Article

Not peer-reviewed version

Socio-Ecological Impacts and Sustainable Transformation Pathways of Soybean Cultivation in the Brazilian Amazon Region

Zhang Min *, Fernando Romero Wimer, Marcos Jardim Pinheiro, Paula Daniela Fernández

Posted Date: 30 May 2025

doi: 10.20944/preprints202505.2387.v1

Keywords: Amazon forest; soybean cultivation; deforestation; sustainable agriculture; agroforestry; international governance; indigenous rights

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 May 2025 doi:10.20944/preprints202505.2387.v1

Article

Socio-Ecological Impacts and Sustainable Transformation Pathways of Soybean Cultivation in the Brazilian Amazon Region

Zhang Min [1,*], Fernando Romero Wimer [2], Marcos Jardim Pinheiro [2] and Paula Daniela Fernández [2,]

[1] Center for American Studies, Nanjing Agricultural University, Nanjing, Jiangsu (China)
[2] Latin American Institute of Economics, Society and Politics, Federal University of Latin American Integration, Foz do Iguaçu (Brazil)
* Correspondence: springzm@njau.edu.cn; Tel.: +86-15951997593

Abstract: This study examines the ecological and socio-economic impacts of soybean cultivation in the Brazilian Amazon region and explores pathways for sustainable transformation. As the world's largest tropical rainforest, the Amazon plays a critical role in global climate regulation and biodiversity conservation. However, soybean expansion since the 1990s, driven by international demand and domestic policies, has led to significant deforestation, soil degradation, water resource depletion, and biodiversity loss. The conversion of forests into monoculture plantations has disrupted hydrological systems, increased pesticide pollution, and exacerbated social inequalities, particularly affecting indigenous communities through land disputes and cultural erosion. Governance challenges, including weak enforcement of environmental laws, conflicting domestic policies, and the limited efficacy of international agreements, further hinder sustainable outcomes. The study proposes agroforestry systems as a viable alternative to monoculture, integrating soybean cultivation with native trees to enhance soil health and biodiversity. It also emphasizes strengthening land governance, revising Brazil's Forest Code, enhancing international cooperation, and improving supply chain regulations to curb deforestation and promote sustainability.

Keywords: Amazon forest; soybean cultivation; deforestation; sustainable agriculture; agroforestry; international governance; indigenous rights

---

1. Introduction

The Brazilian Amazon, the world's largest tropical rainforest, serves as a cornerstone of global ecological stability. Renowned for its unparalleled biodiversity and critical role in carbon sequestration, this vast biome regulates global climate patterns, sustains hydrological cycles, and harbors countless endemic species. However, since the late 20th century, the region has faced escalating pressures from agricultural expansion, particularly soybean cultivation. Driven by surging international demand for animal feed and biofuels, alongside domestic policies promoting agribusiness, soybean production has transformed the Amazon into a key agricultural frontier. This expansion, while economically lucrative, has come at a profound ecological and social cost.

The conversion of forests into monoculture soybean plantations has triggered widespread deforestation, disrupting ecosystems and accelerating biodiversity loss. Soil degradation, water resource depletion, and pesticide pollution further compound environmental challenges. Socioeconomically, soybean-driven land use changes have intensified social inequalities, displacing rural communities and igniting conflicts over indigenous territories. Governance frameworks, both domestic and international, have struggled to reconcile economic growth with sustainability, hampered by weak enforcement of environmental laws, conflicting policies, and the limited effectiveness of voluntary agreements. In 2025, with the beginning of the tariff war between China

 doi:10.20944/preprints202505.2387.v1

and the United States, as well as the increasingly close relationship between China and Brazil, American soybeans in the Chinese market will soon be replaced by Brazilian soybeans. This has further deepened concerns about the relationship between Brazilian soybean production and the sustainable development of Brazilian Amazon region.

This study seeks to unravel the complex interplay between soybean cultivation and its multidimensional impacts in the Brazilian Amazon. By examining historical drivers, ecological consequences, socioeconomic disparities, and governance failures, it aims to identify viable pathways for sustainable transformation. Proposed solutions include agroforestry systems that integrate soybean cultivation with native vegetation, alongside policy reforms to strengthen land governance and international cooperation. Through this analysis, the research contributes to global dialogues on balancing agricultural development with the urgent need to preserve Earth's most vital ecosystems.

The article is structured as follows: Section 2 traces the historical trajectory of soybean cultivation in the Amazon; Sections 3 and 4 analyze its ecological and socioeconomic impacts; Section 5 evaluates governance challenges; and Section 6 proposes actionable strategies for sustainability. By bridging scientific inquiry with policy relevance, this work underscores the imperative of reimagining soybean production practices to safeguard the Amazon's ecological integrity and social equity.

2. History of Soybean Cultivation in the Brazilian Amazon

Soybeans originated in East Asia and began to spread to the West from the 18th century. The first record of soybeans in Brazil appeared in 1882, discovered by Gustavo D 'Utra, but due to the grain's intolerance to cold climates at the time, it did not succeed. Oilseed cultivation was successful after being introduced to the subtropical region of Rio Grande do Sul. The first commercial planting took place in Santa Rosa, Rio Grande do Sul [1]. After the 1970s, with the increasing demand for soybeans in international markets and the growing liberalization of soybean trade, the scale of soybean cultivation in Brazil rapidly expanded. However, due to the soybean varieties not being suitable for the tropical climate of the Amazon region, early development of soybeans production was mainly in non-Amazonian regions.

After successful cultivation of soybean varieties suitable for the Amazon region in 1990s, soybean cultivation in the Amazon region experienced a remarkable boom [2]. Apart from the novel variety, there are other two factors contributed to this expansion. Firstly, the international market demand for soybeans soared, driven by the growing need for animal feed and biofuel. Secondly, significant progress in agricultural technology, such as improved seeds and farming techniques, made it possible to cultivate soybeans in the Amazon's challenging environment. This period was marked by the United Nations Ecological Conference in 1992, which solidified the environmental agenda in global debates and emphasized the importance of protecting tropical forests. Despite of this, the expansion of soybean production has become a major project on Brazil's export agenda, attracting waves of domestic migration, particularly from southern and southeastern Brazil, which has intensified the occupation of Amazonian biomes and environmental degradation [3].

Between 2000 and 2014, the cropped area in Brazil expanded by 79%, going from around 26.0 million hectares (Mha) to nearly 46.5 Mha. The states that more than doubled their cropped areas – Mato Grosso, Mato Grosso do Sul, Pará, Bahia, Maranhão, Piauí and Tocantins – were defined as agricultural frontier [4]. According to IBGE data,, the evolution of the planted area in the Amazon states highlights the centrality of the state of Mato Grosso in this expansion dynamic [5]. In 2000, Mato Grosso already had 2.9 million hectares planted, jumping to almost 12 million in 2023, an increase of more than 9 million hectares in the period. Among the other states, Tocantins, Maranhão and Pará stand out, which also registered growth, but on a much smaller scale [6]. Between October 2020 and October 2021, the state of Mato Grosso exported approximately US$ 253.2 million in soybean products, with emphasis on the Chinese market. Although the oilseed represents an important part of the state's agricultural GDP, its expansion poses significant threats to native vegetation, both through direct and indirect conversion, especially in the Cerrado and Amazon biomes. It is estimated

 doi:10.20944/preprints202505.2387.v1

that, between 2021 and 2050, the crop will advance another 12.4 million hectares in the state, 10.8 million of which in the Cerrado alone, a biome with a low level of legal protection [7].

Table 1. Soybean area in the Amazon region of Brazil (1994/1995-2023/2024) Unit:thousands hectares.

Year	Amazonas	Pará	Mato Grosso	Maranhão	Rondônia	Acre	Amapá	Tocantins	Roraima
1994/1995	-	-	2,295.4	91.7	4.8	-	-	16.6	-
1995/1996	-	-	1,905.2	89.1	-	-	-	4.9	1.8
1996/1997	-	-	2,095.7	120	3.3	-	-	21.9	-
1997/1998	-	2.6	2,600	144	4.7	-	-	40.1	-
1998/1999	-	1.6	2,548	162.7	8.7	-	-	40.1	-
1999/2000	-	2.3	2,800	175.7	11.8	-	-	45.6	0.0
2000/2001	-	0.7	3,120	210	25.0	-	-	66.0	-
2001/2002	1.1	2.9	3,853,2	238.3	28.6	-	-	105.0	3.5
2002/2003	2.1	15.5	4,419.6	274	41.0	-	-	148.1	3.0
2003/2004	2.1	35.2	5,540.5	342.5	59.5	-	-	243.6	12.0
2004/2005	2.8	69.0	6,105.2	375	74.4	-	-	355.7	20.0
2005/2006	1.9	79.7	6,196.8	382.5	106.4	-	-	309.5	10.0
2006/2007	-	47.0	5,124.8	384.4	90.4	-	-	267.7	5.5
20072008	-	71.1	5,675	421.5	99.8	-	-	331.6	15.0
2008/2009	-	72.2	5,828.2	387.4	106.0	-	-	311.4	8.0
2009/2010	-	86.9	6,229.5	502.1	122.3	-	-	364.3	1.4
2010/2011	-	104.8	6,398.8	518.2	132.3	-	-	404.7	3.7
2011/2012	-	119.2	6,980.5	559.7	143.5	-	-	451.2	3.7
2012/2013	-	172.2	7,818.2	586	167.7	-	-	549.6	12.0
2013/2014	-	221.4	8,615.7	662.2	191.1	-	-	748.4	18.0
2014/2015	-	336.3	8,934.5	749.6	231.5	-	-	849.6	23.8
2015/2016	-	428.9	9,140	786.3	252.6	-	-	870.8	24.0
2016/2017	-	500.1	9,322	821.7	296.0	-	18.9	964.0	30.0
2017/2018	1.5	549.6	9,518.6	951.5	333.6	0.5	20.2	988.1	38.2
2018/2019	2.2	561.4	9,699.5	992.4	333.7	1.5	20.9	1,028.6	40
2019/2020	2.3	607.4	10,004.1	976.4	348.4	4.0	20.9	1,078.0	49.8
2020/2021	4.3	731.9	10,479.	1,005.7	396.5	6.1	5.3	1,210.5	70.0
2021/2022	4.5	828.5	11,108.5	1,075.1	491.7	6.1	6.5	1,340.8	95.0
2022/2023	6.9	939.5	12,086.0	1,192.7	595.0	12.0	7.4	1,438.4	123.0
2023/2024	17.7	1,129.3	12,376.1	1,329.7	643.2	17.5	7.5	1,456.7	118

Source: Own elaboration based on *Companhia Nacional de Abastecimento* (CONAB) (2025) [8]..

3. The Multidimensional Impact of Soybean Cultivation on the Amazonian Ecosystem

3.1. Soybean Cultivation and Amazon Deforestation

Since the 1990s, concerns over deforestation caused by soybean production in the Amazon region of Brazil have never ceased. Despite much debate about the relationship between soybeans and Amazon deforestation, Greenpeace's 2006 report "Eating Up the Amazon" exposed the practice of multinational grain companies planting soybeans on deforested land in the Amazon [9], drawing global attention. Following this, Greenpeace, alongside non-state actors, launched the Amazon Soybean Moratorium, a voluntary agreement that garnered support from major grain traders, Brazilian soybean growers, and exporters [10]. Meanwhile, the Brazilian government introduced the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) [11],deploying technological and legal tools to rigorously monitor and curb forest-clearing activities. These combined efforts led to measurable improvements in reducing Amazon deforestation rates.

However, after 2012, with the introduction of the new forest code [12], and the subsequent shift in Amazon deforestation governance from monitoring and control to market-driven ecosystem services, deforestation began to increase significantly. After 2019, during the Bolsonaro era, more lenient environmental governance measures were implemented, further exacerbating deforestation in the Amazon [13]. At the same time, there has been a notable increase in soybean cultivation in the Brazilian Amazon region.The soybean production area in 2019 in Brazilian Amazon states is 1.347 thousands ha, and this figure increased to 1.753 thousands ha in 2022. Although it remains to be demonstrated whether this expansion of soybean production directly led to deforestation in the Amazon, there are certain correlations between the two issues in many Amazonian states in Brazil.

Table 2. Deforestation of primary humid forest in the Amazon region of Brazil (2002-2023). Unit: millions of hectares

Year	Amazonas	Pará	Mato Grosso	Maranhão	Rondônia	Acre	Amapá	Tocantins	Roraima
2002	0.061	0.415	0.695	0.027	0.307	0.055	0.006	0.006	0.021
2003	0.074	0.367	0.771	0.020	0.240	0.027	0.004	0.009	0.026
2004	0.070	0.651	0.907	0.023	0.255	0;054	0.005	0.005	0.017
2005	0.125	0.578	0.582	0.040	0.315	0.124	0.007	0.012	0.015
2006	0.116	0.533	0.407	0.040	0.228	0.034	0.005	0.007	0.021
2007	0.068	0.451	0.366	0.032	0.137	0.030	0.005	0.008	0.030
2008	0.061	0.500	0.281	0.029	0.092	0.045	0.006	0.006	0.027
2009	0.080	0.311	0.128	0.013	0.080	0.030	0.012	0.006	0.025
2010	0.111	0.367	0.389	0.037	0.170	0.035	0.006	0.005	0.017
2011	0.064	0.288	0.238	0.017	0.120	0.032	0.005	0.009	0.014
2012	0.120	0.389	0.346	0.026	0.133	0.054	0.009	0.007	0.014
2013	0.088	0.241	0.132	0.023	0.060	0.044	0.007	0.011	0.015
2014	0.106	0.328	0.215	0.028	0.154	0.055	0.006	0.010	0.021
2015	0.119	0.257	0.207	0.022	0.131	0.041	0.006	0.011	0.022
2016	0.453	1.12	0.418	0.227	0.212	0.067	0.022	0.019	0.267
2017	0.197	0.832	0.625	0.055	0.227	0.070	0.020	0.038	0.033
2018	0.160	0.546	0.309	0.026	0.160	0.074	0.007	0.020	0.033
2019	0.183	0.480	0.299	0.014	0.159	0.077	0.005	0.010	0.120
2020	0.201	0.567	0.577	0.024	0.168	0.080	0.005	0.012	0.027
2021	0.277	0.497	0.375	0.020	0.204	0.108	0.003	0.007	0.022
2022	0.358	0.585	0.432	0.022	0.186	0.133	0.003	0.007	0.027
2023	0.255	0.407	0.219	0.034	0.078	0.056	0.011	0.008	0.039
Total	3.347	10.71	8.918	0.799	3.816	1.33	0.166	0.234	0.857

Source: Own elaboration based on Global Forest Watch (2025) [14]..

The Amazon region is one of the most biodiverse areas on earth [15], home to numerous unique species. Deforestation has led to the loss of vast habitats, directly threatening the survival of many wild plant and animal species. Many of these species have yet to be discovered by the scientific community [16], making their disappearance irrevocable. Deforestation results in significant habitat loss, which directly threatens the survival of numerous plant and animal species. Many of these species are not yet known to science, making their loss even more tragic [17]. At the same time, the conversion of forests into large-scale monoculture soybean plantations and the extensive use of glyphosate to ensure normal soybean growth further exacerbate the loss of biodiversity in deforested areas [18].

3.2. The Impact on Soil Quality in the Amazon

The conversion of native forests to agricultural land, including crops and pastures, leads to soil physical degradation. Manifestations include increased soil density, reduced macroporosity and reduced total porosity, which negatively affect soil water conductivity and overall soil health [19]. Beyond physical changes, deforestation followed by agricultural utilization also triggers substantial losses of soil organic carbon (SOC), a critical component for maintaining soil structure and fertility.

Studies have demonstrated that the conversion of forest to agricultural land reduces SOC stocks substantially [20].

Brazil's soybean cultivation employs a technology system developed in the United States, including genetically modified soybean varieties, glyphosate pesticides, and no-till farming [21]. Coupled with large-scale monoculture planting [22], this technology system has brought numerous negative impacts to the already less fertile soils of the Amazon region. First, the increased usage of fertilizers. Soybeans have nitrogen-fixing capabilities [23], which can increase soil nitrogen levels. However, soybean cultivation also requires substantial phosphorus fertilizers [24]. The soybean cultivation in the Amazon will significantly increase the phosphorus in the Amazonian soil. Second, the increased risk of soil degradation. While no-till technology can reduce soil erosion, its effect on improving soil structure is limited [25]. Long-term use of no-till techniques for soybean cultivation can make the soil more compact [26], reducing its aeration and water permeability [27], which affects the activity of soil microorganisms and further depletes soil fertility.

3.3. The Impact on Water Resources in the Amazon Region

Forests play a vital role in maintaining water quality and supply. Conversion of forests to agricultural land has altered hydrological regimes, increasing surface runoff and decreasing groundwater contributions [28]. For instance, in the Upper Teles Pires basin, forest conversion to agriculture increased surface runoff by 30.8% and decreased groundwater contributions by 5.29% between 1986 and 2014 [29]. Similarly, in the Jari River Watershed, deforestation and climate change scenarios projected increased surface runoff and variability in streamflow, intensifying flood risks and reducing water availability during dry periods [30].

Large-scale soybean cultivation requires substantial water resources. Despite the Amazon region's abundant water supply, extensive irrigation facilities are needed to be constructed to meet the water needs of soybean farming [31], which may cause some disruption to river ecosystems. These irrigation systems draw large amounts of water from rivers, leading to reduced flow rates. Some small rivers have even dried up, affecting the balance of river ecosystems. Moreover, soybean fields intercept more rainfall compared to intact forests, leading to reduced net precipitation and potentially lower water availability in the long term [32]. This change in water balance can affect regional hydrology and water resources [33].

Another issue is that chemical fertilizers and pesticides used in industrial agricultural production enter rivers via water flow, causing water pollution and adversely affecting the survival and reproduction of aquatic organisms. Large-scale soybean farming contributes to the pollution of aquatic ecosystems with pesticide residues such as atrazine, metolachlor, DDTs, and endosulfan. These contaminants are found in groundwater, surface water, and sediments near soybean fields [34].

4. The Impact on the Socio-Economic Situation in the Amazon Region

4.1. Agricultural Economic Income and Distribution Imbalance

Soybean production has been a key driver of economic development in the region. It has increased rural incomes and contributed to the overall economic growth of municipalities involved in soybean farming [35]. The increase in GDP per capita in soybean-producing areas highlights the economic benefits [36]. Despite the economic benefits, soybean production has also been closely associated with heightened social inequality. Large-scale soybeans farming often benefits wealthier farmers, exacerbating existing ethnic and social tensions between them and local populations [37]. The expansion of soybean farming has resulted in the displacement of local populations to urban areas, contributing to higher unemployment rates among young people. This displacement can deepen social divides and create economic disparities [38]. Concurrently, land consolidation by more technically skilled and capital-rich farmers has led to the deepening of class divisions in rural areas, further increasing social inequality [39].

Beyond social fragmentation, the intensive use of pesticides in soybean cultivation has had negative health impacts on rural workers and nearby residents, affecting the longevity dimension of the Human Development Index (HDI) [40]. Additionally, the expansion of soybean farming has led to the development of large logistical structures and transportation corridors, which have further transformed rural landscapes and influenced land commodification [41].

4.2. Conflict with Indigenous Community and Land Tenure Dispute

The Amazon region serves as a critical stronghold for Brazil's indigenous populations. This region holds 43% of Brazil's indigenous people and contains 99% of the country's indigenous lands [42]. Brazilian law prohibits the cultivation of genetically modified crops in indigenous land. Therefore. according to Brazilian law, genetically modified soybeans cannot be grown in indigenous land. Nonetheless, soybean production still has a significant impact on the indigenous people of the Amazon region.

Brazil's democratic Constitution of 1988 represented a major paradigm shift from a view that aimed to integrate and assimilate indigenous populations to one that, for the first time, recognized the right of indigenous people to their own culture. However, the demarcation of indigenous land still faces challenges today [43]. Weak land governance and incomplete demarcation of indigenous land boundaries in the Brazilian Amazon have created fertile ground for conflict [44]. In the Amazon region of Brazil, land disputes caused by soybean cultivation have led to intense conflicts between indigenous communities and agricultural developers [45]. Such land encroachment not only infringe on the legitimate rights and interests of indigenous people, but also destroy the local ecological environment and cultural diversity. However, the existing judicial relief mechanism is inadequate to solve these problems.

On the one hand, judicial procedures are cumbersome and protracted. When indigenous communities seek legal recourse, they often have to go through lengthy litigation processes, which consume a great deal of time and energy. Many indigenous people, due to a lack of legal knowledge and financial support, are unable to effectively protect their rights. On the other hand, local governments and judicial institutions, when handling these cases, are often influenced by agricultural lobbying groups, leading to favoritism towards agricultural developers. This makes it difficult for the judicial relief mechanism to function as intended, and land rights disputes in indigenous communities remain unresolved.

In addition, the transformation of the Amazon into a commercial agriculture center has often been at odds with the traditional socio-ecological practices of indigenous communities. This shift has led to cultural displacement and the erosion of traditional ways of life [46].

5. Governance Framework and Dilemmas

5.1. Brazilian Domestic Law and Polices

Brazil has taken numerous measures to curb Amazon deforestation, with the most prominent being the Amazon Deforestation Prevention and Control Program (PPCDAm) [47]. Although this program once achieved good results, its long-term effectiveness is still questionable due to the risk of policy instability. For example, the government of the former President Bolsonaro undermined the PPCDAm and removal of important agenda from the Ministry of Environment, fragmenting the well-nested system that structured that program [48]. Meanwhile, several domestic laws in Brazil have indirectly encouraged deforestation. One example is the 2012 Forest Code, which introduced impunity for certain deforestation activities [49], effectively lowering the regulatory threshold for forest clearance.

Beyond problems above-mentioned, conflicts between local and federal government policies have emerged as a critical challenge.The ties between the levels of government are considered diffuse and conflicting, and responsible for the fragmentation of power [50]. Agricultural lobbyists exert influence through political donations and interest-driven advocacy, pressuring local authorities to prioritize economic growth and political gains [51]. In response, some local governments have relaxed environmental regulations for soybean agribusinesses, weakening the implementation of national environmental laws at the regional level and exacerbating ecological degradation in the Amazon.

5.2. International Governance Frameworks Based on Sovereignty

The international community has established a legal system governing environmental protection and land tenure, with key instruments spanning climate action, biodiversity conservation, pesticide regulation, and indigenous rights. These international laws include: the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) , ILO Convention No. 169 (Indigenous and Tribal Peoples Convention,1989), the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). In addition, to address various unsustainable issues in the global soybean supply chain, some countries and regions have established specialized international treaties to regulate these problems. For example, the European Soya Declaration launched in 2017 that committed them to promote sustainable and certified soybean (and other legumes) production and markets in Europe [52], requiring soybean production to avoid damaging high-value protected areas such as forests and regions with high carbon storage.

However, due to constraints of sovereignty, the effectiveness of these legal efforts by the international community is not ideal, as these international rules are difficult to implement in soybean-producing countries like South America.

5.3. Voluntary Governance of Non-State Actors

In order to reduce the adverse environmental and social impacts of soybean production and trade, non-state actors such as multinational corporations, industry associations and environmental organizations are actively exploring the transnational sustainable trade of soybean and have formulated relevant voluntary governance rules. Amazon Soy Moratorium is one of the more representative ones.

The Amazon Soy Moratorium (ASM), implemented in 2006, has had a significant impact on reducing deforestation in the Brazilian Amazon, particularly in areas suitable for soy cultivation [53]. The ASM led to an 84% decrease in the rate of deforestation in the Brazilian Amazon between 2004 and 2012, contributing to one of the great conservation successes of the twenty-first century [54]. However, the direct deforestation for soybean expansion declined following the implementation of the ASM, accompanied by indirect deforestation associated with soybean expansion and transferring of deforestation to the Cerrado region [55].

Other voluntary governance measures include: the Responsible Roundtable on Soybeans (RTRS), the Soja Plus Sustainable Soybean Program [56], the Forest-Friendly Soybean Pilot Project [57], and the Soybean Procurement Guidelines from the European Feed Manufacturers Association (FEFAC). However, due to flaws in the supply chain regulation of multinational corporations, these voluntary standards are prone to greenwashing issues [58]. Some suppliers, in an effort to cut costs, often choose to plant soybeans on illegally deforested land, making it challenging for multinational corporations to trace the source of these soybeans. Moreover, the lack of uniform standards and norms in the regulatory process among multinational corporations leads to variations in the intensity and methods of regulation across different companies, providing opportunities for unscrupulous suppliers.

6. Pathways for Sustainable Transformation of Soybean Production in Brazil Amazon

6.1. Agroforestry Systems as a Viable Alternative

Soybean production in the Brazilian Amazon is a significant economic activity, driven by both domestic and international demand. The expansion of soybean cultivation has been a major factor in the transformation of land use in the region, often at the expense of natural forests and other ecosystems [59]. However, agroforestry systems, which integrate trees with crops, present a promising alternative for sustainable soybean production in the Brazilian Amazon. These systems can enhance soil health, improve biodiversity, and provide additional income sources [60].

This model integrates soybean cultivation with forest protection, meeting the needs of agricultural production while also contributing to ecological balance. By intercropping soybeans with trees, the soil quality can be improved. The roots of native tree species can penetrate deep into the soil, enhancing its aeration and water retention, while also fixing nutrients in the soil and reducing soil erosion. Soybeans, through nitrogen fixation by rhizobia, provide additional nitrogen to the soil, promoting tree growth. This mutually beneficial symbiotic relationship effectively enhances soil fertility, laying a foundation for long-term agricultural production. As one of the countries with the longest history of soybean cultivation, China has long adopted this model. The ancient Chinese agricultural text "Qi Min Yao Shu" records that soybeans benefit mulberry trees [61], meaning that intercropping soybeans with mulberry trees can promote the growth of mulberry leaves.

Currently, the Brazilian Agricultural Research Corporation, Embrapa, has developed a series of technical solutions for this model [62]. By selecting suitable intercropping soybean varieties and native tree species, they have optimized planting density and layout, enhancing the system's productivity and stability [63]. Through proper spatial configuration, both soybeans and trees can make full use of sunlight, water, and nutrients. Studies have shown, soybean yield in agroforestry systems can vary significantly based on the arrangement and density of tree rows. Wider alleys (e.g. 42 meters) between tree rows tend to result in higher soybean yields compared to narrower alleys (e.g. 18 meters) [64].

6.2. Improving Domestic Laws and Policies in Brazil

Due to significant deficiencies in Brazil's domestic laws and policies in preventing deforestation in the Amazon, to promote sustainable soybean production in the Amazon, Brazil needs to enhance its domestic legal and policy frameworks. Firstly, Improving land governance is crucial as deforestation primarily occurs where property rights are not clearly established. Efforts such as the Terra Legal program and improvements in the registration process can address public land problems and reduce deforestation rates [65]. Secondly, the law should be revised to close the loopholes that allow for "legal deforestation". The current impunity issue in the several laws have contributed to forest destruction. A more stringent and well - defined legal system can better protect the Amazon rainforest.

In addition to policy formulation, enforcement and monitoring need to be strengthened. The rural environmental registration system (CAR) can be integrated more effectively. This system requires landowners to register their environmental assets and management plans. By ensuring that all landowners comply with the registration requirements and regularly update their information, the government can better monitor land use and enforce environmental regulations [66].

6.3. Strengthen International Cooperation on Sustainable Soybean Governance in the Amazon Region

Given that the limitations of Brazil's domestic legal frameworks can't be solved in short term, strengthening international cooperation has become critical to advancing sustainable soybean production governance in the Amazon. Over recent decades, the international community has launched numerous collaborative initiatives for Amazon forest protection, including the Pilot Programme to Conserve the Brazilian Rainforests (PPG7), the Amazon Fund, and REDD+ (Reducing Emissions from Deforestation and Forest Degradation). While these projects have yielded partial success, they have not fundamentally curbed Amazon deforestation. A key limitation lies in their focus on localized governance—prioritizing governance of the Amazon region, while overlooking drivers in distant international markets.

In an era of telecoupling, the factors driving Amazon deforestation extend far beyond the region's borders. Soybean production in the Brazilian Amazon region heavily influenced by distant international markets, exemplifies a telecoupling system [67]. Thus, addressing these transboundary drivers is essential to ensuring sustainable soybean development in the Amazon and reducing soy-driven deforestation. To this end, major soybean-importing countries must enhance governance of the soybean supply chain through transnational supply chain legislation, preventing unsustainable Amazonian soybeans from entering domestic markets. European nations have led in this effort by prohibiting imports of soybeans linked to deforestation [68]. However, other major importers—such as China—still need to strengthen their regulatory frameworks in this area.

Additionally, greater oversight of voluntary soybean standards established by non-state actors is required to mitigate greenwashing risks and amplify their role in promoting sustainable production. This could involve rigorous audits of standard implementation, mandating that importers provide verifiable proof of origin and transportation documentation to ensure compliance.

Author Contributions: Conceptualization, Zhang Min and Fernando Romero Wimer; methodology, Fernando Romero Wimer; formal analysis, Zhang Min and Fernando Romero Wimer; resources, Marcos Jardim Pinheiro and Paula Daniela Fernández; data curation, Marcos Jardim Pinheiro and Paula Daniela Fernández; writing—original draft preparation, Zhang Min and Fernando Romero Wimer; writing—Zhang Min and Fernando Romero Wimer.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: During the preparation of this manuscript/study, the author(s) used ChatGPT for the purposes of Language proofreading. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Gazzoni, Decio Luiz; Dall`Agnol, Amélio. A saga da soja. Brasília: EMBRAPA, 2018.
2. Cattelan, A. J., & Dall'Agnol, A. (2018). The rapid soybean growth in Brazil. OCL, 25(1), D102.
3. IMAZON. Linha do tempo: Entendo como ocorreu a ocupaÇão da Amazônia. IMAZON. 2013. https://imazon.org.br/imprensa/linha-do-tempo-entendacomo-ocorreu-a-ocupacao-da-amazonia/.
4. Zalles, V.; Hansen, M. C.; Potapov, P. V.; Stehman, S. V.; Tyukavina, A.; Pickens, A.; Song, X.-P.; Adusei, B.; Okpa, C.; Aguilar, R.; John, N.; Chavez, S. Near Doubling of Brazil's Intensive Row Crop Area Since 2000. Proc. Natl. Acad. Sci. USA 2019, 116, 428–435, https://doi.org/10.1073/pnas.1810301115.
5. IBGE - – Instituto Brasileiro de Geografia e Estatística. IBGE. [Online] April 1st, 2025. https://www.ibge.gov.br.
6. IBGE - – Instituto Brasileiro de Geografia e Estatística. IBGE. [Online] April 1st, 2025. https://www.ibge.gov.br.
7. Valdiones, A. P.; Silgueiro, V.; Carvalho, R.; Bernasconi, P.; Vasconcelos, A. Soja e desmatamento ilegal: estado da arte e diretrizes para um protocolo ampliado de grãos em Mato Grosso. Relatório técnico – Instituto Centro de Vida 2022, 1–9.
8. Companhia Nacional de Abastecimento (CONAB) (2025). "Soja" https://www.gov.br/conab/pt-br/atuacao/informacoes-agropecuarias/safras/series-historicas/graos/soja
9. Langert, B. (2019). The Battle for the Amazon Rainforest. In The Battle to Do Good (pp. 171-188). Emerald Publishing Limited.
10. Amaral, D. F., de Souza Ferreira Filho, J. B., Chagas, A. L. S., & Adami, M. (2021). Expansion of soybean farming into deforested areas in the amazon biome: the role and impact of the soy moratorium. Sustainability Science, 16(4), 1295-1312.
11. Silva Junior, C. H., Pessôa, A. C., Carvalho, N. S., Reis, J. B., Anderson, L. O., & Aragão, L. E. (2021). The Brazilian Amazon deforestation rate in 2020 is the greatest of the decade. Nature ecology & evolution, 5(2), 144-145.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 May 2025 doi:10.20944/preprints202505.2387.v1

12. Vieira, R. R. S., Ribeiro, B. R., Resende, F. M., Brum, F. T., Machado, N., Sales, L. P., ... & Loyola, R. (2018). Compliance to Brazil's Forest Code will not protect biodiversity and ecosystem services. Diversity and Distributions, 24(4), 434-438.
13. Menezes, R. G., & Barbosa Jr, R. (2021). Environmental governance under Bolsonaro: dismantling institutions, curtailing participation, delegitimising opposition. Zeitschrift für vergleichende politikwissenschaft, 15(2), 229-247.
14. Global Forest Watch (2025). Brazil. https://www.globalforestwatch.org/dashboards/country/BRA/1/?map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D
15. Garda, A. A., Da Silva, J. M. C., & Baiao, P. C. (2010). Biodiversity conservation and sustainable development in the Amazon. Systematics and Biodiversity, 8(2), 169-175.
16. Barreto, C., & Machado, J. (2001). Exploring the Amazon, explaining the unknown: views from the past. Unknown Amazon: studies in visual and material culture, 232-251.
17. Feng, X., Merow, C., Liu, Z., Park, D. S., Roehrdanz, P. R., Maitner, B., ... & Enquist, B. J. (2021). How deregulation, drought and increasing fire impact Amazonian biodiversity. Nature, 597(7877), 516-521.
18. Lozano, V. L., & Pizarro, H. N. (2024). Glyphosate lessons: is biodegradation of pesticides a harmless process for biodiversity?. Environmental Sciences Europe, 36(1), 55.
19. Moratelli, F. A., Alves, M. A. B., Borella, D. R., Kraeski, A., Almeida, F. T. D., Zolin, C. A., ... & Souza, A. P. D. (2023). Effects of Land Use on Soil Physical-Hydric Attributes in Two Watersheds in the Southern Amazon, Brazil. Soil Systems, 7(4), 103.
20. Maia, S. M., Ogle, S. M., Cerri, C. E., & Cerri, C. C. (2010). Soil organic carbon stock change due to land use activity along the agricultural frontier of the southwestern Amazon, Brazil, between 1970 and 2002. Global Change Biology, 16(10), 2775-2788.
21. Ofstehage, A., & Nehring, R. (2021). No-till agriculture and the deception of sustainability in Brazil. International Journal of Agricultural Sustainability, 19(3-4), 335-348.
22. Rodrigues, R. R., Gandolfi, S., Nave, A. G., Aronson, J., Barreto, T. E., Vidal, C. Y., & Brancalion, P. H. (2011). Large-scale ecological restoration of high-diversity tropical forests in SE Brazil. Forest Ecology and Management, 261(10), 1605-1613.
23. Hungria, M., & Mendes, I. C. (2015). Nitrogen fixation with soybean: the perfect symbiosis?. Biological nitrogen fixation, 1009-1024.
24. Khan, B. A., Hussain, A., Elahi, A., Adnan, M., Amin, M. M., Toor, M. D., ... & Ahmad, R. (2020). Effect of phosphorus on growth, yield and quality of soybean (Glycine max L.): A review. Ijar, 6(7), 540-545.
25. Díaz‐Zorita, M., Grove, J. H., Murdock, L., Herbeck, J., & Perfect, E. (2004). Soil structural disturbance effects on crop yields and soil properties in a no‐till production system. Agronomy Journal, 96(6), 1651-1659.
26. Ferreira, C. J. B., Tormena, C. A., Severiano, E. D. C., Zotarelli, L., & Betioli Júnior, E. (2021). Soil compaction influences soil physical quality and soybean yield under long-term no-tillage. Archives of Agronomy and Soil Science, 67(3), 383-396.
27. Betioli Junior, E., Tormena, C. A., Moreira, W. H., Ball, B. C., Figueiredo, G. C., Silva, Á. P. D., & Giarola, N. F. B. (2014). Aeration condition of a clayey Oxisol under long-term no-tillage. Revista Brasileira de Ciência do Solo, 38, 990-999.
28. Robinet, J., Minella, J. P., de Barros, C. A., Schlesner, A., Lücke, A., Ameijeiras-Mariño, Y., ... & Govers, G. (2018). Impacts of forest conversion and agriculture practices on water pathways in Southern Brazil. Hydrological Processes, 32(15), 2304-2317.
29. Lopes, T. R., Zolin, C. A., Mingoti, R., Vendrusculo, L. G., de Almeida, F. T., de Souza, A. P., ... & Uliana, E. M. (2021). Hydrological regime, water availability and land use/land cover change impact on the water balance in a large agriculture basin in the Southern Brazilian Amazon. Journal of South American Earth Sciences, 108, 103224.
30. Rufino, P. R., Gücker, B., Volk, M., Strauch, M., Cardozo, F. D. S., Boëchat, I. G., ... & Pereira, G. (2025). Modeling the Nexus of Climate Change and Deforestation: Implications for the Blue Water Resources of the Jari River, Amazonia. Water, 17(5), 660.

31. da Silva, E. H., Gonçalves, A. O., Pereira, R. A., Júnior, I. M. F., Sobenko, L. R., & Marin, F. R. (2019). Soybean irrigation requirements and canopy-atmosphere coupling in Southern Brazil. Agricultural Water Management, 218, 1-7.
32. Bäse, F., Elsenbeer, H., Neill, C., & Krusche, A. V. (2012). Differences in throughfall and net precipitation between soybean and transitional tropical forest in the southern Amazon, Brazil. Agriculture, ecosystems & environment, 159, 19-28.
33. Hayhoe, S. J., Neill, C., Porder, S., McHorney, R., Lefebvre, P., Coe, M. T., ... & Krusche, A. V. (2011). Conversion to soy on the Amazonian agricultural frontier increases streamflow without affecting stormflow dynamics. Global Change Biology, 17(5), 1821-1833.
34. de Azeredo Morgado, M. G., Passos, C. J. S., Garnier, J., De Lima, L. A., de Alcântara Mendes, R., Samson-Brais, É., & Lucotte, M. (2023). Large-scale agriculture and environmental pollution of ground and surface water and sediment by pesticides in the Brazilian Amazon: the case of the santarém region. Water, Air, & Soil Pollution, 234(3), 150.
35. Weinhold, D., Killick, E., & Reis, E. J. (2013). Soybeans, poverty and inequality in the Brazilian Amazon. World Development, 52, 132-143.
36. Andrade Neto, A. O. D., & Raiher, A. P. (2023). Socioeconomic impact of soybean crop in the minimum comparable areas of Brazil. Revista de Economia e Sociologia Rural, 62, e267567.
37. Weinhold, D., Killick, E., & Reis, E. J. (2013). Soybeans, poverty and inequality in the Brazilian Amazon. World Development, 52, 132-143.
38. Oliveira, R. C. D., & de Souza e Silva, R. D. (2021). Increase of agribusiness in the Brazilian Amazon: development or inequality?. Earth, 2(4), 1077-1100.
39. Lima, M., Skutsch, M., & de Medeiros Costa, G. (2011). Deforestation and the social impacts of soy for biodiesel: perspectives of farmers in the South Brazilian Amazon. Ecology and Society, 16(4).
40. Andrade Neto, A. O. D., & Raiher, A. P. (2023). Socioeconomic impact of soybean crop in the minimum comparable areas of Brazil. Revista de Economia e Sociologia Rural, 62, e267567.
41. Wesz Junior, V. J., Kato, K., Leão, A. R., Leão, S. A., & Lima, M. D. S. B. D. The recent dynamics of agribusiness sector from the west of Pará (Brazil): soybean expansion and logistical corridors.
42. au Brésil, C. D. I. (2015). En marge ou à la marge? Les populations amérindiennes du Brésil. Espace populations sociétés, 2014, 2-3.
43. Chiavari, J., & Lopes, C. L. (2020). Indigenous land rights in brazil: challenges and barriers to land demarcation. Indigenous Amazonia, Regional Development and Territorial Dynamics: Contentious Issues, 39-59.
44. Sullivan, L. (2013). Identity, territory and land conflict in Brazil. Governing Global Land Deals: The Role of the State in the Rush for Land, 253-273.
45. Franco da Silva, C. A., & Bampi, A. C. (2019). Regional dynamics of the brazilian Amazon: between modernization and land conflicts. Cuadernos de Geografía: Revista Colombiana de Geografía, 28(2), 340-356.
46. Adams, R. T. (2015). Neoliberal Environmentality among Elites: Becoming "Responsible Producers" in Santarém, B razil. Culture, Agriculture, Food and Environment, 37(2), 84-95.
47. Castelo, T. B. (2015). Brazilian forestry legislation and to combat deforestation government policies in the Amazon (Brazilian Amazon). Ambiente & Sociedade, 18, 221-242.
48. DAVID, H. C., & MACFARLANE, D. W. (2025). Controls on deforestation in the Brazilian Amazon: Explaining past success actions, new challenges and recommendations. Acta Amazonica, 55, e55es24213.
49. Azevedo, A. A., Rajão, R., Costa, M. A., Stabile, M. C., Macedo, M. N., Dos Reis, T. N., ... & Pacheco, R. (2017). Limits of Brazil's Forest Code as a means to end illegal deforestation. Proceedings of the National Academy of Sciences, 114(29), 7653-7658.
50. Neves, E. M. S. C. (2012). Environmental policy, municipalities and intergovernmental cooperation in Brazil. estudos avançados, 26, 137-150.
51. Oliveira Gozetto, A. C., & Thomas, C. S. (2014). Interest groups in Brazil: a new era and its challenges. Journal of Public Affairs, 14(3-4), 212-239.

 doi:10.20944/preprints202505.2387.v1

52. Debaeke, P., Tibi, A., Forslund, A., Guyomard, H., & Schmitt, B. (2022). Could domestic soybean production avoid Europe's protein imports in 2050?. OCL Oilseeds and fats crops and lipids, 29, 38.
53. Heilmayr, R., Rausch, L. L., Munger, J., & Gibbs, H. K. (2020). Brazil's Amazon soy moratorium reduced deforestation. Nature Food, 1(12), 801-810.
54. Heilmayr, R., Rausch, L. L., Munger, J., & Gibbs, H. K. (2020). Brazil's Amazon soy moratorium reduced deforestation. Nature Food, 1(12), 801-810.
55. Nepstad, L. S., Gerber, J. S., Hill, J. D., Dias, L. C., Costa, M. H., & West, P. C. (2019). Pathways for recent Cerrado soybean expansion: extending the soy moratorium and implementing integrated crop livestock systems with soybeans. Environmental Research Letters, 14(4), 044029.
56. Oliveira, A. C. T., da Silva Júnior, A. G., & Min, Z. (2023). Sustainability of Soybean Farms Participating in the Agro Plus Program in Minas Gerais State, Brazil: An Application of Cluster and Principal Component Analyzes. International Journal on Food System Dynamics, 14(4), 431-442.
57. Steward, C. (2007). From colonization to "environmental soy": a case study of environmental and socio-economic valuation in the Amazon soy frontier. Agriculture and Human Values, 24(1), 107-122.
58. Inês, A., Diniz, A., & Moreira, A. C. (2023). A review of greenwashing and supply chain management: Challenges ahead. Cleaner Environmental Systems, 11, 100136.
59. del Carmen Vera-Diaz, M., Kaufmann, R. K., Nepstad, D. C., & Schlesinger, P. (2008). An interdisciplinary model of soybean yield in the Amazon Basin: the climatic, edaphic, and economic determinants. Ecological Economics, 65(2), 420-431.
60. Balbinot Junior, A. A., Franchini, J. C., Debiasi, H., Mandarino, J. M. G., & Sichieri, F. (2018). Soybean performance in agroforestry systems using eucalyptus with sandy soil and tropical climate.
61. Jia Sixie. (1998) Qi Min Yao Shu. Nanjing, Jiangsu Guangling Ancient Book Engraving Society.
62. Junior, S. B., & Yared, J. A. G. (1991). Agroforestry systems as an ecological approach in the Brazilian Amazon development. Forest Ecology and Management, 45(1-4), 319-323.
63. Werner, F., Balbinot, A. A., Franchini, J. C., Ferreira, A. S., & Silva, M. A. D. A. E. (2017). Agronomic performance of soybean cultivars in an agroforestry system1. Pesquisa Agropecuária Tropical, 47(03), 279-285.
64. Ribeiro, R. D. S., Passos, A. M. D., & Aker, A. M. (2020). Agronomic performance of soybean crops under integrated production systems in the Southwestern Brazilian Amazon biome. Revista Brasileira de Engenharia Agrícola e Ambiental, 24(12), 793-799.
65. Reydon, B. P., Fernandes, V. B., & Telles, T. S. (2020). Land governance as a precondition for decreasing deforestation in the Brazilian Amazon. Land use policy, 94, 104313.
66. Carvalho, W. D., Mustin, K., Hilário, R. R., Vasconcelos, I. M., Eilers, V., & Fearnside, P. M. (2019). Deforestation control in the Brazilian Amazon: A conservation struggle being lost as agreements and regulations are subverted and bypassed. Perspectives in Ecology and Conservation, 17(3), 122-130.
67. Yao, G., Hertel, T. W., & Taheripour, F. (2018). Economic drivers of telecoupling and terrestrial carbon fluxes in the global soybean complex. Global Environmental Change, 50, 190-200.
68. Min, Z., & Wimer, F. R. (2025). Transnational governance of soybean land use in south America: A polycentric approach. Transnational Environmental Law, 14(1), 145-170.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.