Title:

Agricultural expansion and intensification in Brazil: A literature synthesis of dynamics, drivers, and implications

Authors:

Haijun Li [1,*]

Affiliations:

[1] Department of Geographical Sciences, University of Maryland, College Park, MD, USA

Email:

*Corresponding author: haijunli@umd.edu

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Agricultural expansion and intensification in Brazil: A literature synthesis of dynamics, drivers, and implications

Haijun Li [1,*]

[1] Department of Geographical Sciences, University of Maryland, College Park, MD 20742, United States

*Corresponding author: haijunli@umd.edu

Abstract

Brazil's long-term agricultural development reflects a complex interplay between human-driven land-use change and natural ecosystems (Fig. 1). Since the 1960s, agricultural production in Brazil has expanded rapidly, driven by global food demand and national economic growth, through two primary pathways: (1) agricultural expansion via conversion of natural vegetation, particularly forests, and (2) agricultural intensification through increased cropping frequency, adoption of agrochemicals, high-yielding crop varieties, and improved livestock breeding. While these processes have substantially increased food production, they have also generated significant environmental consequences, including deforestation, biodiversity loss, carbon emissions, soil degradation, and water pollution. In the context of a growing global population, rising global food demand, and climate change, reconciling agricultural productivity with environmental sustainability remains a critical challenge. This paper synthesizes the existing literature to examine the dynamics, drivers, and environmental implications of agricultural expansion and intensification in Brazil, providing insights to support the development of more sustainable agricultural systems.

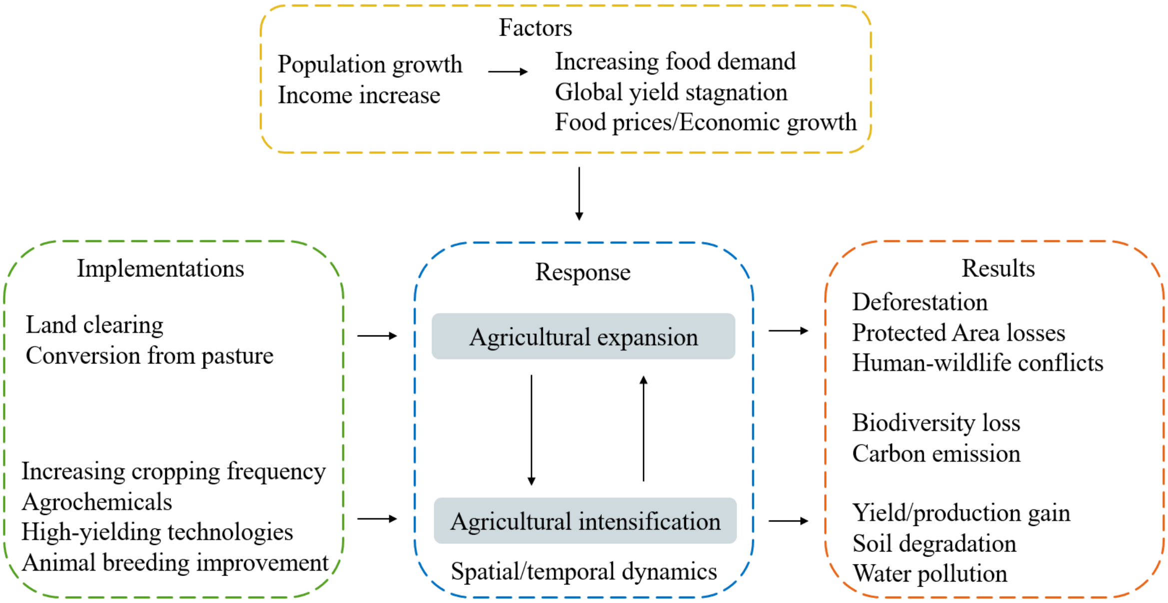

Fig. 1 Agricultural expansion and intensification in Brazil as a coupled human and natural system. Agricultural expansion and intensification are driven by multiple factors that significantly increase food production while causing environmental damage.

Keywords

Agricultural expansion; Agricultural intensification; Land use change; Brazil; Socioeconomic drivers; Deforestation

1. Introduction

The world's population is projected to reach approximately 9.7 billion by 2050 (United Nations, 2022). It remains a worldwide challenge to achieve the United Nations Sustainable Development Goal 2 to end hunger, ensure food security and improved nutrition, and promote sustainable agriculture for such a rapidly increasing population, especially under the circumstances of global climate change. All these threats indicate that long-term agricultural sustainability is in urgent need. The average yields of major commodity crops (such as maize, rice, wheat, and soybean) have been increasing since the 1960s, at the global scale (Cassman and Grassini 2020). However, the relative crop yield growth rates (calculated as the ratio of the linear rate of yield gain and trend-line yield in a given year) are noticeably decreasing or even reaching stagnations in some regions, such as wheat production in northern Europe and rice production in California (Cassman and Grassini 2020). Meanwhile, rising income demands more livestock consumption such as meat and dairy products, which increases additional burdens on agricultural production (Cassman and Grassini 2020).

In response to the emerging threats to food security, such as crop yield growth stagnation and extreme climate events including droughts and floods, agricultural expansion has been seen as one of the main strategies to boost agricultural production. From 2003 to 2019, global cropland expansion accelerated with an approximately doubled annual rate, and the global cropland area increased by 9%, with a total annual net primary production (NPP) increased by 25% (Potapov et al. 2021). Although crop yield and production gains are derived from this massive increase, they are usually involved in dramatic land use changes from natural vegetation of forests, grassland, shrubland, savannahs, and wetlands to agricultural fields. As a result, substantial environmental impacts emerged from the conversation of these natural ecosystems, such as reductions in biodiversity and carbon stocks, soil degradation, as well as water cycling decreases (Nunes et al. 2022; Spera et al. 2016).

On the other hand, agricultural intensification is another way to support increased food production and use the limited cropland resources simultaneously and sustainably (Rasmussen et al. 2018). Unlike the expansion strategy, the goal of intensification is to gain per-unit yields for crop and livestock on existing agricultural land without further converting vegetation land (e.g., forest, shrub, grass) into farms (i.e., to meet increasing production demands by using current agricultural lands yet sparing land for nature). Agricultural intensification calls for a paradigm shift from direct spatial expansion to land use intensity increase – cropping frequency and patterns are adapted to have multiple harvesting seasons in a single year; more agrochemicals such as fertilizers and pesticides are introduced to enrich soil fertility; high-yielding crop varieties are developed to gain more yields; precise agricultural techniques are employed to conduct agricultural management timely and scientifically. Nevertheless, the potential negative effects of agricultural intensification on natural resources should not be ignored, such as soil degradation and water pollution.

In the twenty-first century, the largest total and per-capita cropland area change was found in South America, in which the vast majority of expansion occurred in Brazil (Potapov et al. 2021). As the main soybean-exporting country, Brazil has experienced a massive expansion in soybean cultivation since the 2000s (Song et al. 2021). Meanwhile, Brazil holds the second-largest cattle herd in the world for beef production (~213 million head in 2018) (https://www.fao.org/faostat/en/#data/QCL Accessed on October 09, 2025), and the associated pasture land use is forecasted to grow continuously (Zu Ermgassen et al. 2018). Given that Brazil has 330 million ha (Mha) of rainforests and savannahs accounting for 60% of the Amazon basin, which is one of the largest areas of biodiversity in the world, the agricultural expansion and intensification in this country has drawn international attention due to the conflicts between the increasing food production and the consequential Amazon deforestation (Zu Ermgassen et al. 2018). The objectives in this paper are trying to investigate the historical dynamics of agricultural expansion and intensification, especially for soybean cultivation and cattle ranching production, within the Brazilian context, and explore the drivers and implications.

2. Agricultural expansion and intensification dynamics in Brazil

The crop types in Brazil diversified dramatically over the past half-century, according to the official statistics provided by FAO (see Fig. 2). During the 1960s, maize had the largest harvested area across the nation, followed by rice, coffee, and sugar cane, whereas sorghum, wheat, soybean, and cocoa beans only accounted for a small proportion. Although Brazil was traditionally regarded as a country with tropical agricultural products such as coffee, sugar, and cocoa, it started cultivating diverse temperate-climate products, especially soybean since the 1970s. During the 1970s and 1980s, the Brazilian agricultural structure changed significantly: the harvested areas for rice, sugar cane, and wheat increased slightly, and the cocoa beans and sorghum areas remained stably low. In contrast, the coffee area saw noticeable drops. The most dramatic change was observed in the soybean area with an increased harvested area of around 10.5 Mha by 1989, which was 13 times greater than the harvested area for maize during the two decades, and reached approximately equal area for maize. From 2000 onwards, soybean cultivation even accelerated with the highest rates, jumping from 12 to 37 Mha, although a temporary downside was clearly shown between the period of 2005 and 2007.

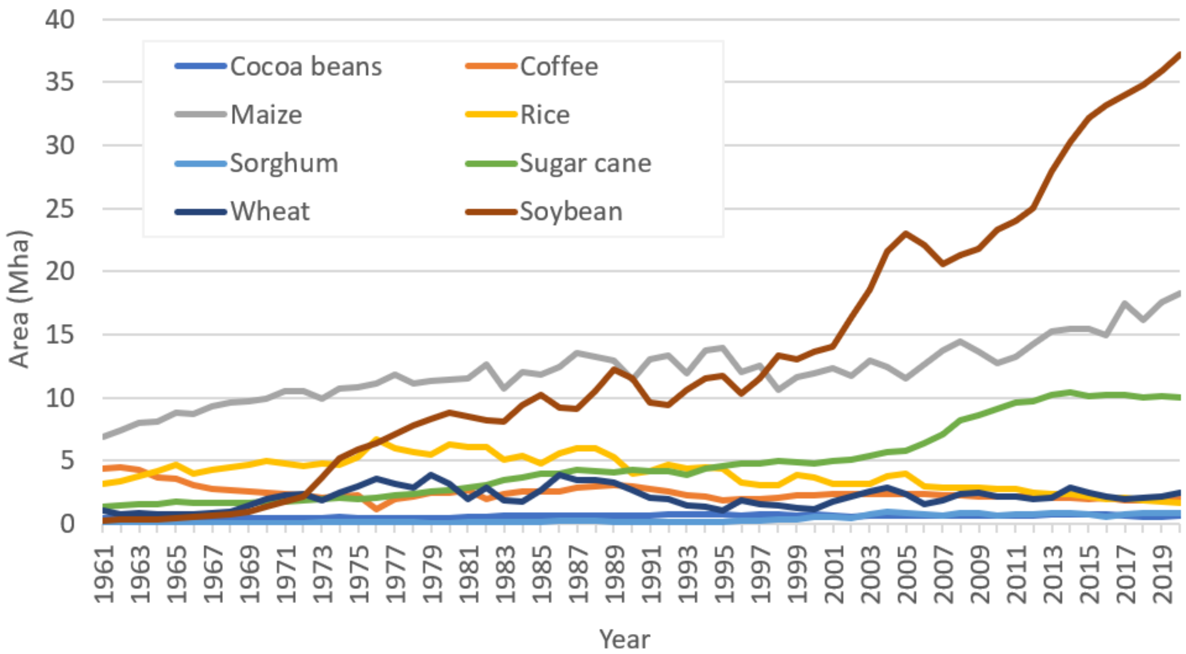

Fig. 2 Harvested area for major crops in Brazil from 1961 to 2020. The harvested area of maize and sugar cane increased steadily throughout this period. The Brazilian soybean harvested area has experienced dramatic increases since the 1970s. Source from FAO (https://www.fao.org/faostat/en/#data/QCL Accessed on November 18, 2025)

The overall land use change in the Brazilian agriculture sector also shows significant agricultural expansion since the 1960s (Fig. 3). The cropland area expanded and doubled from 31 Mha in 1961 to 64 Mha in 2020. For livestock production, the area of meadows and pastures increased from 126 Mha in 1961 to 173 Mha in 2020. Regarding the overall agricultural land use, including crop cultivation and livestock production, the number boomed in the first three decades from 157 Mha in 1961 and peaked at 240 Mha in 1984.

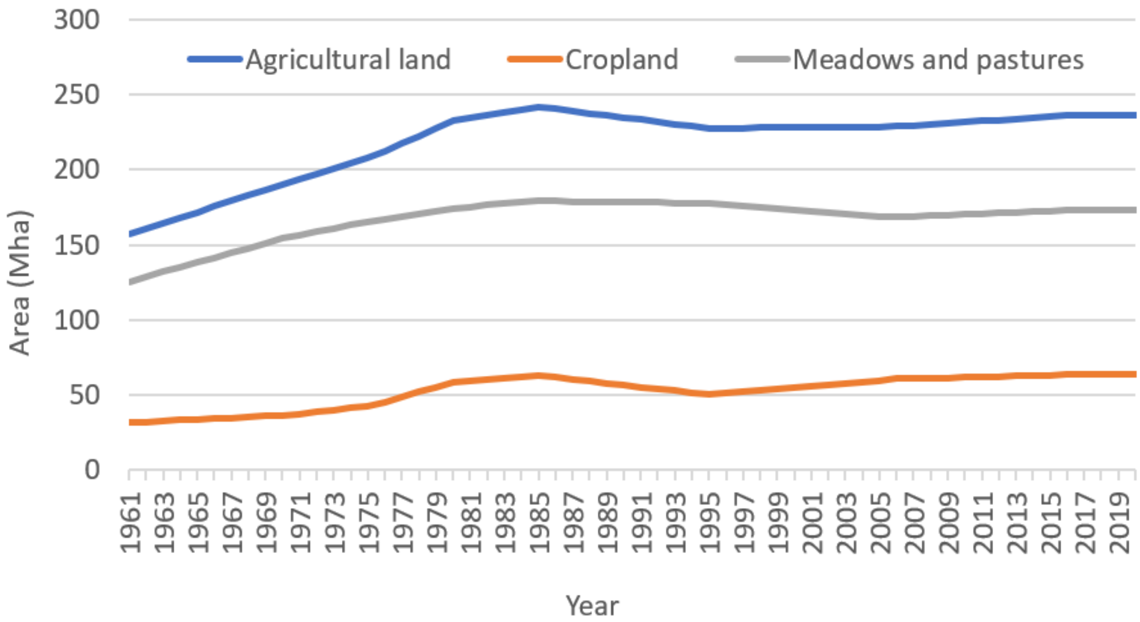

Fig. 3 Overall land use change in the agriculture sector in Brazil from 1961 to 2020. The agricultural land area increased consistently from 1961 to 1985. Although declines could be found in the 1990s, the areas of the cropland, meadows, and pastures showed slight increasing trends in the recent two decades. Source from FAO (https://www.fao.org/faostat/en/#data/QCL Accessed on November 18, 2025)

The national-scale statistics provide general time-series trends of the agricultural expansion in Brazil, but fail to measure the spatially explicit frontiers and hotspots in which expansion occurs most intensively. These dynamics over space and through time could be compensated for by remote sensing techniques, with the increasing data availability of satellite imagery. For example, earlier research by Morton et al. (2006) combined field surveys and MODIS satellite imagery to investigate the land use conversion among forest, cattle pasture, and cropland in Mato Grosso, the state with the highest soybean production since 2001. They reported 3.6 Mha growth of agricultural land in the Brazilian Amazon between 2001 and 2004. Zalles et al. (2019) studied the intensive row cropping (e.g., soybean, sugar cane, cotton, and corn) in Brazil by utilizing a historical archive of satellite data and revealed that the Brazilian cropland extent expanded from 26.0 Mha to 46.1 Mha between 2000 and 2014. In addition, the spatial dynamics of cropland extensification in Brazilian states and biomes were reported in detail (see Fig. 4): (1) the states of Maranhão, Tocantins, Piauí, Bahia (collectively MATOPIBA), Mato Grosso, Mato Grosso do Sul, and Pará all more than doubled in cropland extent; (2) the states of Goiás, Minas Gerais, and São Paulo individually experienced more than 50% growth; (3) from the perspective of Brazilian biomes, the majority of cropland expansion occurred in Amazon and Cerrado forest.

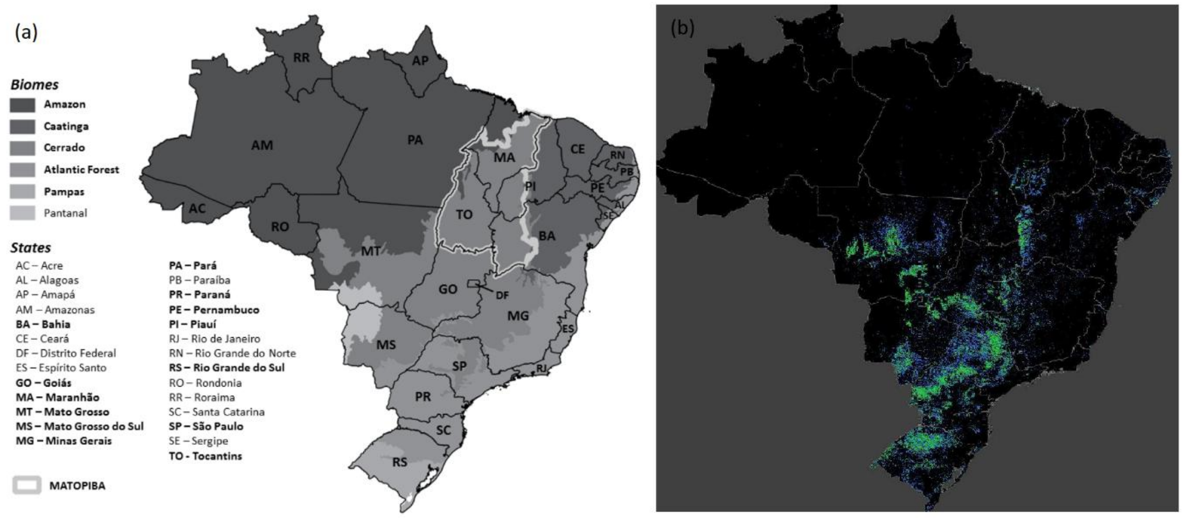

Fig. 4 Cropland expansion in Brazil from 2000 to 2014, adapted from Zalles et al. (2019). (a) Brazilian states, biomes. (b) Satellite-based cropland classification results, with cropland extent in 2000 as green and cropland expansion through 2014 as blue. The majority of cropland expansion in Brazil from 2000 to 2014 occurred in the Amazon and Cerrado forests.

The MapBiomas Project, launched in 2015 in São Paulo, has carried out even more comprehensive investigations on the land use and land cover change (LULCC), including the Brazilian agricultural expansion from 1985 to 2021 (MapBiomas 2022). Annual maps at 30-m resolution for the entire nation have been produced by using long-term Landsat imagery collections. During this period, the area dominated by crop cultivation and cattle ranching (pasture) increased from 21% to 31% of the entire territory, and accounted for one-third of land use in 2021 (see Fig. 5). A noticeable 228% growth was found in the agricultural land. In addition, the pasture area for livestock production increased to 151 Mha in 2021. Agricultural land for crop cultivation could be found in all biomes, with clustering in the southern Amazon, Pampa, southern Cerrado, and Atlantic forest. Although beef cattle production systems existed in all Brazilian states, the pasture land was mostly discovered in the biomes of Amazon and Cerrado forest, indicating tremendous land use and land cover changes from forest to pasture for cattle-raising (MapBiomas 2022).

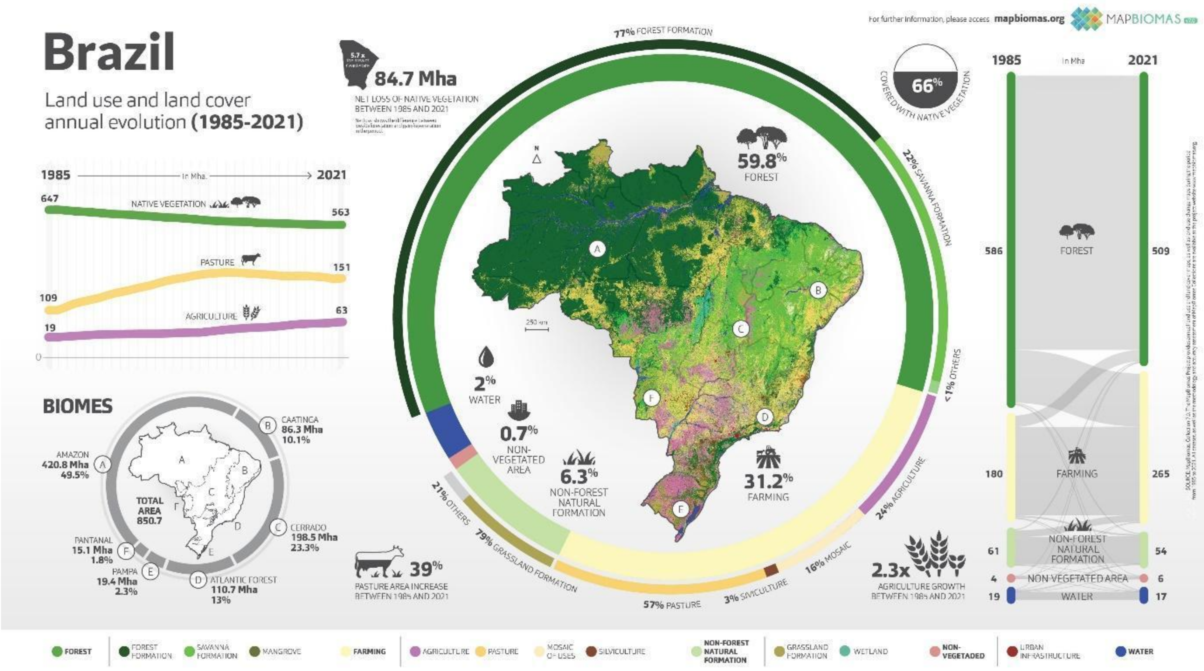

Fig. 5 Land use and land cover annual evolution in Brazil from 1985 to 2021 (MapBiomas 2022). The land use and land cover types are mapped based on satellite images over all six biomes: Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa, and Pantanal. The quantitative land use conversions are also shown among different land use categories of forest, farming, non-forest natural formation, non-vegetated area, and water. Throughout this period, the area of agriculture and pasture increases noticeably, along with a continuous decline in native

vegetation area, which reaches 84.7 Mha of net loss in 2021.

For soybean cultivation specifically, Song et al. (2021) produced the time-series soybean extent and expansion maps at 30-m resolution in South America, including Brazil, by utilizing satellite-based observations and sample-based field survey, for two decades from 2000 to 2019. The map-derived soybean cultivation area in Brazil was estimated to grow at an average rate of 1.2 Mha per year and to a total increase by a factor of 2.6, which was greater than the doubling expansion of the whole continent from 26.4 Mha to 55.1 Mha (Song et al. 2021). The soybean expansion has been observed in multiple directions across the country (see Fig. 6): (1) in southern Brazil, the originally traditional soybean cultivation area has expanded to surrounding regions; (2) in central-west and northeastern states of agricultural frontiers, the soybean area has been spreading towards lower latitude regions (Fig. 5a, b). The details showed spatiotemporal dynamics of this specific crop expansion with precise geographical locations and unbiased change magnitude estimates.

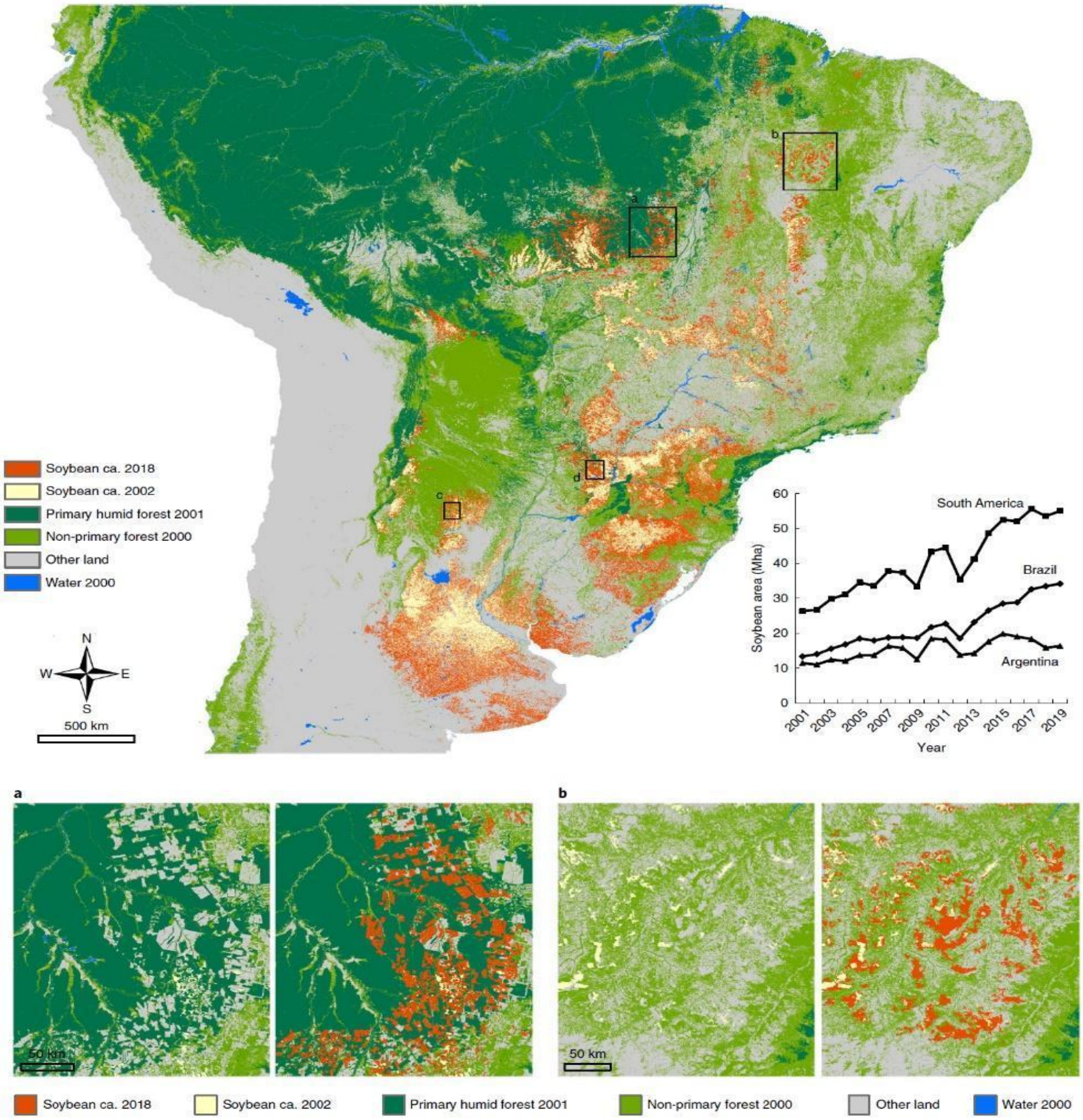

Fig. 6 Soybean expansion in South America from 2001 to 2019, adapted from (Song et al. 2021). A 3-year majority filter for the beginning and ending years is used to derive soybean layers ca. 2002 and 2018. The inset shows annual soybean areas over South America, Brazil, and Argentina, derived from the annual soybean maps. (a) Eastern side of the Xingu River Basin in Mato Grosso, Brazil. (b) Southern part of Maranhão and Piauí, Brazil. For (a) and (b), the left panel shows land cover and soybean distribution ca. 2002, and the right panel shows land cover and soybean distribution ca. 2018. The comparisons show the Brazilian soybean expansion associated with land use conversion from forest to agricultural land.

Apart from the horizontal expansion, the rapid agricultural intensification in Brazil has also been explored by researchers. For example, in the Brazilian Mato Grosso, the agriculture-forest frontiers spanning both Amazon and Cerrado biomes, the crop and pasture intensification between 2001 and 2013 was quantified by using remote sensing and agricultural survey data (Garrett et al. 2018). The cropping pattern has been shifting from single cropping of soybean to double cropping of soybean-corn, which contributed to an increasing double crop proportion, accompanied by a significant growth in agricultural outputs. In many single-cropping soybean production regions, the cropping supply chains developed rapidly, which allowed decreased costs and investments in crop intensification to adapt single cropping to double cropping practices (Richards et al. 2015). Meanwhile, the pasture intensification of cattle-raising was also confirmed by the overall increasing stocking rates and facilities in the supply chain (Garrett et al. 2018). The public conservation policies and supply-chain initiatives to control deforestation in Brazil play an important role in such a diagram shift (Lambin et al. 2018; Nepstad et al. 2014). As the feedback in the agricultural systems to governmental interventions, at the regional scale, agricultural encroachment in native vegetative land has been constrained, while intensification on limited land has been incentivized.

For soybean cultivation, in addition to the massive expansion at spatiotemporal scales, the annual yield also presented a continuous growth, demonstrating the evidence of agricultural intensification (see Fig. 7). In general, the annual soybean yield increased from 1,126 kg/ha in 1961 to a record of 3,390 kg/ha in the year of 2018, with a total yield increase of 201%. These increases were mainly attributed to agricultural intensification, technological advances adopted in crop cultivation, including soybean varieties resistant to weeds and pests, planting and harvesting machinery, precision agriculture techniques, agroforestry practices, no-till system to reduce soil erosion, as well as double-cropping strategies of soybean-maize (Cattelan and Dall'Agnol 2018).

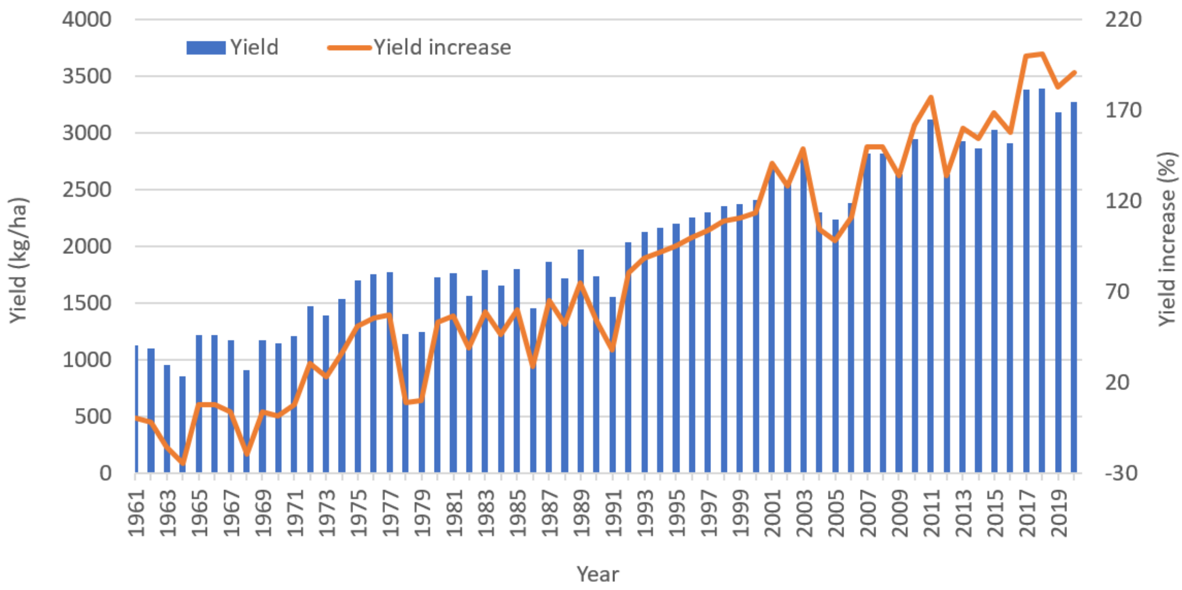

Fig. 7 Annual soybean yield and the increase rate in Brazil from 1961 to 2020. The annual yield increase is calculated between a specific year and the year of 1961. Source from FAO (https://www.fao.org/faostat/en/#data/QCL Accessed on November 18, 2025)

Overall, in the past half-century, especially during the twenty-first century, Brazil experienced massive agricultural expansion and intensification, which has been revealed through information derived from agricultural statistics and remote sensing data.

3. Drivers and implications of the Brazilian agricultural development

3.1. *Drivers*

The agricultural sector in Brazil experienced extraordinary growth in the last six decades, enabling the country to play a critical role in the global food supply chain. The crop and livestock products have been consumed to feed an increasing population around the world. Several factors have contributed to this dramatic expansion and intensification of agriculture in Brazil.

Firstly, the growing domestic food demand originally stimulated the agricultural strategy of expanding agricultural and livestock production. In the 1950s and 1960s, as a result of population growth and the national process of Import Substitution Industrialization (ISI), aiming to reduce dependence on foreign imports by advocating domestic production (Santana and Gasques 2019), the Brazilian agricultural sector was assigned an important role to carry out active land expansion for domestic agricultural products. Therefore, massive cropland expansion started in the 1960s.

Secondly, governance and agricultural policies have been the most important factors since the 1960s, although the feedback in the agricultural sectors in response to these policies varied in different periods. Aligned with the orientation of meeting domestic food demands and contributing to the national industrialization process, various agricultural policies were introduced. In the 1960-1990 period, especially, the Brazilian agri-food sector witnessed strong national interventions (Santana and Gasques 2019). The rural credit was one of the most important governmental policies for the promotion of agricultural modernization, after the National Rural Credit System (NRCS) was established in 1965. Financial investments boosted owing to abundant and cheap official credits, and agriculture expanded with increasing production. During the 1970s and 1980s, Brazil even started to export temperate-climate products, and agricultural producers migrated from Rio Grande do Sul to Mato Grosso, Mato Grosso do Sul, Goiás, and the west of Bahia, representing the first important agricultural frontier expansion in Brazil (Soares and Nassar 2007). Another important governmental tool was the Guaranteed Minimum Price Policy to stabilize agricultural product prices and ensure income for producers. This guaranteed farmers' basic economic security. Since the 2000s, the focus of the agricultural policy has shifted from generating short-term outputs to pursuing long-term development incorporating environmental sustainability and biodiversity conservation, aiming to achieve high-yielding production with limited horizontal expansion. This agricultural practice diagram shift was deeply impacted by forest conservation policies in both the public governance and private sectors. For example, the governmental Low-Carbon Agricultural Plan was enacted in 2010, aimed to reduce deforestation and increase sustainable agriculture by providing subsidies to low-carbon agricultural farms such as integrated crop and livestock systems (MAPA, 2011). In the private sectors, retailers, nongovernmental organizations, and major soybean traders launched the Brazil's Soy Moratorium, which voluntarily agreed not to purchase soy planted in the Brazilian Amazonian deforested lands after July 2006 (Gibbs et al. 2015). The active conservation policies imposed higher costs for farmers to produce agricultural products from illegal deforestation. As a response to the resultant decreasing availability of agricultural land, increasing cropping frequencies on existing land was implemented to gain profits.

Thirdly, agricultural research helped increase agricultural productivity deeply. Influenced by the "Green Revolution" with objectives to increase food crop yield and production, the Brazilian Agricultural Research Enterprise (EMBRAPA) was established in 1972, which turned out to be a milestone in the Brazilian agriculture development (Santana and Gasques 2019). High-yielding or high-adaptive crop cultivars were developed, which directly drove the soybean expansion towards low latitudes to the northern territory of the country (see Fig. 6 above) (Cattelan and Dall'Agnol 2018). Likewise, pasture intensification was implemented by high-quality grass, high-efficiency forage, and advanced animal-raising techniques (Latawiec et al. 2014).

Lastly, the global food market and international commodity crops trade have direct impacts on the agriculture sector in Brazil. For example, in 2017, China and the European Union were the two largest destinations for Brazil's agricultural products: more than $20 billion of Brazilian soybean production was exported to China, accounting for 88% of Brazilian agricultural exports to this country; 14% of Brazilian agricultural exports to the European Union was soybean (Gale et al. 2019). For Brazilian beef production, the export to the global food market boomed in the 2000s, with the majority proportion of the export to North Africa, Western Asia, and the European Union (FAO, https://www.fao.org/faostat/en/#data/QCL

Accessed on November 10, 2025). However, in the recent decade, the proportion of beef export to Russia has significantly increased partly owing to the rebound of Russian domestic beef consumption (Schierhorn et al. 2016). Considering the international agricultural trade dependence among these telecoupled countries, the global food market will serve as an important factor in Brazilian agricultural development consistently.

3.2. *Implications*

The agricultural expansion and intensification have transformed Brazil from a provider of domestic food demands and an exporter of tropical agricultural products (e.g., coffee, sugar) in the 1960s to a critical global food provider for soybean, corn, and meat during the twenty-first century. The agricultural exports have surged with an annual increasing rate of 12% since 2000, and accounted for 37% of the total exports in 2020 (Valdes et al. 2020). Nowadays, Brazil has become an important agricultural exporter to the global food market and a competitor of other suppliers in international trade, such as the European Union (EU) and the United States.

However, boosting food production through expansion, at the cost of encroachment of natural vegetation land in all biomes across the country, has raised various environmental concerns. Between 1985 and 2021, the Brazilian cropland expanded 2.3 times, and pasture area increased 39%, accompanied by 84.7 Mha net loss of native vegetation (MapBiomas 2022). This remarkable land cover change indicates tremendous biodiversity loss, such as a decline in Amazon tree species richness (Gomes et al. 2019) and a reduction in the diversity of ants and birds (Nunes et al. 2022). Under the ongoing compound influence of agricultural expansion and intensification, Brazil is projected to be one of the regions having the highest risk of biodiversity loss in terms of terrestrial vertebrate species (Kehoe et al. 2017). The Brazilian Amazon experienced deforestation with the highest rates, which has been driven largely by the expansion of pasture for beef production and cropland for commodity crop production (Song et al. 2021; Zalles et al. 2019). The resultant deforestation further caused well-documented environmental issues, including carbon emission increase (Aragao et al. 2018), rainfall reduction (Spracklen and Garcia-Carreras 2015), tree species extinction (Gomes et al. 2019), as well as public health concerns (MacDonald and Mordecai 2019). To reduce deforestation, especially driven by agriculture, governmental policies and supply-chain interventions have been introduced, which have enabled a remarkable reduction of deforestation rates since 2004 (Nepstad et al. 2014). However, the rebound of deforestation rate in the recent decade demonstrates that it remains a big challenge to maintain high agricultural productivity with zero deforestation in this country (Silva Junior et al. 2021).

Regarding agricultural intensification, the traditional single cropping system has been adopted to double cropping in some Brazilian states, such as Mato Grosso, and this shift was found to reduce local deforestation, in the short term (Garrett et al. 2018). Recent studies show that cattle ranching intensification could be a viable solution to spare land from deforestation and reduce global greenhouse gas emissions (GHG) (Cohn et al. 2014). In addition, the soybean intensification via yield improvement and land area expansion only from existing pasture could keep the continuation of the increasing trend in soybean production, yet help the Amazon forest protection simultaneously (Marin et al. 2022). However, the potential environmental impacts related to such intensification need to be explored further, such as soil degradation, water balance, and threats to primarily farmland species (Hunke et al. 2014; Spera et al. 2016; Zabel et al. 2019).

From the social perspective, while the agricultural development (especially soybean production) depleted natural ecosystems and led to adverse environmental impacts, it brought national economic growth, raised living standards, and improved general social well-being in the country (Song et al. 2021). Some regions gained social benefits of increased income, better education and health resources, although income inequality and rural violence related to this boom in agricultural production also occurred (Stabile et al. 2020).

4. Conclusion

Brazil’s agricultural sector has undergone a profound transformation over the past six decades, driven by domestic demand, governmental policy, technological innovation, and global market integration. Together, these factors led to both agricultural expansion into new frontiers and intensification on existing agricultural lands, making Brazil one of the most influential actors in the global food system. Yet these agricultural activities have caused far-reaching environmental consequences. Large-scale conversion of native vegetation into cropland and pasture has created persistent threats to ecosystem services. Understanding the spatiotemporal trajectories of Brazil’s agricultural development, along with their underlying drivers and implications, remains essential for designing integrated strategies that reconcile agricultural productivity with conservation objectives. As global food demand continues to increase with an increasing global population, a synthesis on Brazil’s agricultural development over half a century provides critical insights on balancing agricultural production, environmental sustainability, and governance in other rapidly transforming agricultural regions worldwide.

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