed why soybeans were selected as a crop for Mato Grosso, why there exists a large global market for soybeans, and where in Mato Grosso they are being grown. Bringing this all together, now, in this section I answer the central question of this project: why has Mato Grosso become the hotspot for soybean expansion? I find that Mato Grosso has been a center for soybean expansion due to its remote and isolated location, both geographically and in the minds of the people.

Until the 1970s, Mato Grosso had a small, dispersed, and isolated population. There was extremely little movement in and out of the region. Between MT's geographic positioning as the center of South America and its near-impassability due to dense vegetation, MT has long flown under the radar as a place of interest for many people around the world. Mato Grosso only began drawing domestic and international attention when deforestation rates reached all time highs in 1995 and again in the early 2000s. Since then, it has largely faded from public view.

Despite being nearly the same size as the neighboring nation of Bolivia,²⁴ Mato Grosso is not well known. Even following the active and tumultuous recent decades, with events ranging from mass deforestation to rapid agricultural land transformation, population growth to indigenous land right disputes, massive amounts of chemical pesticide and herbicide application in one of the most biodiverse regions of the entire world, Mato Grosso continues to go relatively unobserved by the global community. Brazil has turned a massive profit on soybean production while incurring massive environmental damages and, so long as the global community doesn't investigate, they will continue to do so, at the expense of hundreds or thousands of species, millions of hectares of the most biodiverse land in the world, and the well-being of the people of Brazil.

Study Critiques

The methods used in this study fail to reveal the precise location of land-use change. Due to large size of microregions, it is unclear whether the conversion of land to soybeans occurred on previously forested land—whether that be in the Cerrado or Amazon—, agricultural land, grassland, pasture land, or some other previous use. It is impossible, from these data and results,

²⁴ Mato Grosso (903,357 km²) is 82.2% the size of the nation of Bolivia (1,098,581 km²).

to determine whether land-use change aligned with the SoyM agreement or followed federal and state law.

I initially worked on this study at the municipal level, a scale that would have better been able to indicate regions with significant change. I collected soybean data from 2005 to 2023. When I attempted to analyze the data, though, I quickly ran into an issue: at the beginning of the study period Mato Grosso was made up of 111 municipalities and by the end, there were 141.²⁵ During the period, the size of the state did not change. In looking at other studies, I realized that almost no other researchers use the PAM data when conducting their analyses; instead, researchers primarily use satellite data.

From my experience, the data collected and made publicly available by the Brazilian government through the PAM is, at least in Mato Grosso, nearly unusable for studies that consider multiple years. With changing collection methodologies and region size, statistical analyses will nearly always have error. Additionally, even if the data were spatially and methodologically consistent across a time period, the formatting of the data makes it extremely difficult to work with. For example, data values with more than three digits are separated with a space, instead of the more typical comma or period.. This renders the data illegible to most statistical analysis softwares. Whether intentional or unintentional, there are barriers to entering the data that are not assumed or observable from the end products as seen in completed studies.

If further research on this topic is to be conducted, I recommend the usage of satellite data or, if available, aerial data. By observing land-use change from space, future research will be able to avoid the issues of changing geographic boundaries in Mato Grosso and instead focus on the land-use change.

²⁵ Even the microregion system was altered during the study period. In 2017, the IBGE redacted the microregion geographic system and replaced it with 'immediate' and 'intermediate' geographic regions (IBGE).

Conclusion

Over the last 70 years, Brazil has undergone a profound agricultural transformation. The global market has hungrily fed on Brazil's continual growth, creating an ever growing global demand for the products of Brazil's agricultural sector. While the tropicalization of soybeans and industrial-scale agriculture are purported as a massive success within Brazil, questions surface regarding the sustainability of these practices in tropical climates. The realities of deforestation and native vegetation loss are seriously downplayed by the Brazilian government and corporations like Embrapa. Further research can seek to identify species native to the Amazon and Cerrado that are at risk of extinction due to the expansion of agriculture; perhaps, then, the global community will deem it worthwhile to pay attention.

This study clearly linked soybean cultivation with increasing meat production. Through the theory of epistemic remoteness, this study suggests how consumers with limited knowledge can make choices that do not align with their moral standpoint. To resolve this moral conflict, I suggest further conversation and education around meat products and the sourcing of feed.

Mato Grossian industrial-scale soybean agriculture relies on the widespread application of pesticides and usage of GMOs. Further research needs to study the long-term implications of the Brazilian industrial scale-model and, with it, the implications on the Amazon rainforest, Cerrado savanna, Pantanal wetlands, and the unique biodiversity that resides within these ecoregions. Mato Grosso will continue to serve as a key case study for the long-term impacts of industrial-scale soybean cultivation.

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