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AGRICULTURE IN THE LEGAL AMAZON

**PRODUCTIVITY CONDITIONS,
CLIMATE RISKS, AND PROPOSALS FOR BETTER
PRODUCTION IN ALREADY CLEARED AREAS**



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Executive Summary

Agricultural policy in the Legal Amazon—Brazil's legally defined administrative region of nine states extending beyond the Amazon biome—has to prioritize increasing production on already-cleared land, reducing climate-related losses, and conserving forests that regulate rainfall. This approach is urgent due to persistently low farm productivity, more frequent droughts and fires, and stricter environmental requirements in credit and trade. In 2019, agriculture and livestock employed about 1.8 million people in the Legal Amazon, 17% of the region's employed population, compared to 8% in the rest of Brazil. Lower incomes, greater informality, and higher poverty mean production and income losses have especially severe social consequences (Alfenas, Cavalcanti, & Gonzaga, 2020).

Experience with grain production shows the region can produce more per hectare when farmers can adopt technology. Soybeans and corn achieve yields close to those of the country's most productive areas in hubs where research, seeds, fertilizers, credit, private technical assistance, storage, logistics, and buyers operate together. This system is consolidated in Mato Grosso and also found in parts of Tocantins, Rondônia, south-eastern Pará, and Maranhão (Conab, 2025; Embrapa, 2020; IBGE[1], 2025; Figures 1–3).

Cassava helps illustrate the contrast. The crop occupies about half of the agricultural area of family farms in Brazil's North region and is directly important for food security and rural income (IBGE, 2019; Smeraldi & Santos, 2021; see Appendix 1 for details). In 2024, Pará produced approximately one-fifth of Brazil's cassava, with yields of about 15 metric tons per hectare (IBGE, 2025). Rondônia followed a different trajectory. According to the Municipal Agricultural Production series, cassava yields rose from about 17 metric tons per hectare in 2007 to approximately 24 metric tons in 2021. Over the same period, the state expanded technical assistance, limestone distribution, and public procurement. The ProLeite Fund, a Rondônia state fund created to support the dairy value chain, financed services that also reached diversified family farms. The evidence indicates that this set of policies contributed to higher productivity, although it does not allow the result to be attributed to any single program (Rondônia, 2009, 2021, 2024a, 2024b; Embrapa Rondônia, 2020; Pereira & Castro, 2021; IBGE, 2025).

Support still reaches too few producers. In 2017, about 10% of farms in Brazil's North region received technical assistance and rural extension services; among family farmers, coverage was about 9% (IBGE, 2019; Pereira & Castro, 2021). Only 9% of family farmers in the region had access to credit, compared with 29% in the South (Souza & Albuquerque, 2023). Distance from markets increases these constraints. The typical municipality in the Legal Amazon had about half the market access of municipalities in other regions. Even after controlling for population distribution, market access was 1.8 times lower, highlighting the impact of transportation costs (Araújo, Bragança, & Assunção, 2022).

Public procurement could offset part of this disadvantage by guaranteeing a market for



family farmers. Through 2025, federal law required at least 30% of federal resources under the National School Feeding Program (Programa Nacional de Alimentação Escolar - PNAE)—a federal program that finances school meals and requires a share of food purchases to come from family farming [2] — to be used to purchase their products. Law No. 15,226/2025 raised this minimum to 45% starting in 2026 (Brasil, 2009, 2025c). Implementation, however, remained uneven. Between 2013 and 2016, only 27.4% of municipalities in the North met the required percentage, compared with 72.5% in the South (Oliveira et al., 2022). Studies on Marajó Island and other areas identify documentation, producer organizations, transportation, and infrastructure as barriers to program participation (Cabral et al., 2023; Gheller et al., 2025).

These production and logistics constraints have become more costly as extreme climate events have increased. Between 2021 and 2024, reported agricultural and livestock losses in the Legal Amazon averaged nearly R\$6 billion per year, based on data from the Integrated Disaster Information System compiled by InfoAmazonia (2025). These records understate total damage because many municipalities do not report economic losses. Droughts reduce production and river navigability. Floods disrupt transportation and marketing. Fires damage crops, pastures, and human health. In May and June 2019, hospital admissions of children for respiratory problems were up to twice as high in about 100 municipalities most affected by fires, particularly in Pará, Rondônia, Maranhão, and Mato Grosso (Fiocruz, 2019).

Part of this climate risk is exacerbated by deforestation. Forest removal reduces moisture recycling, decreases precipitation, and lengthens the dry season (Spracklen & Garcia-Carreras, 2015; Marengo et al., 2018). In the southern portion of the Brazilian Amazon, Leite-Filho et al. (2021) estimated that controlling deforestation could avoid agricultural losses of up to US\$1 billion per year by 2050. The estimate applies to the area studied and should not be extrapolated to the entire region, but it shows that forest loss imposes measurable costs on production.

These costs are already affecting financing decisions. By May 2025, the Rural Credit Bureau—Brazil's highest-level body for monetary, credit, and financial-system policy—had blocked registration of 16,271 operations totaling R\$6.38 billion due to environmental restrictions under National Monetary Council rules. Most blocks occurred after CMN Resolution No. 5,081/2023 (Banco Central do Brasil [BCB], 2025c; see Box 1). In foreign trade, the European Union Deforestation Regulation requires traceability and proof that covered products were not produced on land deforested after December 31, 2020 (União Europeia, 2023, 2025). Environmental compliance has begun to affect access to credit and important markets. Pressure to prevent further deforestation does not preclude production growth. Veríssimo, Assunção, and Barreto (2022) estimated that, under a higher-productivity scenario, the 84 million to 86 million hectares already deforested in the Amazon could accommodate the projected expansion of agriculture and livestock through 2030, while leaving more than 30 million hectares available for other uses, such as forest production. At the national level, Bolfe et al. (2024) identified about 28 million hectares of degraded planted pasture with natural conditions favorable to crop production. Using these lands depends on local assessments of soil,



climate, infrastructure, land tenure conditions, and restoration costs.

The ABC+ Plan 2020–2030 and the Caminho Verde Brasil Program recognize this potential by incorporating pasture restoration and climate adaptation into agricultural policy. Under Caminho Verde Brasil, the Ministry of Agriculture and Livestock announced a target to restore up to 40 million hectares over 10 years (Brasil, 2023; MAPA, 2025a). In the Amazon, results will depend on the areas selected, producers' access to financing and assistance, and safeguards that prevent the opening of new areas.

The main lesson from the diagnosis is that policy instruments must arrive in a coordinated manner and proper sequence. Credit without technical guidance can finance inefficient investments. Roads built before public land is formally allocated and enforcement is in place raise the value of irregular occupations and facilitate deforestation. Public procurement has little effect when calls for bids disregard producers' scale, production calendars, transportation constraints, and sanitary requirements. Productivity rises when research, assistance, credit, infrastructure, and markets reinforce one another, while controlling deforestation removes the economic advantage of expanding into new areas (Barreto, 2021).

The recommendations below are intended to increase farming productivity and resilience by leveraging existing instruments and expanding or improving them.

1. Create stable funding sources for research, assistance, and adaptation. Besides credit, stable resources are needed to purchase goods and services that isolated producers cannot obtain at scale. One tested model is sectoral funds financed by a levy collected at an organized point in a value chain and earmarked by law for these purposes, as already exists for coffee, oranges, rice, and milk. In the Amazon, livestock may offer the most promising funding base because it occupied 78% of already-cleared land in agricultural use in 2024[3] and is widely practiced by small and medium-sized producers who also grow crops. Between 2008 and 2017, livestock production received at least R\$11 billion per year in subsidies and tax expenditures [4], roughly twice the amount the country spent annually on public technical assistance (CNM, 2025). Converting part of this benefit into regional funds, governed by a council bringing together producers, government, and civil society, and subject to auditing and evaluation of results, could finance productivity and adaptation. Rondônia's ProLeite experience shows both the potential and the need for safeguards: resources collected from the dairy chain helped finance limestone and rural extension services that also benefited cassava production, but in 2025, the state government again required that the funds be transferred exclusively to public management.

2. Strengthen the resilience of isolated small-scale producers. Two federal programs create guaranteed markets for family farming: the National School Feeding Program (PNAE), which purchases food for public school meals, and the Food Acquisition Program (Programa de Aquisição de Alimentos - PAA), which purchases production and directs it to social assistance networks such as community kitchens and food banks. Enabling more producers in the region to serve these markets has required adaptations to producers' circumstances, including harvest calendars, small-scale production, dif-



difficult transportation, and regionally typical foods. The traditional-food commissions for Indigenous and traditional peoples—Catrapoa in Amazonas and the nationwide Catrapovos initiative—show how procurement can be adapted [5]. Between 2019 and 2024, local meetings involving the Federal Public Prosecutor’s Office (Ministério Público Federal - MPF)[6], education departments, sanitary-surveillance authorities, and community organizations led to adjustments in calls for bids, packaging, and sanitary requirements, while more than R\$11 million was allocated to traditional foods (MPF, 2025). These purchases should be accompanied by improvements in local infrastructure and agronomic assistance, including climate adaptation support, to strengthen the managerial and productive capacity of small-scale producers.

3. Select infrastructure based on local returns and the risks it avoids, not on project size. For small and medium-sized producers serving local markets, the first and last stages of transportation may matter most: local access roads that remain passable during the rainy season, small ports, storage facilities, electricity, and rural internet access (World Bank, 2018; Fuglie et al., 2020). Experience from other countries confirms this priority. In China, investment in basic rural roads generated more than 1.5 times its value in agricultural production, while major highways had virtually no effect (Fan & Chan-Kang, 2005). Large transport projects should move forward only after land tenure governance and enforcement are in place. Their evaluation should consider the full area of economic influence rather than only the road corridor, because highways change land prices and attract occupation over tens of kilometers (Araújo, Bragança & Assunção, 2022). Highway BR-319, which connects Manaus (AM) and Porto Velho (RO), illustrates the risk of reversing this sequence. The announcement that it would be paved was followed by increased illegal land grabbing (the fraudulent or unauthorized appropriation of public land for private ownership or control) and deforestation along the road (Ferrante, Andrade, & Fearnside, 2021).

4. Expand research on climate adaptation in the Amazon. The Amazon should be incorporated quickly into the Agricultural Climate Risk Zoning by Management Level (Zoneamento Agrícola de Risco Climático Níveis de Manejo - ZarcNM)—an extension of ZARC that incorporates farm-management practices affecting soil water retention and climate resilience—, and the “From Risk to Decision” project because the region combines growing climate risks—drought, heat, fire, and hydrological instability—with high vulnerability among family farmers, small-scale livestock producers, and isolated producers. Although ZarcNM rewards good practices with lower assessed risk and insurance premium subsidies of up to 50%, its recent expansion excluded important Amazonian states. In addition, Embrapa’s project to anticipate risks has only R\$2 million over 48 months and includes only one unit in the Legal Amazon, in Sinop, Mato Grosso [7] (MAPA, 2025; MAPA, 2026; Embrapa, 2026). The priority is to expand these initiatives to produce an Amazon-wide atlas of risks and adaptation for family farming that can guide research, technical assistance, insurance, credit, and technologies for cassava, corn, livestock, agroforestry systems, and the most exposed producers.



5. Treat standing forest as production infrastructure. The forest regulates rainfall, reduces fire risk, and sustains rivers that transport freight and generate energy; losing it makes agriculture itself more expensive and unstable. A structural measure for protecting forests is to formally allocate still-undesigned public forests (public forestlands that have not yet been formally allocated to a specific conservation, Indigenous, community, or other legally defined use) to conservation, sustainable use, or recognition of Indigenous peoples' rights, thereby placing them beyond the reach of illegal land grabbing. The importance of this measure is highlighted by the fact that, in 2025, there were 50 million hectares of public forests in the Amazon, where 20% of deforestation occurred (Observatório das Florestas Públicas, 2026). In addition to allocating public lands, it is necessary to strengthen satellite monitoring and enforcement and maintain the rule denying credit to those who illegally deforest—a combination that has reduced deforestation in the past (Assunção, Gandour, & Rocha, 2019; Assunção et al., 2020). One possible source of funding for effective protected-area management and forest restoration is the Pre-Salt Social Fund (Fundo Social do Pré-Sal), a public savings fund financed by oil production that now includes environmental protection and climate adaptation among its authorized purposes (Brasil, 2025a). The Pre-Salt Social Fund is Brazil's sovereign fund, financed primarily by federal revenues from oil and natural gas production in the country's offshore pre-salt fields.

Implementation. Taken together, the evidence suggests how the private and public sectors can complement and sequence actions to improve productivity and rural development. The value of these lessons lies in converting limited budgets into cumulative gains by prioritizing critical actions that unlock other factors. For example, combating deforestation through the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal - PPCDAm), Brazil's principal interagency strategy for reducing Amazon deforestation, and requiring quality in beef and cassava encouraged technology adoption and the use of rural credit to raise productivity. Adapting procurement notices facilitated the expansion of public purchases from small-scale producers. Where improving the factors of production is costly and slow, expanding social assistance, especially health and education, where services are deficient, becomes essential to reducing the vulnerability of small farmers.



1. Introduction

This report assesses agricultural conditions in the Legal Amazon and proposes measures to raise productivity on already-cleared land, reduce producers' vulnerability to climate change, and ensure that production growth does not depend on further deforestation. Forest protection is part of agricultural policy because forests contribute to rainfall formation and river maintenance, while their loss lengthens the dry season, increases fire risk, and can reduce agricultural income. In this report, the term "Amazon" refers to Legal Amazon. When a statistical source covers only Brazil's North region or the Amazon biome, that scope is specified in the text (Spracklen & Garcia-Carreras, 2015; Marengo et al., 2018; Leite-Filho et al., 2021).

Agriculture and livestock have greater social weight in the Amazon than in the rest of the country. In 2019, the sector employed about 1.8 million people, equivalent to 17% of the region's employed population, compared with 8% in the rest of Brazil. The region also had lower per capita household labor income, greater informality, and a higher incidence of poor households (Alfenas, Cavalcanti, & Gonzaga, 2020). These conditions link agricultural performance to income, food security, and households' ability to withstand climate-related losses.

Grains and cassava were selected because they reveal important differences in producers' capacity to adopt technology. Soybeans and corn account for most mechanized agriculture in the region and are linked to value chains that provide research, credit, inputs, private technical assistance, buyers, and logistics. Soybeans, in particular, respond to international prices and demand (Companhia Nacional de Abastecimento [Conab], 2025; Seixas et al., 2020; USDA ERS, 2026). Cassava is fundamental to food security and family-farm income and represents about half of the agricultural area of family farms in Brazil's North region (IBGE, 2019; Smeraldi & Santos, 2021; see Appendix 1 for details). The Legal Amazon also contains about 66% of the families and 90% of the area of Brazil's rural settlements, as detailed in Appendix 2.

In grain production, farmers more often encounter a combination of technology, financing, and demand that can reward higher productivity. In cassava production, technical knowledge may be available even when producers lack regular buyers, scale, transportation, continuous assistance, or sales security. In many cases, buyers do not pay for quality differences. Public policy needs to address the predominant constraint in each territory. Credit or technical assistance alone produces little result when markets, infrastructure, and practical conditions for marketing production are absent.

Droughts, floods, and fires already cause substantial losses. Between 2013 and 2024, disasters recorded by municipalities caused R\$732.2 billion in losses in Brazil. Agriculture accounted for 44.5% of that amount and livestock for 12.9%. The estimate is incomplete because only 48.3% of municipalities that issued disaster-related decrees



reported economic losses. In the Amazon, falling river levels add transportation costs and supply difficulties to damage suffered in the field (CNM, 2025).

Deforestation aggravates some of these risks. The forest recycles moisture and contributes to rainfall that supplies producing areas both inside and outside the Amazon. Its removal reduces precipitation, lengthens the dry season, and favors fires. Leite-Filho et al. (2021) estimated that, in the southern portion of the Brazilian Amazon, controlling deforestation could avoid agricultural losses of up to US\$1 billion per year by 2050. The estimate should not be extrapolated to the entire region, but it shows that forest loss imposes measurable costs on production. The forest serves as water infrastructure by helping maintain the regularity of rainfall, on which agriculture and livestock depend (Spracklen & Garcia-Carreras, 2015; Marengo et al., 2018; Leite-Filho et al., 2021).

The effects extend to financing. Central Bank of Brazil rules restrict rural credit in cases of noncompliance with environmental legislation, including properties under embargo for illegal deforestation, as detailed in Box 1 (BCB, 2025a). The rules also prohibit the use of controlled or directed funds for projects that involve clearing native vegetation, although under specific conditions, they allow financing for environmental restoration. These restrictions increase the economic cost of irregularities and seek to prevent rural credit from financing activities associated with illegal deforestation.

In foreign trade, the European Union Deforestation Regulation requires traceability and proof that covered products were not produced on land deforested after December 31, 2020. The obligations will apply beginning December 30, 2026, to medium-sized and large operators and to small operators already covered by the European timber regulation. For other small and micro-operators, the deadline will be June 30, 2027 (União Europeia, 2023, 2025). Deforestation control has thus begun to influence access to credit, legal risk, and the entry of agricultural products into important markets.

Production can grow on land that has already been cleared. Veríssimo, Assunção, and Barreto (2022) estimated that the 84 million to 86 million hectares already deforested in the Amazon could accommodate the projected expansion of agriculture and livestock through 2030, provided that part of this land were used more productively. At the national level, Bolfe et al. (2024) identified approximately 28 million hectares of planted pasture with intermediate or severe degradation and natural conditions favorable to crop production. Using this land could increase Brazil's annual-crop area by about 35% relative to the 2022/2023 crop year. This is a national estimate of biophysical potential, not immediate availability. Soil, climate, infrastructure, land tenure status, secondary vegetation, and financial feasibility need to be assessed at each location.

Federal agricultural policy already recognizes part of this relationship. The Plan for Adaptation and Low-Carbon Emissions in Agriculture—ABC+ Plan 2020–2030—provides for restoration of degraded pastures, increased productive efficiency, climate adaptation, and conservation of natural resources. The National Program for the Conversion of Degraded Pastures into Sustainable Agricultural and Forestry Production Systems, established by Decree No. 11,815/2023 and promoted by the Ministry of Agriculture and Livestock as the Caminho Verde Brasil Program, has a target of restoring



up to 40 million hectares over ten years (Brasil, 2023; MAPA, 2025a). The program is national; its contribution to the Amazon will depend on the selection of areas, environmental safeguards, and the effective channeling of financing toward land that has already been cleared.

Agribusiness leaders have also stated that the country has sufficient land and technology to increase production without further deforestation (MAPA, 2018, 2019; Frente Parlamentar da Agropecuária, 2023; Senado Federal, 2019). These statements document political support for the objective; evidence of feasibility comes from studies of productivity and the use of already-cleared land. Implementing this vision, however, depends on the practical alignment of policies that reduce the economic advantage of both illegal and legal deforestation. When clearing land is cheaper than restoring degraded land, production incentives can increase deforestation rather than productivity (Barreto, 2021).

The following chapters examine the factors that determine productivity, the constraints faced by grain and cassava producers, and the gaps in public procurement, climate risk, and infrastructure. The recommendations include technical assistance adapted to local conditions, more predictable public procurement, Agricultural Climate Risk Zoning by Management Level adapted to the Amazon, infrastructure with safeguards and deforestation controls, and treatment of the forest as the water infrastructure of agricultural production.

Box 1. Climate and Environmental Risks Are Already Restricting Rural Credit

Public and private banks are already changing their rural lending practices in response to deforestation and climate risks. As of May 2025, the Rural Credit Bureau had blocked 16,271 transactions totaling R\$6.38 billion, of which 15,276 transactions, or R\$6.07 billion, were blocked after CMN Resolution No. 5,081/2023 took effect (BCB, 2025c). BNDES, the Brazilian Development Bank, also prevented more than R\$1.1 billion in rural credit from being extended between February 2023 and April 2026, following 5,592 active alerts showing potential illegal deforestation, representing about 1% of the 551,700 applications reviewed during the period (Agência BNDES de Notícias, 2026).

This shift reveals that droughts, extreme heat, heavy rainfall, and floods affect agricultural production, rural incomes, collateral values, and borrowers' ability to repay, while also causing supply shocks and exerting upward pressure on food inflation (BCB, 2025a; BCB, 2025b). In its April 2025 Financial Stability Report, the Central Bank of Brazil estimated that drought and prolonged dry spells accounted for 84.4% of the National Financial System's exposure to physical climate risks, while the consumer staples macro-sector—which includes agriculture, livestock, food, and beverages—accounted for 52.6% of that exposure (BCB, 2025a).



2. What Determines Agricultural Productivity

Agricultural productivity results from the combination of natural resources, technology, human capital, infrastructure, markets, and institutions. Productivity is the ability to produce more with the same quantity of resources or to maintain production while using less land, labor, capital, energy, and inputs. In economic terms, the broadest measure is Total Factor Productivity (TFP), which compares output growth with growth in the combined factors of production. Institutions, in this context, are formal and informal rules and the public or private capacity to enforce them in areas such as property rights, commercial contracts, sanitary and environmental standards, and credit rules. In Brazil, between 1975 and 2020, the agricultural output index grew much more than the input index, and TFP accounted for a large share of production growth (Gasques et al., 2022). International studies point in the same direction: sustained productivity gains generally depend on research, technology diffusion, human capital, functioning markets, infrastructure, and institutions (Fuglie et al., 2020; Kim & Loayza, 2019; Akerman et al., 2025; OECD, 2025).

The biophysical base defines productive potential, but technology adoption depends on incentives and the capacity to respond. Soil, water, terrain, temperature, rainfall patterns, solar radiation, pests, diseases, and fire risk condition agricultural performance. This potential is converted into production when farmers have access to appropriate seeds or genetic material, technical assistance, credit, insurance, infrastructure, information, skilled labor, and marketing channels. When these items are missing, available technologies tend to be adopted at low rates even where technical solutions already exist (Kim & Loayza, 2019; World Bank, 2018; IPCC, 2022). In Brazil, differences in scale, technical assistance, market integration, and capital availability help explain the divergent productivity trajectories of small and large farms (Rada et al., 2019; Helfand & Taylor, 2021).

Markets and institutions affect productivity by changing rights, transaction costs, access to credit, risks, and expected returns on investment. Producers tend to invest when they expect an economic return, lower risk, or continued market access (North, 1990; Feder et al., 1985; Sunding & Zilberman, 2001; Besley, 1995; Karlan et al., 2014). Returns may arise from product requirements, such as cassava starch content, sanitary standards, and absence of contamination. They may also arise from requirements related to the production process, such as the absence of illegal deforestation, traceability of origin, environmental compliance, animal welfare, and compliance with labor law. These requirements can induce changes in production and post-harvest management, but they can also exclude producers who lack the capacity to adapt (Henson & Reardon, 2005; Henson & Jaffee, 2008; Reardon et al., 2009).



In the Amazon, regulatory and market incentives related to the production process tend to be decisive because they change the relative cost of expanding irregularly versus producing more efficiently on land that has already been cleared. When illegal deforestation becomes more costly, riskier, or incompatible with access to credit and markets, incentives increase to restore cleared land, improve production management, and document origin. The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), the Soy Moratorium, livestock Conduct Adjustment Agreements (Termos de Ajustamento de Conduta, TACs), and credit restrictions for properties with illegal deforestation increased the cost of irregular expansion. Studies indicate that enforcement with penalties, combined with economic incentives, reduces deforestation (Assunção, Bragança, & Hemsley, 2016; Assunção et al., 2020) and stimulates productivity gains (Garrett et al., 2018).

The experience of the Soy Moratorium indicates that market requirements concerning production processes can change land-use decisions. After the agreement, buyers stopped purchasing soybeans produced on land in the Amazon that had been deforested after July 2006 and began using satellite imagery to monitor. This arrangement reduced incentives for direct forest conversion where technology, infrastructure, and already-cleared land were available. Before the moratorium, about 30% of soybean expansion occurred on recently deforested land; afterward, that share fell to 1% (Gibbs et al., 2015). Later studies reinforce the role of monitoring, market pressure, and private governance, while indicating that these instruments can displace deforestation to other regions (Arima et al., 2011; Moffette & Gibbs, 2021).

In cattle production, the “China cattle” market illustrates how product and process requirements can induce productive investment. The Chinese market began demanding younger animals slaughtered before 30 months of age, specific sanitary standards, traceability, and appropriate carcass characteristics. The premium paid for this beef increased incentives to restore degraded pastures, use artificial insemination, improve genetics, accelerate finishing, adjust nutritional management, intensify production systems, and adopt feedlots in some hubs. Because exports to China accounted for about 16% of national production, demand was large enough to influence production decisions. Between 2013 and 2023, the share of rural credit directed to productivity-enhancing activities, such as pasture restoration, increased from 13% to 24% during a period of rising livestock productivity (Barreto et al., 2025).

In cassava production, demand for quality can also induce technology adoption, but through different mechanisms. When starch-processing plants pay for starch content because it serves industrial as well as food uses, the root's industrial yield creates an incentive to invest in appropriate varieties, soil management, pest control, and harvesting at the correct time. When Geographical Indications (GIs), such as Cruzeiro do Sul flour in Acre, add value to traditional flours, demand combines product and process attributes by linking quality to production practices and local knowledge. Public procurement can create an additional incentive by providing a market, regular demand, and minimum quality and food-safety standards. When buyers reward quality and consistency, producers have more reason to invest in better planting material, liming,



pest control, good manufacturing practices, and post-harvest quality. When the market buys undifferentiated products, technical gains tend not to translate into price, contracts, or marketing security, reducing incentives to adopt available technologies (Vilpoux, 2011; Barrett et al., 2012; Reardon et al., 2003; Embrapa Acre, 2017).

The effect of global warming on agriculture and livestock is already significant. Between 1985 and 2017, research, higher educational attainment, and technological progress explained about 60% of productivity growth, which in turn accounted for approximately 60% of the increase in production. Extreme heat, however, reduced the efficiency with which land, labor, machinery, and other inputs convert into output. In Brazil, this effect offset about 36% of productivity gains, reaching 95% in the Caatinga, 44% in the Amazon, 36% in the Cerrado, and 29% in the Atlantic Forest. In the Amazon, where approximately 69% of production growth resulted from additional input use (Helfand et al., 2026), productivity losses increase the risk that production growth will increasingly depend on new land.

Hsiao et al. (2026) show that this risk has already materialized along agricultural frontiers. Using data from 2001 to 2019, the authors estimated that extreme-heat shocks caused persistent forest loss, especially in the tropics, which they attributed almost entirely to cropland expansion. In Brazil, heat reduced crop yields, increased local agricultural prices, and encouraged the expansion of cultivated area. Between 2006 and 2019, the study attributed about 1.20 million hectares of deforestation along Brazil's agricultural frontier to extreme heat, equivalent to 8.17% of forest loss observed in that area and period.

These results indicate that agricultural adaptation, productivity growth, and forest protection should be integrated into the same policy. Research should develop crops and systems that are more heat-resistant; technical assistance should support their adoption; credit and insurance should reduce the risks of transition without financing deforestation; and infrastructure, traceability, territorial planning, and enforcement should prevent yield losses from being offset by opening new areas. Buyers and financiers should also establish verifiable requirements and support producers in meeting them. Without such coordination, extreme heat can offset part of the benefits of technology and turn territorial expansion into a private response to climate damage, increasing the economic and environmental costs of production growth (Hirschman, 1958; World Bank, 2018; Fuglie et al., 2020; Pereira & Castro, 2021; Araújo, Bragança, & Assunção, 2022; Helfand et al., 2026; Hsiao et al., 2026).



3. Diagnosis of Agricultural Productivity in the Legal Amazon and Sector Risks

3.1 Structural Productivity Challenges

Agricultural productivity challenges in the Legal Amazon result from the combination of limited technical assistance, poorly tailored credit, costly and vulnerable logistics, markets that provide little reward for quality, and weak territorial governance. These factors reduce technology adoption, increase losses, limit scale, keep producers out of more demanding markets, and can turn infrastructure, credit, and demand into incentives for irregular expansion when they arrive before land-tenure governance and enforcement.

Limited coverage of technical assistance and rural extension. Effective rural technical assistance and extension (ATER), Brazil's system of farm-level technical and extension services, enables the proper use of seeds, fertilizers, limestone, mechanization, irrigation, pest control, credit, and insurance. The broadest independent study in Brazil found a statistically significant increase of about R\$490 in the monthly income of family farmers who received technical assistance (Rocha Junior et al., 2020). Without assistance, farmers may receive credit and still plant an unsuitable variety, misuse resources, miss the planting window, or fail to meet quality requirements. In 2017, the average share of farms receiving technical assistance in the North region was close to 10%, far below the South; Rondônia, at 18.7%, was a regional exception associated with the work of Emater-RO and sectoral arrangements (Pereira & Castro, 2021; IBGE, 2019; Embrapa Rondônia, 2020). Inequality also exists within the North itself: 8.8% of family farmers received assistance, compared with 18% of non-family producers (Appendix 1).

Access to capital suited to raising productivity, rather than generic rural credit alone. Small producers in the Amazon are underfinanced: only 9% of family farmers in the North access credit, compared with 29% in the South; nationwide, only 10% of family producers with up to four hectares obtain credit, compared with 20% of those with 10 to 100 hectares. In 2022, the National Program for Strengthening Family Farming (Pronaf)—Brazil's main federal rural-credit program for family farmers—lending in the North amounted to R\$83/ha, eighteen times less than the R\$1,451/ha recorded in the South. In the North and Northeast, credit financed only 2% of the value of family-farm agricultural production, compared with 14%–15% in commercial agriculture. Cassava, bananas, cocoa, pineapples, oranges, and açaí received credit equivalent to



less than 10% of their sales value through Pronaf, while corn, wheat, and soybeans received more than 40% (Souza & Albuquerque, 2023).

Credit has also frequently been used without improvements in productivity indicators in the Amazon. For example, in 2013, only about 13% of rural credit was used for purposes that could plausibly raise productivity, such as pasture restoration, fertilization, and infrastructure, while most credit was used to purchase cattle, which is not necessarily associated with productivity gains. Credit for productivity-enhancing purposes rose to about 23% after Chinese demand for beef from younger cattle induced productivity investments (Barreto et al., 2025).

Logistics. Poor or missing logistics reduce agricultural prices and delivery reliability and increase costs in the Amazon, stemming from producers being farther from markets, relying on more fragile transportation infrastructure and, in many areas, relying on rivers vulnerable to drought. The typical municipality in the Legal Amazon has potential market access 2.1 times lower than the typical municipality elsewhere in the country; after removing the effect of population distribution, market access is still 1.8 times lower, indicating that transportation costs are the main determinant of the difference (Araújo, Bragança, & Assunção, 2022). This constraint can lead to losses of perishable products or discourage production. Dependence on rivers magnifies risk: severe droughts in the Amazon reduce navigability, isolate communities, and limit access to food, fuel, medicines, and basic services; in 2005, 2010, and 2016, the most severe episodes added more than a month of low-water conditions in affected regions (Santos de Lima et al., 2024).

Lack of markets that reward quality. Productivity rises when producers see that quality generates a price premium, a contract, or greater certainty of sale. In many territories, local buyers pay for basic volume rather than starch content, standardization, traceability, good practices, or consistency. The absence of a premium reduces incentives to adopt technology. Value-chain research shows that supermarkets, contracts, and demanding buyers can induce quality and investment when they reduce uncertainty over sales; the cassava cases indicate that this mechanism operates through starch processors, geographical indications, and public procurement (Reardon et al., 2003; Berdegué et al., 2005; Barrett et al., 2012; Vilpoux, 2011).

Territorial governance. Infrastructure, credit, and markets can stimulate productivity, but they can also encourage deforestation and illegal land grabbing when they arrive before land-tenure governance, environmental regularization, and enforcement. Undesignated public forests in the Amazon total about 50 million hectares; in 2025, they accounted for 20% of deforestation and included roughly 10 million hectares at high risk of illegal land grabbing, according to the Public Forests Observatory (2026). Formally allocating these areas is among the measures with the greatest potential to structurally reduce deforestation (Gandour et al., 2023; Moutinho et al., 2022; IPAM, 2025).

Productivity policies in the Amazon, therefore, need to combine technical assistance, targeted credit, infrastructure, markets that reward quality, and territorial governance (Table 1). If these instruments are applied without deforestation control, formal alloca-



tion of public lands, environmental regularization, and protection of critical areas, they may increase production while simultaneously increasing pressure on forests and public lands (Araújo, Bragança, & Assunção, 2022; Gandour et al., 2023; Moutinho et al., 2022).

Table 1. Structural Challenges and Effects on Agricultural Productivity in the Legal Amazon

Challenges	How decreases productivity	Corresponding policy
Insufficient ATER	Technology is not converted into correct practice; risk of management errors increases.	Stable financing for ATER in specific territories and public targets.
Incomplete credit or credit not conditioned on productivity improvements	Producers adopt technologies only partially and are unable to obtain returns.	Credit combined with assistance, soil analysis, sanitary support, and market access.
Deficient logistics	Post-harvest losses, lower prices received, and disruptions during droughts.	Infrastructure selected based on territorial impact and resilience.
Markets without a quality premium	Quality and productivity do not translate into income.	Public procurement, Geographical Indications, agro-industry, contracts, and remunerated standards.
Deforestation and land-tenure insecurity	Increase climate, reputational, and speculative risk.	Land allocation, enforcement, and credit restrictions for non-compliant producers.

Source: Authors' own elaboration based on IBGE (2019), Zebalho et al. (2023); Pereira & Castro (2021); Araújo, Bragança, & Assunção (2022); World Bank (2018).

3.2 Soybeans and Corn: Comparable Productivity When the System Is Integrated

Soybeans and corn show that the Legal Amazon can achieve productivity levels comparable to those of other regions when agronomic potential is combined with an integrated production system. Economies of scope have contributed to Brazilian agricultural productivity by allowing the same productive base—improved soil, machinery, technical assistance, credit, logistics, research, and buyers—to serve multiple rural activities. This mechanism lowers average costs, improves the use of capital throughout the year, and raises returns on investments that would be expensive for a single crop.

These value chains depend less on the isolated producer and more on the combination of tropical agricultural research, input retailers, financing, private technical assistance, machinery, trading companies, cooperatives, storage, and contracts. This system reduces uncertainty, facilitates technology adoption, and enables a rapid response to prices and demand.



Brazil's grain-production trajectory confirms this pattern: the country accumulated Total Factor Productivity (TFP) gains, expanded input supply, increased labor productivity, and consolidated soybeans and second-crop corn as a central axis of intensification per hectare per year (Gasques et al., 2023; Embrapa, 2020; Conab, 2025; OECD, 2025; USDA ERS, 2026).

The expansion of soybeans and second-crop corn in Brazil resulted from technological complementarity. Adapted cultivars, soil-acidity correction, fertility management, biological nitrogen fixation, no-till farming, larger machinery, crop-protection products, climate information, and agricultural calendars made it possible to combine two crops in the same year. Earlier soybean harvesting opens a window for corn; corn uses part of the infrastructure and capital mobilized for soybeans; scale reduces average costs; and domestic and foreign demand converts productivity into revenue (Rada & Valdes, 2012; Embrapa, 2020; Gasques et al., 2022; Conab, 2025; Conab, 2026).

In the Legal Amazon, this pattern is found primarily in Mato Grosso, Tocantins, Rondônia, southeastern Pará, and transition areas of Maranhão (Figures 1, 2, and 3). In these regions, productivity approaches the average of established production hubs when farmers have access to seeds, inputs, assistance, storage, credit, and buyers. The contrast with isolated small producers stems less from agronomic suitability than from unequal access to the production system. Grain performance confirms that soil and rainfall are not enough: productivity depends on the combination of capital, knowledge, markets, and logistics (Embrapa, 2020; Conab, 2025; IBGE, 2025).

Climate risk, however, raises management requirements. Intensive systems depend on narrow planting and harvesting windows. Soybeans require regular rainfall at planting and during reproductive stages; second-crop corn depends on the end of the rainy season and becomes vulnerable when soybean harvesting is delayed. Drought, heat, and extreme events can reduce yields within days. Grain expansion in the Amazon, therefore, requires insurance, Agricultural Climate Risk Zoning (ZARC)[8], soil management, and forest protection, given the forest's role in regulating regional moisture (MAPA, 2025b; MAPA, 2026).

Public policy should treat grains and family farming differently. Grain value chains already have private mechanisms for technology diffusion, financing, marketing, and risk management that are missing from other value chains. For grains, the priority is to direct expansion toward already-cleared land, strengthen environmental compliance, reduce climate risk, and increase soil resilience. For cassava and family farming, the priority is to create basic market mechanisms, technical assistance, quality systems, processing, appropriate credit, and reliable purchasing (USDA ERS, 2012; Conab, 2025; MAPA, 2026).

The grain experience does not imply that cassava, rice, beans, fruit, or regional foods should be replaced by soybeans and corn. It shows that productivity rises when research, financing, quality standards, technical assistance, logistics, and markets operate in a coordinated manner. In smaller value chains, coordination needs to be proportional to scale: cooperatives, cassava-flour processing houses, small agro-industries, public procurement, soil laboratories, shared transportation, and community-based ATER can perform functions similar to those provided by trading companies, large storage facilities, and private assistance in grain production.



Figure 1. Soybeans in Brazilian Municipalities: Harvested Area, Production, and Yield (Metric Tons per Hectare), 2024

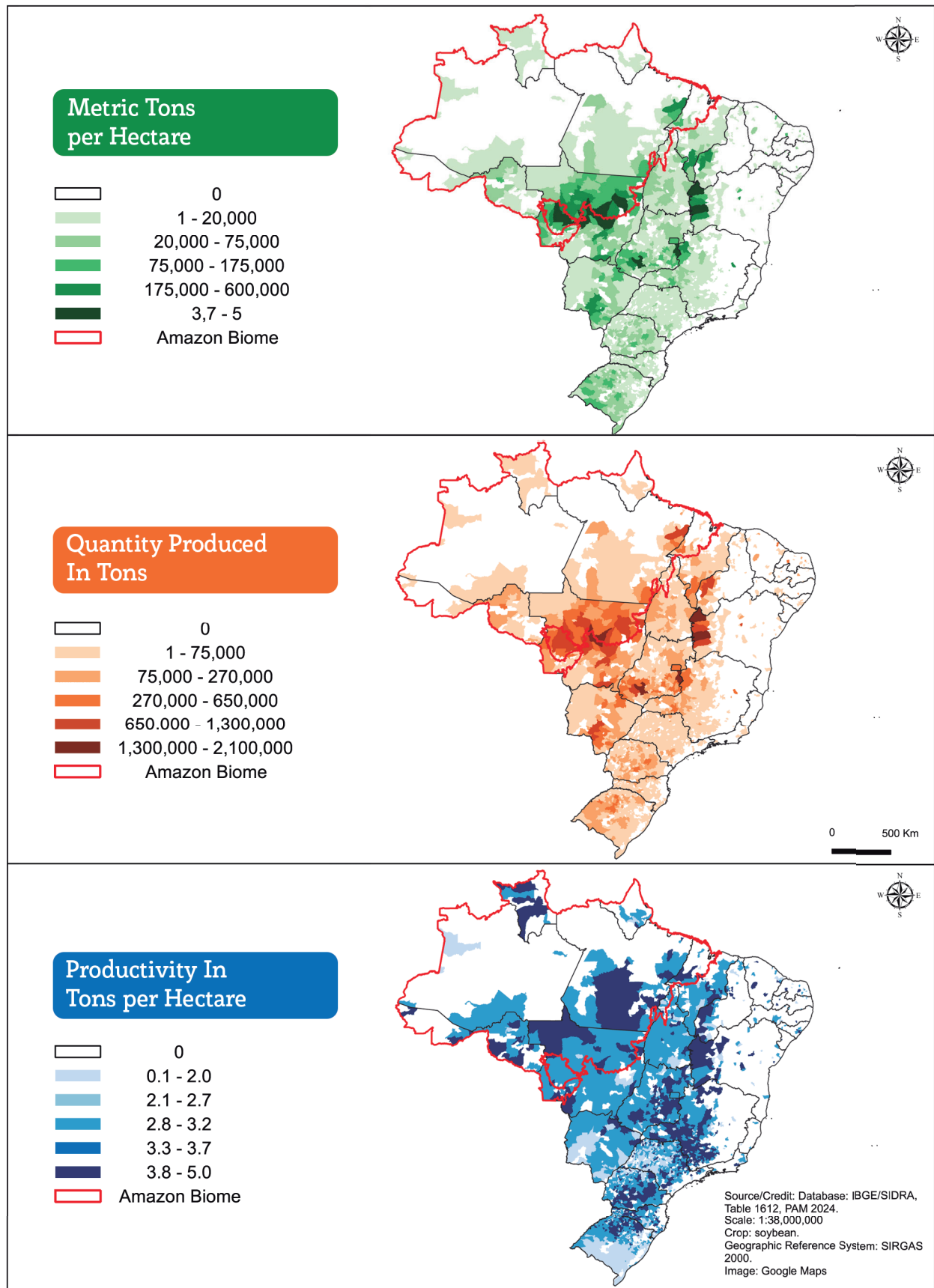




Figure 2. Corn in Brazilian Municipalities: Harvested Area, Production, and Yield (Metric Tons per Hectare), 2024

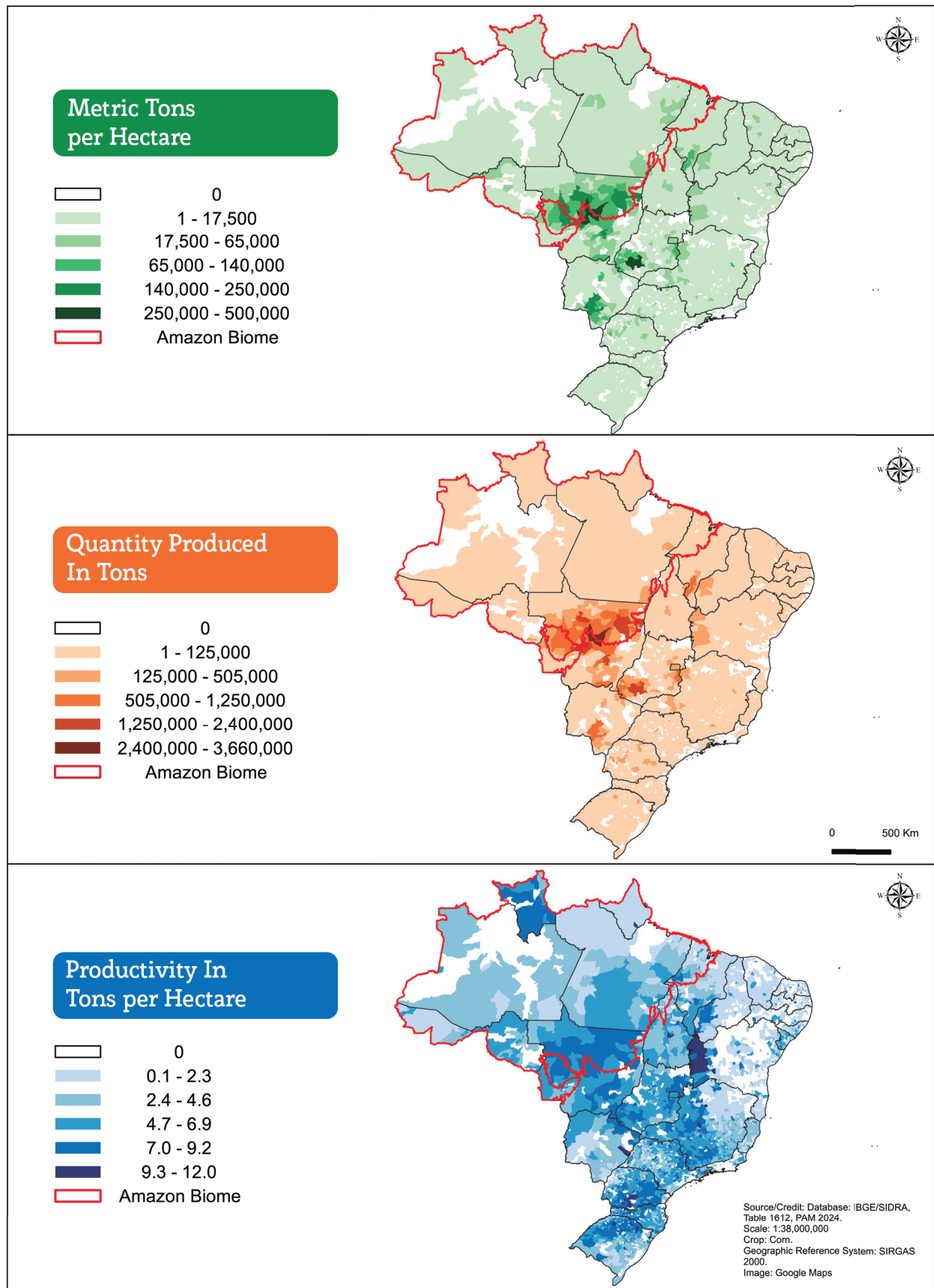
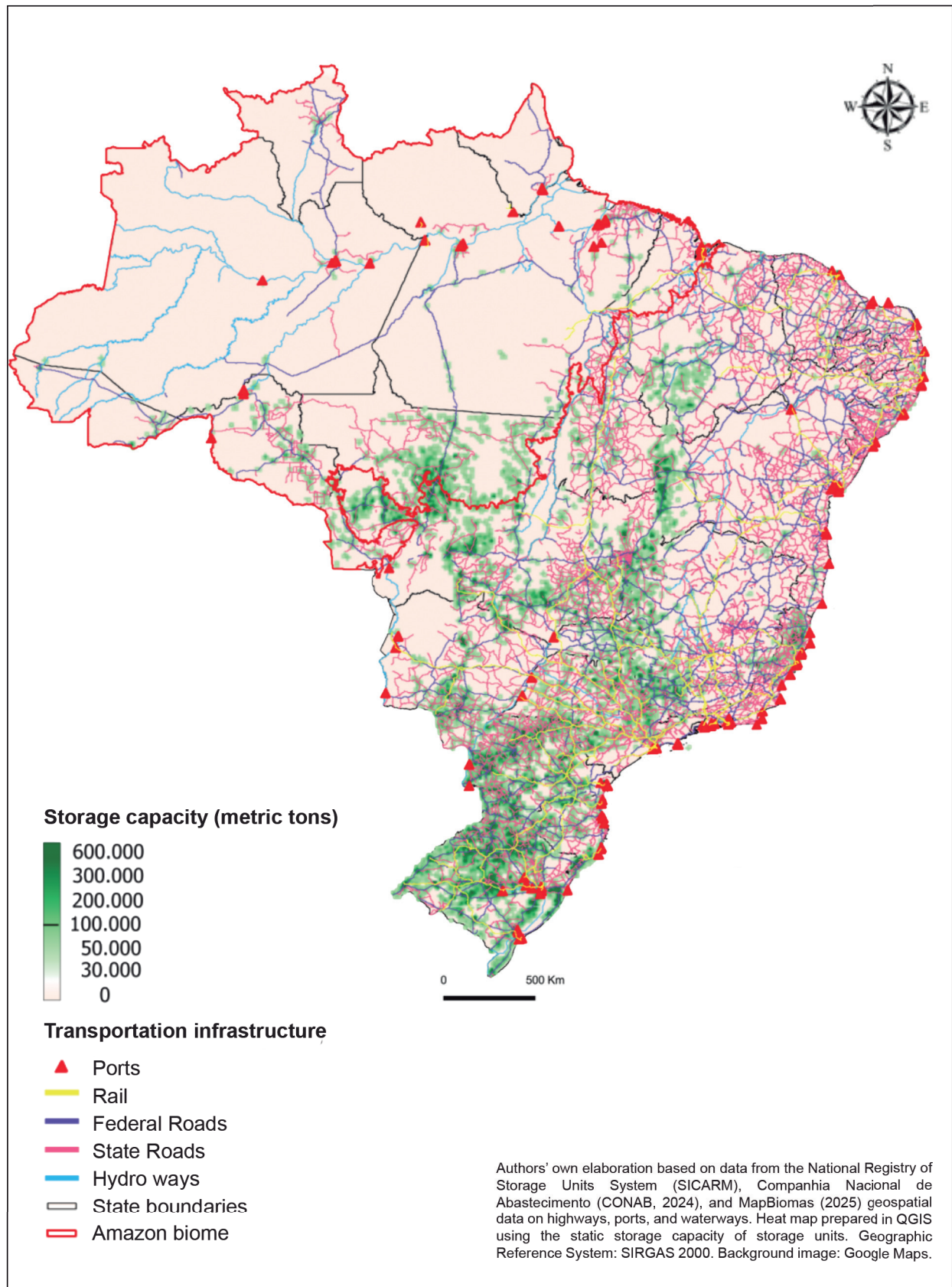




Figure 3. Grain Storage Capacity and Transportation Infrastructure in Brazil





3.3 Cassava: Demand for Standards, Productive Support, and Productivity

In 2024, average cassava productivity in Brazil was 15.46 t/ha. Paraná, Mato Grosso do Sul, Acre, and Rondônia exceeded 20 t/ha (Figure 4 and Table 2). Pará produced about 4 million metric tons, close to one-fifth of national production, but yielded about 15 t/ha. Because Pará's weight influences the national average, the relevant question is: Why did other states produce more per hectare? Differences in productivity reinforce the argument that farmers are more likely to adopt technology when a buyer pays for or requires a standard and when support is available to meet that standard (IBGE, 2025; CEPEA & ABAM, 2025). Producers operating in markets with low demand for quality and low levels of support tend to produce less (see Table 2 and Appendix 3 for details).

Paraná and Mato Grosso do Sul have been organized around the cassava-starch and modified-starch industry, which requires roots with adequate starch content, sanitary quality, consistency, and feasible delivery. In Brazil's Center-South, starch processors govern part of the production process because their margins depend on the quality of the roots they receive. Starch content, moisture, impurities, sanitary condition, harvest schedule, and distance to the plant affect industrial yield and transportation costs. Based on 37 starch plants, Vilpoux (2011) classified supply arrangements ranging from spot markets—open sales when product is available—to vertical integration, according to the degree of guaranteed raw-material delivery. The mechanism is familiar in buyer-driven value chains: industry guides suppliers, selects varieties, organizes delivery, and reduces supply uncertainty. This relationship gives farmers an economic incentive to invest in soil management, planting material, and timely harvesting.

Sector data on cassava-starch production support this mechanism. In 2024, Brazilian starch plants processed about 3 million metric tons of roots and produced 690,000 metric tons of starch. Paraná, Mato Grosso do Sul, and São Paulo accounted for 97% of national starch production. Research also followed this demand: Embrapa released BRS CS01 for the Center-South industry, selected for its productivity and dry matter content (Embrapa, 2016).

Acre illustrates differentiation through product quality and price. A Geographical Indication (GI) was established for flour from the municipality of Cruzeiro do Sul, with rules of use, good practices, and quality control. The GI was developed over approximately twelve years through delimitation of the area, georeferencing of cassava-flour processing houses, rules of use, good practices, and producer organization (Souza et al., 2017; Instituto Nacional da Propriedade Industrial [INPI], 2017; Embrapa Acre, 2017). Between 2019 and 2020, Embrapa analyzed 79 flour samples and reported results to producers. In the third monitoring cycle, 70% of samples were classified as Type 1; an earlier survey cited by Embrapa reported 13%. Embrapa also reported that the price of a 50-kg sack rose from about R\$50 to approximately R\$120 after the quality-improvement work (Embrapa Acre, 2021). The state's productivity of 22.7 t/ha in 2024 makes the case



relevant, although the strongest evidence comes from measures of flour quality and commercial appreciation.

Rondônia involved a distinctive combination of public extension, soil correction, planting material, and government procurement, with resources and services spilling over from dairy policy to diversified family farms. A diagnosis of the cassava value chain identified sales through intermediaries, limited assistance, and little financing (Rosa Neto et al., 2009). At the same time, the state government created a policy to expand quality milk production. Complementary Law No. 547/2009 created the ProLeite Fund to support dairy farming, a more formalized value chain than cassava (Rondônia, 2009). Resources that supported the dairy chain were combined with cassava-specific support. Limestone, soil analysis, input transportation, technical guidance, and planting material are not restricted to dairy production once they reach a farm. The state expanded the dissemination of techniques by increasing rural extension services: in 2017, 18.7% of farms received technical guidance, above the North-region average (Embrapa Rondônia, 2020; Pereira & Castro, 2021).

In 2021, Rondônia's "More Limestone" program (Programa Catrapoa), which supports family farmers by providing agricultural limestone and subsidizing its transportation, reported serving more than 1,000 family farmers in 52 municipalities with more than 40,000 metric tons of limestone, free transportation, and restoration of more than 14,000 hectares (Rondônia, 2021). In 2024, the state Food Acquisition Program (PAA) served 558 individual producers and 12 cooperatives with R\$3 million in funding; the federal PAA allocated R\$2.83 million to 1,066 producers across the 52 municipalities (Rondônia, 2024a, 2024b). In the same year, Rondônia produced about 361,000 metric tons of cassava, with a yield of 20.5 t/ha, above the national average (IBGE, 2025; Embrapa Rondônia, 2024).

Pará maintained high output with a more dispersed market dominated by flour, household consumption, and weakly differentiated local sales (Vilpoux, 2011; Souza et al., 2017; Rosa Neto et al., 2009; Silva et al., 2014). The state has scale, but a substantial share of production serves flour production, household consumption, and local markets. Silva et al. (2014) identified weak consolidation of productive arrangements, insufficient assistance, and poor coordination. The Productivity Trio experience in the municipality of Moju shows that technology is available: the evaluation estimated an additional average gain of 7 t/ha—which would raise the average from 15 to 22 metric tons per hectare—and net income per hectare 61.3% higher than under the traditional system (Silva, 2013). The difficulty lies in linking technology, assistance, credit, logistics, and buyers at the scale of a state that produced about 4 million metric tons in 2024.

Applying these cases to the rest of the Amazon begins with the buyer and the standard that will be rewarded. Starch processing requires scale, energy, water, logistics, and regular delivery. A GI requires an established reputation, rules of use, local control, and an association capable of protecting the collective name. Public procurement requires feasible calls for bids, regular payment, transportation, sanitary assistance, and minimum production. Policy design should answer five questions before investment: Who will



buy? What standard will be rewarded? What service will help the producer meet that standard? Who will coordinate the arrangement? And how will results be measured?

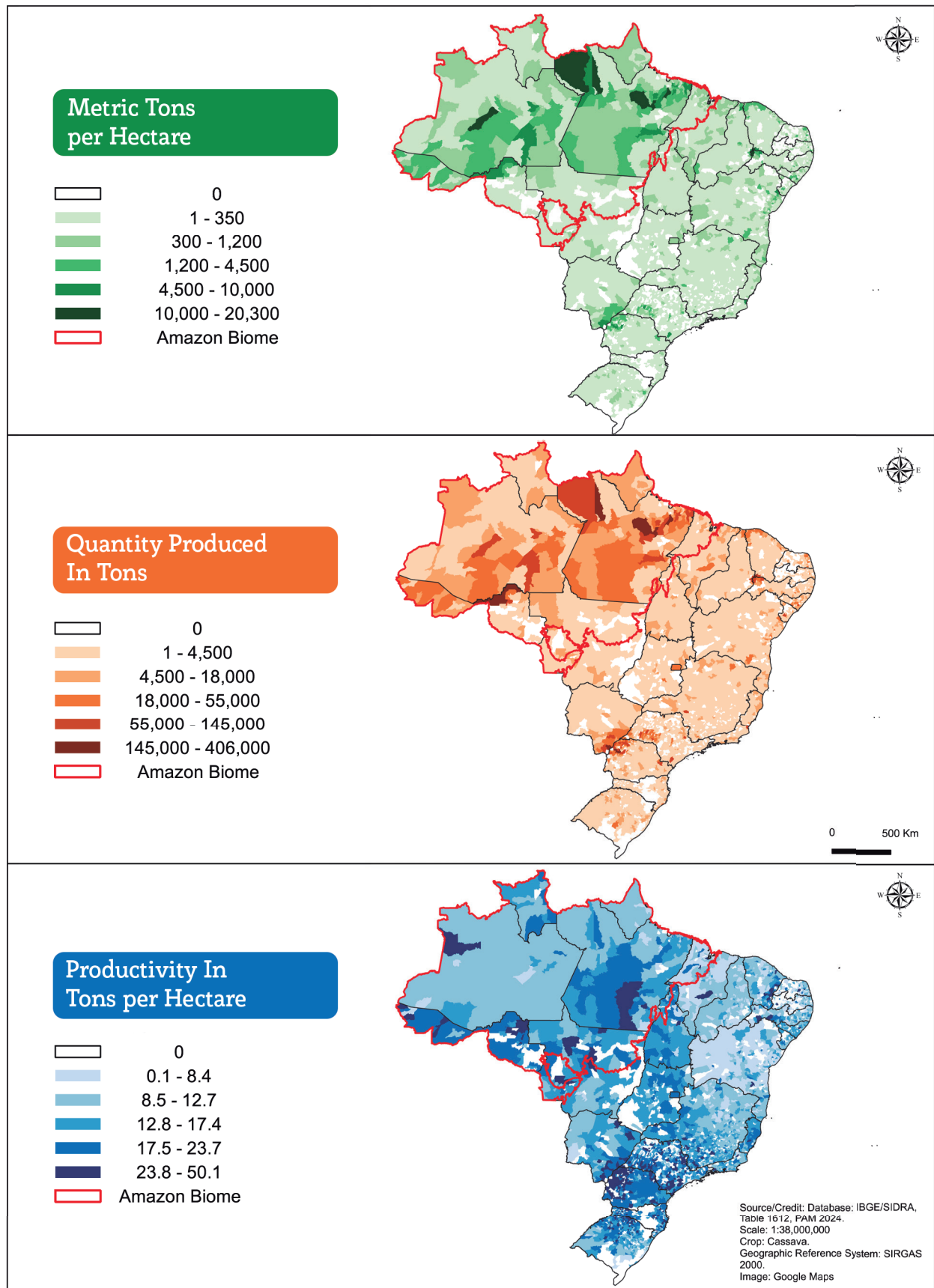
Table 2. Summary of Cassava Production and Productivity Cases in 2024

State	Productivity and production in 2024	Standard that guides farmers decisions	Sector's summary
Paraná	25.4 t/ha; 3.7 million t	Starch content, consistency, sanitary quality, and delivery to starch plants.	65.6% of Brazilian cassava starch in 2024; studies of producer-starch-plant transactions.
Mato Grosso do Sul	22.2 t/ha; 1.3 million t	Roots for starch, modified starches, and exports.	21.3% of Brazilian cassava starch; state starch exports rose from 854.9 t in 2012 to about 23,000 t in 2022.
Acre	22.7 t/ha; 496,000 t	Artisanal flour of territorial origin, rules of use, and good practices.	GI developed over about 12 years; 79 samples monitored; 70% Type 1 in the third cycle; Embrapa reported the price of a sack rose from about R\$50 to R\$120.
Rondônia	20.5 t/ha; 361,000 t	Family production with ATER, liming, input transportation, and public procurement.	18.7% of farms received technical guidance in 2017; More Limestone program and PAA in 2024; the Agricultural Bulletin confirms similar production.
Pará	15.0 t/ha; 4.0 million t	Flour and roots with limited commercial differentiation.	Largest national output; studies indicate weak coordination; the Productivity Trio increased yields in Moju but did not spread statewide.

Sources: IBGE/SIDRA, Table 1612, PAM 2024; CEPEA & ABAM (2025); ABAM (2023); Embrapa Acre (2021); Embrapa Rondônia (2020, 2024); Rondônia (2021, 2024a, 2024b); Silva (2013); Silva et al. (2014); Vilpoux (2011); Zembalho et al. (2023).



Figure 4. Cassava in Brazilian Municipalities: Harvested Area, Production, and Yield (Metric Tons per Hectare), 2024





3.4 The Role of Public Procurement and Assistance for Small Producers

Isolated small producers need predictable demand and assistance to turn potential production into income, quality, and productivity. Credit alone does not solve simultaneous constraints involving capital, scale, logistics, documentation, transportation, packaging, sanitary compliance, and the capacity to fulfill contracts. Without a defined buyer, producers have little incentive to improve varieties, management, processing, and delivery standards; without institutional support, even where demand exists, communities may be unable to issue invoices, set prices, organize transportation, meet sanitary requirements, or provide required accounting (IBGE, 2019; Pereira & Castro, 2021).

The National School Feeding Program (PNAE) and the Food Acquisition Program (PAA) should be designed as policies for productive inclusion, local income, and healthy diets, not merely as food-purchasing mechanisms. These programs create predictable public demand for family farmers, connect small producers with schools and other institutional buyers, and can direct public spending toward local, diverse, nutritious, and culturally appropriate foods; under PNAE, the federal requirement for purchases from family farming rose from 30% to 45% of program resources beginning in 2026 (Elias et al., 2024; FNDE, 2025; FAO, 2021). In 2024, PNAE purchases in the Legal Amazon totaled R\$930 million, equivalent to 15% of the Brazilian total (R\$4.2 billion), while PAA purchases totaled R\$794 million nationwide. Evidence shows that public procurement works well only when government combines procurement notices, menus, and payment with technical assistance, supply organization, logistics, sanitary rules proportional to risk, and genuine priority for poor farmers, Indigenous peoples, quilombola communities^[9], riverine populations (traditional Amazonian communities whose livelihoods and transportation depend heavily on rivers), forest extractivists (communities whose livelihoods depend substantially on harvesting forest products such as nuts, fruits, oils, latex, and fibers), and women. Without this support, better-organized producers tend to capture the public market more effectively, while the most vulnerable groups remain excluded (FAO, Alliance of Bioversity International, CIAT, 2021; FAO, 2026; Elias et al., 2024).

The experience of the Commission on Traditional Foods of Peoples in Amazonas (Catrapoa) and Catrapovos Brasil demonstrates the role of the Federal Public Prosecutor's Office (MPF) in fostering institutional coordination to open the school-meals market to Indigenous peoples, quilombola communities, riverine populations, forest extractivists, and family farmers. MPF action helped bring together the National Education Development Fund (FNDE), Collaborating Centers for School Food and Nutrition (CECANEs), education departments, sanitary-surveillance authorities, rural technical assistance and extension, the National Foundation of Indigenous Peoples (Funai), and community organizations to adapt procurement notices, documentation, menus, logistics, and sanitary requirements to local conditions. In 2023, for example, FNDE advised the use of the Social Identification Number (Número de Identificação



Social - NIS), an identification number used to register individuals in Brazilian social programs, when the Pronaf Eligibility Declaration (Declaração de Aptidão ao Pronaf - DAP)—the former federal credential used to establish family farmers' eligibility for Pronaf and related policies—or National Family Farming Registry (Cadastro Nacional da Agricultura Familiar - CAF)—the federal registry used to identify family farmers eligible for public policies—was unavailable (FNDE, 2023a; Rocha, Leite, & Dias, 2024). Evidence indicates gains in market access and income: between 2019 and 2024, more than R\$11 million was allocated to purchases of traditional foods for school meals. In Amazonas, there were more than 30 public calls, more than 200 schools, about 20,000 students, and more than 1,000 supplying families; in Oriximiná, about R\$1 million has been spent to purchase 100 metric tons of local foods since 2022 (MPF, 2025; FAO, 2025c). Adopting this model can help increase production and productivity by linking demand, assistance, and logistics, as has occurred in other cases (FNDE, 2023a, 2023d; see Appendix 4 for details).

3.5 Climate Change, Losses, and Rural Insurance

Climate change and deforestation already affect Brazilian agriculture through three main channels: yield losses, higher costs, and logistical disruption. In the Amazon, these effects are more severe because the region combines long distances, dependence on rivers, low density of public services, informality, and greater vulnerability; drought reduces productivity, raises the cost of fuel and other inputs, isolates communities, and makes access to schools, health care, and markets more difficult (IPCC, 2022; World Weather Attribution, 2024; CNM, 2023; Santos de Lima et al., 2024). Amazon deforestation also affects production outside the region by reducing evaporation, moisture recycling, precipitation, and the stability of the agricultural calendar. Studies show that forest loss reduces rainfall in the Amazon and downwind areas, delays the onset of the rainy season, and lengthens dry periods in the southern Amazon (Spracklen & Garcia-Carreras, 2015; Leite-Filho, Pontes, & Costa, 2019; Smith, Baker, & Spracklen, 2023). Li et al. (2026) estimated that tree evaporation accounts for about one-third of rainfall during Brazil's soybean growing season and that deforestation reduced seasonal precipitation by 6%–30% in the producing states analyzed; the cumulative effect was an estimated loss of 702,000 metric tons of soybeans, with the largest absolute loss in Rio Grande do Sul—227,000 metric tons, equivalent to about 6% of regional production (Li et al., 2026).

Crops are affected through different channels. In soybeans, water shortages impair crop emergence and, especially, flowering and grain filling; Embrapa estimates that the crop requires about 120–300 mm of well-distributed water between flowering and the completion of grain filling (Farias et al., 2007; Embrapa, 2020). In corn, water deficits during flowering impair pollination and grain formation, while stress during grain filling reduces grain weight; Embrapa studies indicate that drought during critical periods can cause losses exceeding 80% under experimental rainfed conditions, supporting the use



of Agricultural Climate Risk Zoning (ZARC) to guide planting dates and locations (Cruz et al., 2010; Albuquerque et al., 2012; Mapa, 2025b). Cassava is more drought-tolerant, but prolonged deficits reduce leaf area, stomatal opening, photosynthesis, root growth, and biomass. Excess moisture also increases the risk of root rot, which Embrapa identifies as a limiting factor in the North, especially in floodplains and waterlogged areas (El-Sharkawy, 2007; Oliveira et al., 1982; Coelho Filho & Oliveira, 2020; Embrapa, n.d.; FAO, 2013). Because cassava is grown largely by family farmers with less access to credit, insurance, technical assistance, and financial reserves, climate losses affect income, food security, and reinvestment capacity (FAO, 2013; Souza & Albuquerque, 2023).

Drought also turns logistics into a production risk. In riverine communities, lower river depth increases travel time, freight costs, and fuel prices; in grain value chains, hydrological instability puts pressure on waterways, ports, storage, and export corridors (Santos de Lima et al., 2024; Chiavari et al., 2025). Fire and smoke reduce work capacity and increase the risk of respiratory illness among rural families. Fiocruz studies estimated that in the deforestation arc, hospital admissions of children for respiratory problems doubled in the most affected areas, from about 2,500 expected admissions to approximately 5,000 observed, at an additional cost of R\$1.5 million to Brazil's Unified Health System. In Amazonas, 87% of hospitalizations during the period analyzed were associated with high smoke concentrations, and in Pará, 68% (Fiocruz, 2019, 2021).

The productive response must reduce risk before expanding credit. Traditional Zarc guides planting periods by crop, soil, and municipality; Agricultural Climate Risk Zoning by Management Level (ZarcNM) goes further by recognizing that no-till farming, soil cover, organic matter, crop rotation, and conservation increase infiltration and available water. In 2026, the Ministry of Agriculture approved the second phase of ZarcNM, expanding soybeans to Paraná, Santa Catarina, Rio Grande do Sul, and Mato Grosso do Sul, including second-crop corn, and raising subsidies under the Rural Insurance Premium Subsidy Program to as much as 50% in areas with the best management levels (Mapa, 2025b; Mapa, 2026; Embrapa, 2026a). In the Amazon, broad adoption still depends on calibration for humid tropical soils, management data series, soil data, and remote sensing; protocols for heavy cloud cover; laboratories; accredited operators; and sufficient technical assistance (Appendix 5).

3.6 Infrastructure, Deforestation, and Climate Risk

Amazon needs infrastructure, but infrastructure without territorial governance can amplify the problem it is intended to solve. Roads, railways, ports, and energy infrastructure reduce costs and can raise income in consolidated areas. However, when projects open access to undesignated public lands without enforcement and without reliable land registries, they encourage illegal land grabbing, speculative deforestation, and irregular occupation. The result is greater climate and reputational risk, as well as pressure on Indigenous peoples and protected areas (Araújo, Bragança, & Assunção,



2022; Barber et al., 2014; Pfaff et al., 2007).

The problem is not the infrastructure itself, but the absence of territorial management before, during, and after construction. Studies of accessibility in the Amazon show that a project's impact should be measured by its effective economic zone rather than only by its right-of-way—that is, the immediate area surrounding a road or railway [10]. A road can change land prices, shift settlement frontiers, and connect remote areas to timber and cattle markets. Impact assessment must therefore include indirect deforestation, land occupation, fire, hydrology, emissions, consultation with affected peoples, and enforcement costs (Araújo, Bragança, & Assunção, 2022; Pfaff et al., 2007).

The BR-319 highway illustrates this tension. The federal government announced social, environmental protection and sustainable development measures for the highway area in Amazonas and Rondônia, including territorial monitoring and protection actions (MMA, 2026). Environmental organizations, however, argue that the plan is late and incomplete because the full implementation of safeguards would continue as construction advances, and because impact studies, consultation, and land tenure governance should precede paving (Observatório do Clima, 2026).

Legal uncertainty over protected areas aggravates the risk. Research on reductions in the size or protection status of protected areas—known by the acronym PADDD (Protected Area Downgrading, Downsizing and Degazettement)—shows that governments can reduce the area or degree of protection of conservation units, weakening expectations of long-term protection (Bernard, Penna, & Araújo, 2014; Pack et al., 2016). When private actors expect future changes in protected-area status, speculation increases, and protection loses credibility. Infrastructure, therefore, needs to be accompanied by stable funding for protected areas, land tenure regularization and territorial surveillance (Bernard et al., 2014; Pack et al., 2016).

In summary, infrastructure planning should ask whether a project reduces production costs without increasing deforestation, illegal land grabbing, and climate risk. If the answer depends on safeguards, those safeguards must be in place before the project has economic effects. Otherwise, infrastructure can destroy the climate foundation that sustains the very productivity it is intended to stimulate (Araújo, Bragança, & Assunção, 2022; Barber et al., 2014; World Bank, 2018).



4. Recommendations

The purpose of this report is to identify how public policies can raise agricultural productivity in the Amazon while reducing producers' vulnerability to climate change (for example, the inability to produce during droughts). The diagnosis showed that the region combines competitive grain hubs, low-productivity family-farming value chains, growing climate risks, vulnerable logistics, and reputational pressure associated with deforestation. Some recommendations are relevant throughout the region—such as treating the forest as productive infrastructure—while others focus on specific challenges, such as isolated family farmers (Table 3).

Table 3. Recommendations, Instruments, and Safeguards

Recommendation	Policy tools	Safeguards
Financing and technology diffusion	Sectoral funds, public budgets, ATER, applied research, laboratories, sanitary services, and data.	Independent governance, public targets, auditing, impact evaluation, and transparency. Do not subsidize producers with environmental or land-tenure irregularities.
Isolated small producers	PAA, PNAE, community ATER, seed/cassava-stem banks, logistics, and guidance-oriented inspection.	Regular payments, proportionate documentation, food safety, and delivery monitoring.
Amazon ZarcNM	Research network, crop-specific pilots, soil, climate, and management data.	Do not restrict benefits to already technology-intensive producers; integrate ATER and social protection.
Infrastructure by impact	Influence-zone assessment, local logistics, energy, internet, storage, and selected projects.	Land-tenure governance, consultation, enforcement, fire control, and maintenance funding.
Forest as infrastructure	Allocation of public forests, enforcement, credit restrictions, traceability, and restoration of already-cleared areas.	Multi-year financing for protected areas, fire brigades, and restoration.

4.1 Create Stable Arrangements for Financing, Applied Research, and Technology Diffusion

The Amazon needs continuous financing to turn knowledge into productivity. Rural credit alone tends to have little effect when producers lack technical assistance, inputs, markets, sanitary support, post-harvest capacity, soil and water management, and the practical conditions needed to carry out an investment. Sectoral funds can finance



collective goods that isolated producers cannot procure at a sufficient scale, such as soil analysis, limestone, seedlings, laboratories, sanitary services, training, adapted varieties, small processing units, climate data, and quality protocols (Pereira & Castro, 2021; Fuglie et al., 2020; CPI/PUC-Rio, 2025).

Brazilian experience indicates that sectoral funds are more robust when revenue is collected through formal, concentrated links in a value chain and earmarked for productive services. The rationale is that a levy gains legitimacy when those who pay see a direct benefit - research, sanitary protection, technical assistance, training, or productive infrastructure - while society benefits from lower climate, environmental, and fiscal risks. The Cooperation and Rice-Growing Defense Fee is collected at formal points in the Rio Grande do Sul rice value chain; Fundecitrus is financed by citrus growers and juice industries for research, phytosanitary protection, and training; and Rondônia's ProLeite combined a sectoral incentive and a fund to develop dairy farming (Fundecitrus, 2025; Receita Estadual do Rio Grande do Sul, 2025; Rondônia, 2009, 2025; SEBRAE/RO, 2002). In Rondônia, resources originating in the dairy sector also benefited crops by financing part of the expenditure on limestone (Section 3.3).

Sectoral funds in the Amazon should therefore be designed as a political compact among value chains, governments, and society. Cattle ranching could support such an arrangement because it occupies 78% of the deforested land for farmland in the Amazon and because many small farmers also raise cattle. In addition, between 2008 and 2017, the sector received at least R\$11 billion per year in subsidies, debt relief, and tax expenditures in Brazil, in 2025 values - about twice the country's public technical-assistance budgets in 2025 (Confederação Nacional dos Municípios, 2025). Governments could therefore convert part of these benefits into a sectoral parafiscal contribution - a mandatory levy on an economic sector to finance services of interest to that same sector - earmarked for rural extension and other collective services for small and medium-sized producers. Productivity improvements in these areas would also benefit the cattle sector, which is increasingly required to become more productive due to quality standards and efforts to combat deforestation (Barreto et al., 2025).

Support for farmers based on the cattle sector would probably not reach all producers. Cattle-linked funds would tend to work better where slaughterhouses, roads, suppliers, and production are concentrated. Barreto, Pereira, and Rocha (2024) estimated that the pastures needed to meet projected demand through 2030 were located within 60 km of slaughterhouses in the Amazon; in 2020, only 43% of agrarian-reform settlements (government-recognized settlement projects created to provide rural families with access to land under Brazil's agrarian-reform policies) were within this zone.

Other resources will therefore be necessary to increase production and climate resilience among isolated small producers. This will require increasing the effectiveness and focus of other resources serving small producers, including the National Rural Learning Service (Serviço Nacional de Aprendizagem Rural-SENAR)[11], which executed a budget of R\$818 million in 2025 in the states of the Legal Amazon (see Appendix 6 for details).

Governance determines the credibility and stability of these funds. Funds captured by



governments or private groups for purposes that provide no direct benefit to producers lose political support and effectiveness. Their design should include a council with producers, the private sector, technical-assistance providers, research institutions, government, civil society, and social oversight; an annual spending plan; territorial criteria; independent auditing; impact evaluation; transparency regarding revenue and expenditures; and a prohibition on using resources for current expenditures unrelated directly to productivity, sanitary protection, quality, or adaptation (Ostrom, 1990; World Bank, 2018).

Rondônia's institutional change in 2025 illustrates the risk of funds without sufficient safeguards. Complementary Law No. 1,283/2025 transferred ProLeite and Funcafé/RO resources and positive balances to Emater-RO's fiscal budget, incorporated the funds' assets and rights into the agency's assets, assigned their obligations and remaining balances to its activities, and determined that revenues previously earmarked to the funds would become Emater-RO revenues. The same law abolished Funcafé/RO, repealed Complementary Law No. 547/2009, which had created ProLeite, and established a 90-day transition period for direct revenue collection by Emater-RO (Rondônia, 2025). The lesson is that sectoral funds need an explicit purpose, management autonomy, asset protection, and clear transition rules.

4.2 Ensure the Resilience of Isolated Small Producers

Policy for isolated producers should combine production, social protection, and public procurement. Family farmers, Indigenous peoples, quilombola communities, riverine populations, and forest extractivists face simultaneous vulnerabilities: low incomes, small-scale operations, fragile logistics, limited assistance, and little savings with which to absorb the additional costs of droughts or floods. Improving or maintaining productivity and resilience among these groups requires reducing these vulnerabilities (IBGE, 2019; Pereira & Castro, 2021).

Public procurement can balance predictable demand, sanitary protection, quality, and operational simplification when PNAE and PAA use public calls compatible with seasonality, transportation, scale, and traditional foods. Sanitary rules should protect food safety without requiring industrial infrastructure for low-risk foods processed at a small scale. The Catrapoa/Catrapovos experience should therefore be expanded as a method, with local working groups bringing together the Federal Public Prosecutor's Office (MPF), education departments, sanitary-surveillance authorities, ATER, and community organizations to adapt procurement notices, products, packaging, and deadlines (Elias et al., 2024; FNDE, 2025; Rocha, Leite, & Dias, 2024). Financing can combine the Pre-Salt Social Fund (see Appendix 6), PAA, PNAE, ATER budgets, Civil Defense, climate funds, earmarked legislative appropriations with targets, and state funds, provided that resources finance actual production and delivery capacity: trans-



portation, processing, packaging, documentation, invoice issuance, guidance-oriented inspection, seed and cassava-stem banks, small cold-storage facilities, and community technical assistance. Research should be expanded and accelerated to address the specific needs of family farming (see the section on climate resilience).

In more isolated areas, where productivity is constrained by distance, high costs, and weak markets, agricultural policy should operate alongside health, education, and social protection. Poor families are more likely to benefit from credit, technical assistance, and new opportunities when they live in territories with better education, health, and economic conditions. Evidence shows that the mobility of Bolsa Família beneficiaries varies sharply by territory: richer regions, such as the South, show mobility almost twice as high as in less advantaged regions, such as the North and is associated with better education and health infrastructure and greater economic activity (Fassarella et al., 2024).

Rural credit, insurance, public procurement, licensing, infrastructure, and tax incentives should converge on production on already-cleared land, restoration of degraded pastures, environmental compliance, and traceability. Public resources or instruments receiving regulatory benefits, including the Safra Plan, the federal government's annual package of rural-credit and agricultural financing measures, and Agribusiness Receivables Certificates (CRAs), Brazilian securities backed by receivables from agribusiness transactions, should not lower the cost of capital for properties with illegal deforestation; they should reward productive restoration, environmental compliance, soil management, and deforestation-free production (Assunção et al., 2020; CPI/PUC-Rio, 2025).

4.3 Select Infrastructure Based on Territorial, Climate, and Fiscal Impact

Infrastructure in the Amazon should be selected on the basis of territorial impact and local productive returns, not project size, visibility, or freight-cost reductions considered in isolation. Projects should be prioritized only when they reduce production costs, losses, commercial isolation, and climate vulnerability without increasing deforestation, illegal land grabbing, fire, pressure on protected areas, and risks to the hydrological regularity that sustains agriculture (Araújo, Bragança, & Assunção, 2022; Barber et al., 2014; World Bank, 2018).

Major corridors can be useful for long-distance freight, but the productivity of family and medium-sized farmers depends on first- and last-mile logistics: passable local roads, small bridges, local ports, productive transportation, electricity, rural internet, storage, soil laboratories, technical assistance, basic processing, and information systems for public procurement. These investments reduce transaction costs, coordination failures, post-harvest losses, and disruptions caused by droughts, floods, or inadequate transportation (World Bank, 2018; Fuglie et al., 2020).



Comparative evidence reinforces this priority. In China, rural and lower-standard roads generated 1.57 yuan of agricultural GDP per yuan invested, whereas higher-standard roads had no statistically significant effect on this indicator. In Uganda, feeder roads had a greater effect on productivity and rural poverty than better-standard roads. In Niger, mobile telephony reduced grain price dispersion by 10%- 16%. In Brazil, only 23% of agricultural space had internet coverage, and on-farm storage remained close to 14%, below Argentina, Canada, and the United States, at 40%, 85%, and 65%, respectively (Aker, 2010; Conab, 2021; Fan & Chan-Kang, 2005; Fan et al., 2004; Ministério da Agricultura, Pecuária e Abastecimento & Escola Superior de Agricultura Luiz de Queiroz, 2021).

Government-led planning should incorporate the effective economic impact zone because roads and railways alter land prices, settlement expectations, and incentives for forest conversion beyond the directly affected corridor. Studies of accessibility and infrastructure in the Amazon show that feasibility analyses and environmental licensing should account for indirect deforestation, illegal land grabbing, enforcement costs, and governance capacity (Araújo, Bragança, & Assunção, 2022; Pfaff et al., 2007; Bragança et al., 2020; Araujo et al., 2025).

BR-319 illustrates the risk of expanding access before safeguards are in place. The government announced a social and environmental protection plan, but implementation through 2028 alongside construction does not resolve the immediate risk if land allocation, consultation, enforcement, operational bases, land-tenure intelligence, and real-time monitoring are not in place before traffic intensifies (Ministério do Meio Ambiente e Mudança do Clima, 2026; Observatório do Clima, 2026; Barber et al., 2014).

Major projects should therefore compete with lower-risk local alternatives offering higher territorial returns, with the costs of indirect deforestation, illegal land grabbing, enforcement, and governance incorporated before they are considered priorities (Araujo et al., 2025; Bragança et al., 2020; Vilela et al., 2020).

4.4 Expand Research on Climate Adaptation in the Amazon

The Amazon should be incorporated quickly into the two climate initiatives now underway - Agricultural Climate Risk Zoning by Management Level (ZarcNM) and the project "From Risk to Decision: Intelligent Solutions for Anticipating and Monitoring Climate Risks in Agriculture." The region combines worsening drought, heat, fire, and hydrological instability with high vulnerability among family farmers, small-scale cattle ranchers, and isolated producers. ZarcNM creates an appropriate incentive by recognizing that soil cover, infiltration, organic matter, and water conservation reduce losses and can increase rural-insurance subsidies. Yet its second phase prioritized soybeans in the South and Mato Grosso do Sul, included second-crop corn, and authorized sub-



sides of up to 50% only for areas at the best management levels, leaving out Amazonian states important for soybeans, corn, cassava, livestock, agroforestry systems, and pasture restoration (MAPA, 2025b; MAPA, 2026).

The same problem appears in the "From Risk to Decision" project. Although necessary for anticipating and monitoring climate risks, it has only R\$2 million for 48 months and includes only one unit in the Legal Amazon, Embrapa Agrossilvipastoril in Sinop, Mato Grosso, without adequately covering the diversity of humid tropical soils, floodplains, uplands, livestock, food crops, and rural populations in the region (Embrapa, 2026b). The response should be to expand these initiatives immediately with Embrapa Amazônia Oriental, Embrapa Amazônia Ocidental, universities, insurers, and ATER, producing an Amazon-wide risk and adaptation atlas that combines climate hazards, crop and livestock exposure, social and productive vulnerability, and producers' adaptive capacity.

4.5 Treat the Forest as Natural Infrastructure for Production

Ending deforestation and making the restoration of already-cleared areas the main vector of production expansion are conditions for protecting the climatic foundation of agriculture in the Amazon. The forest regulates rainfall, reduces fire risk, sustains waterways, stabilizes energy supply, and protects productivity. Loss of forest cover reduces rainfall and agricultural revenue, increases the risk of ecosystem function loss, and threatens agriculture, energy, navigation, and water security (Leite-Filho et al., 2021; Spracklen & Garcia-Carreras, 2015; Flores et al., 2024).

Reducing deforestation depends on combining the formal allocation of public lands, satellite monitoring, enforcement, and sanctions such as credit restrictions for properties with illegal deforestation. PPCDAm demonstrated the effectiveness of this combination by reducing deforestation through monitoring, enforcement, credit restrictions, and institutional coordination (Assunção et al., 2016; Assunção et al., 2020). The current challenge is to sustain the policy, increase transparency in the value chain, and prevent subsidized credit from financing environmental noncompliance (Assunção et al., 2020; Gibbs et al., 2015; CPI/PUC-Rio, 2025).

Federal and state governments should prioritize the formal allocation of public forests to conservation, sustainable use, and recognition of the territorial rights of Indigenous peoples, because the absence of territorial governance encourages illegal land grabbing and speculative deforestation. The Pre-Salt Social Fund can help address chronic underfunding of protected areas in the Amazon because Law No. 15,164/2025 (Brasil, 2025a) included the environment, climate adaptation, food security, water infrastructure, and disaster response among its eligible purposes. Funds could finance territorial surveillance, land tenure regularization, fire brigades, forest restoration, and management infrastructure (Senado Federal, 2025; Prizibiszki, 2024; Marengo et al., 2018). Details on the fund are provided in Appendix 7.



5. Conclusion

Improving rural development in the Legal Amazon depends on productivity, resilience, and climate adaptation. Agriculture generates income and employment but faces droughts, floods, fire, logistical disruptions, and growing requirements to comply with environmental laws. In 2019, the sector employed 1.84 million people, 17% of the employed population, compared with 8% in the rest of Brazil; agricultural and livestock losses totaled R\$40.5 billion since 1991, and the annual average rose to R\$6.07 billion in 2021-2024 (Alfenas, Cavalcanti, & Gonzaga, 2020; InfoAmazonia, 2025). Productivity, adaptation, and forest protection should therefore be complementary objectives.

The cases analyzed indicate that productivity rises when policies and markets create linkages that support technology adoption. The Soy Moratorium required deforestation-free production and monitored compliance; as a result, the share of soybean expansion occurring on recently deforested land fell from about 30% to 1% (Gibbs et al., 2015). The "China cattle" case combined demand for young animals, sanitary standards, and a price premium, inducing greater use of existing techniques such as pasture restoration and management, feedlots for finishing, and genetic improvement (Barreto et al., 2025).

The public sector should complete linkages where markets do not provide sufficient scale or coordination, including applied research, credit and insurance adapted to regional risks, tailored public procurement, enforcement against illegal deforestation, land tenure regularization, formal allocation of public lands, and infrastructure that does not encourage deforestation. These services reduce costs, uncertainty, and risk and can turn requirements for quality, traceability, and legality into incentives for investment rather than barriers to inclusion (North, 1990; Fuglie et al., 2020; Kim & Loayza, 2019; World Bank, 2018; Assunção et al., 2016).

The order of implementation matters. In grain hubs, the bottleneck may be improving environmental compliance and insurance, which induce practices to reduce climate risk. In isolated communities, documentation, transportation, inspection, and community-based ATER may need to precede delivery to PNAE or PAA. A well-chosen action creates demand for the next one; credit without a market or infrastructure without territorial governance tends to produce incomplete results, such as low technology adoption, or adverse ones, such as deforestation (Hirschman, 1958; World Bank, 2018; Araújo, Bragança, & Assunção, 2022).

In isolated areas, where improving the factors of production is costly, agricultural policy and social assistance should work together to reduce vulnerability - especially through health and education services - while infrastructure and local markets are being developed.



6. Appendices

6.1 Appendix 1. Characteristics of Land Use and Agriculture in Brazil

Table 4. Number of Rural Establishments by Producer Type and Region, 2017

Region	Non-family farming	Family farming	Total	% of total
North	100,038	480,575	580,613	11%
Northeast	483,873	1,838,846	2,322,719	46%
Southeast	280,470	688,945	969,415	19%
South	187,547	665,767	853,314	17%
Center-West	123,988	223,275	347,263	7%
Brazil	1,175,916	3,897,408	5,073,324	100%
% of total	23.2%	76.8%		

Source: IBGE (2019)

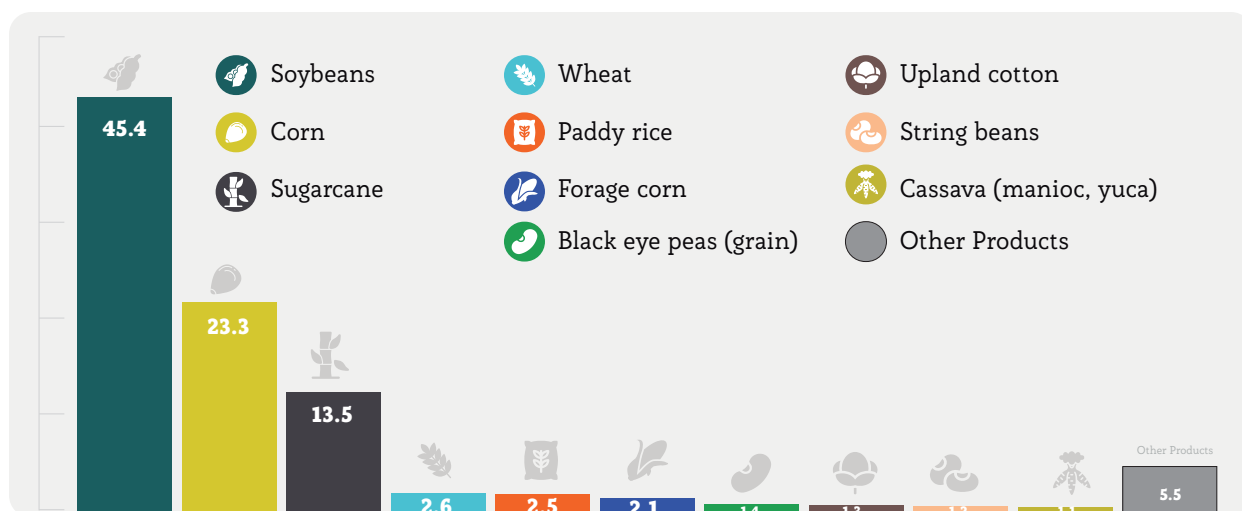
Table 5. Hectares of Rural Establishments by Producer Type and Region, 2017

Region	Non-family farming	Family farming	Total	% of total
North	45,446,150	19,767,199	65,213,349	19%
Northeast	44,968,122	25,925,743	70,893,865	20%
Southeast	46,567,098	13,735,871	60,302,969	17%
South	31,382,790	11,492,520	42,875,310	12%
Center-West	102,034,572	9,969,750	112,004,322	32%
Brazil	270,398,732	80,891,083	351,289,815	100%
% of total	77.0%	23.0%		

Source: IBGE (2019)



Table 6. Percentage of Harvested Area by Crop, Region, and Producer Type, 2017
"% of total harvested hectares for annual crops in Brazil"



Non-family farming

Crop	North	Northeast	Southeast	South	Center-West	Brazil
Soybeans	62.0	51.6	19.4	54.8	54.2	48.2
Corn	21.5	16.6	12.3	16.5	31.3	22.5
Sugarcane	2.5	13.1	54.8	4.5	7.2	15.4
Wheat	0.0	0.1	1.6	8.7	0.1	2.5
Paddy rice	7.0	0.7	0.1	7.7	0.6	2.5
Forage corn	0.6	1.3	2.9	1.0	0.4	1.1
Black eye peas	1.1	3.3	0.1	0.0	0.5	0.6
Upland cotton	0.3	4.1	0.2	0.0	2.5	1.6
String beans	0.3	0.8	2.4	0.7	0.7	1.0
Cassava	1.1	0.8	0.4	0.4	0.1	0.3
Other Products	3.6	7.5	5.8	5.7	2.5	4.4
Total	100	100	100	100	100	100



Family farming

Crop	North	Northeast	Southeast	South	Center-West	Brazil
 Soybeans	9.9	0.2	14.5	42.8	46.7	29.1
 Corn	22.7	32.5	27.1	25.5	36.4	28.1
 Sugarcane	0.7	2.4	14.5	0.4	1.6	2.5
 Wheat	0.0	0.0	0.6	6.7	0.0	3.7
 Paddy rice	6.9	4.2	0.3	2.6	1.3	2.8
 Forage corn	0.6	4.7	16.6	8.5	4.3	7.8
 Cowpeas	3.0	24.4	1.0	0.0	1.1	5.9
 Upland cotton	0.0	0.1	0.0	0.0	0.0	0.0
 Common beans	1.4	5.5	5.4	0.5	0.5	2.2
 Cassava	47.7	9.2	5.5	1.6	4.6	5.8
 Other Products	7.1	16.8	14.4	11.5	3.4	12.2
Total	100	100	100	100	100	100

Source: IBGE (2019)

Table 7. Agricultural Use of Deforested Areas in the Legal Amazon, 2024

Land use type	Area (hectares)	% of total
Pasture	72,479,200	78.4
Temporary crops	16,206,180	17.5
Permanent crops	250,874	0.3
Land-use mosaic	3,525,379	3.8
Total considered deforested	92,461,633	100.0

Source: Authors' calculations based on MapBiomass (2026) data.



6.2 Appendix 2. Agrarian-Reform Settlements by State in the Legal Amazon

Traditional settlements. For this report, "traditional settlements" refers primarily to conventional family-farming settlement projects, while "differentiated settlements" refers to modalities that recognize collective territorial rights, traditional livelihoods, or environmental commitments. These are conventional resettlement projects in which access to land occurs through demarcated individual plots, and whose central objective is family-based agricultural production. This modality represents 85.2% of projects, 71.4% of families, and 45.0% of total settlement area. According to Incra data, in 2026, Legal Amazon had about 480,000 families and approximately 33 million hectares in this category, accounting for 79% of the total area and 60% of the families in this settlement category.

Differentiated settlements. These modalities recognize collective territorial rights, specific ways of life, or environmental commitments. They represent 14.8% of projects, 28.6% of families, and 55.0% of total area, reflecting the large territorial extent of forest-based and extractive projects in the Amazon.

Overall, the Legal Amazon contains 39.5% of Brazil's settlement projects, 66.2% of settlement families, and 87.8% of total settlement area. The concentration is even greater among differentiated settlements: 58.5% of projects, 81.1% of families, and 96.0% of differentiated-settlement area are in the Legal Amazon, reflecting the large extent of Extractive Reserves (RESEX)[12], Sustainable Development Projects (PDS), and National Forests (FLONA) in Amazonas and Pará.

Table 8. Settlements by State in the Legal Amazon, 2026

State / region	Traditional settlements			Differentiated settlements.			Total		
	Projects	Families	Area (ha)	Projects	Families	Area (ha)	Projects	Families	Area (ha)
Legal Amazon (9 states)									
Pará *	748	133,571	12,092,350	448	166,495	14,094,994	1,196	300,066	26,187,344
Amazonas	41	16,185	1,411,692	116	51,076	27,196,627	157	67,261	28,608,319
Maranhão	980	127,574	4,439,579	113	14,188	671,739	1,093	141,762	5,111,318
Mato grosso	525	82,300	5,784,688	40	3,568	154,250	565	85,868	5,938,939
Rondônia	191	42,188	4,400,896	40	1,763	1,796,243	231	43,951	6,197,139
Acre	116	24,327	1,818,538	52	11,459	3,741,294	168	35,786	5,559,832
Tocantins	378	24,132	1,253,548	26	777	163,149	404	24,909	1,416,696
Roraima	51	15,839	1,237,621	2	599	607,524	53	16,438	1,845,145
Amapá	37	10,712	682,184	27	7,343	1,653,893	64	18,055	2,336,077
Legal Amazon subtotal	3,067	476,828	33,121,095	864	257,268	50,079,714	3,931	734,096	83,200,809
Rest of Brazil subtotal	5,417	315,854	9,538,253	614	59,848	2,078,819	6,031	375,702	11,617,072
Brazil total	8,484	792,682	42,659,348	1,478	317,116	52,158,533	9,962	1,109,798	94,817,881

Data source: INCRA/SIPRA (2026)



***Methodological note.** Data extracted directly from the SIPRA CSV file (Report 0227, generated March 6, 2026). The Legal Amazon comprises the states of AC, AM, AP, MA, MT, PA, RO, RR, and TO, according to the SUDAM boundary (Complementary Law No. 124/2007). Maranhão and Mato Grosso are included in full because SIPRA does not subdivide data by intrastate subregion. Two records were excluded because of evident registration errors: SP0406000 (34.7 million ha, 0 families) and SE0046000 (11.4 million ha, 44 families). Traditional: PA, PE, PAD, PAR, PIC, PAC, PAM, and variants (SIPRA types 1, 3, 4, 6, 9, 10, 11, 12, 14, 15, 28). Differentiated: PAE, PCA, PAQ/RTRQ, PDS, RESEX, PAF, FLONA, RDS, PRB, PFP, FLOE (SIPRA types 2, 7, 17, 18, 19, 21, 22, 23, 24, 25, 29, 31).

6.3 Appendix 3. Cassava: Demand for Standards, Productive Support, and Productivity

Differences in cassava productivity among states do not result only from soil, climate, or individual farmer effort. Productivity tends to rise when there is demand for a clear product standard and support that enables farmers to meet it. Cassava responds to known technologies: healthy stem cuttings, suitable varieties, liming, weed management, pest control, harvesting at the correct time, and post-harvest care. The recurring problem is turning technology into an economic decision: producers need buyers, prices, contracts, transportation, technical assistance, and lower risk before changing their production system (Barrett et al., 2012; Henson & Reardon, 2005; Reardon et al., 2009).

The cases discussed in Section 3.3 show four different mechanisms. Paraná and Mato Grosso do Sul illustrate the strength of the starch industry. Acre shows how territorial reputation, rules of use, and quality control can add value to artisanal flour. Rondônia shows how extension, liming, public procurement, and resources originating in a more formalized value chain can reach diversified family farms. Pará provides the contrast: large output and available technology, but weak coordination, little assistance, and a market that does not always reward quality.

The starch industry demonstrates the first mechanism: the buyer converts agronomic quality into economic value. Each metric ton of roots delivered to a plant contains water, fiber, impurities, and starch. The plant gains when roots have higher starch content, lower losses, and predictable delivery. Farmers gain when industry reduces uncertainty over sales and provides guidance on varieties, management, and harvest schedules. Analyzing 37 starch plants, Vilpoux (2011) showed that supply arrangements range from spot markets to contracts and vertical integration, depending on the need to ensure raw material availability. This helps explain why the Center-South can link research, suppliers, and industry. Embrapa reinforced this direction by releasing BRS CS01, a variety selected for the Center-South industry for its productivity and dry matter content (Embrapa, 2016).

Acre illustrates another mechanism: territorial reputation and quality control. The Geographical Indication for Cruzeiro do Sul flour was developed through area delimitation, product characterization, surveys of cassava-flour processing houses, rules of use, good practices, and producer organization (Souza et al., 2017; INPI, 2017; Embrapa Acre, 2017). The economic incentive lies in



the collective name. If flour sold under the Cruzeiro do Sul brand loses its standard, everyone loses value. Rules and technical monitoring, therefore, protect reputation. Embrapa reported that a 50-kg sack, previously sold for about R\$50, reached approximately R\$120 after the quality-improvement process; this indicates commercial appreciation but does not isolate the effect of the GI from other market factors (Embrapa Acre, 2021).

Rondônia illustrates support for the family production unit rather than a single crop. Family farmers often combine milk, cassava, corn, vegetables, and other foods on the same farm. Limestone, soil analysis, input transportation, planting material, and technical assistance can serve more than one activity. Complementary Law No. 547/2009 created the ProLeite Fund to support dairy farming. Its relevance to cassava lies in the type of productive goods that can spill over to diversified farms when rural extension and the state secretariat operate shared services (Rondônia, 2009). The earlier diagnosis of Rondônia's cassava value chain documented high intermediation, limited assistance, and limited financing, making it plausible that the diffusion of inputs, management practices, and sales channels contributed to higher yields (Rosa Neto et al., 2009).

The evidence from Rondônia does not prove isolated causality but is consistent with the argument (Figure 5). The state had technical-assistance coverage above the regional average: 18.7% of farms in 2017, compared with close to 10% in the North region (Embrapa Rondônia, 2020; Pereira & Castro, 2021). The Mais Calcário (More Limestone) program reported serving more than 1,000 family farmers across all 52 municipalities, providing free transportation for more than 40,000 metric tons of limestone, and restoring more than 14,000 hectares in 2021 (Rondônia, 2021). In 2024, the state Food Acquisition Program served 558 individual producers and 12 cooperatives with R\$3 million in funding; the federal PAA allocated R\$2.831 million to 1,066 producers across all 52 municipalities (Rondônia, 2024a, 2024b). That year, Rondônia produced about 361,000 metric tons of cassava, yielding 20.5 t/ha, above the national average (IBGE, 2025; Embrapa Rondônia, 2024).

Pará shows why available technology is not enough. The state produced about 4 million metric tons of cassava in 2024, close to one-fifth of national output, but productivity remained near 15 t/ha, similar to the Brazilian average (IBGE, 2025). Part of the crop is consumed on farms, processed into flour, or sold through local channels with little price differentiation (Smeraldi & Santos, 2021). Silva et al. (2014) describe weak consolidation of Pará's cassava production arrangement, with problems involving coordination, assistance, and public policy. Evaluation of the Productivity Trio in Moju shows that a technical solution exists: the study estimated an average gain of 7 t/ha and a net income per hectare 61.3% above that of the traditional system (Silva, 2013). The challenge is to connect this technology to assistance, credit, planting material, logistics, and a buyer willing to pay for the resulting standard.

Section 3.3 should therefore be read as a comparison of arrangements. Where demanding buyers, assistance, and financing are connected, productivity tends to rise. Where markets purchase undifferentiated products, assistance is scarce, and transportation is uncertain, technology remains confined to pilots or isolated producers. Agricultural-development policy for the Amazon should answer five questions before investing: Who buys? What standard will be rewarded? What service helps the producer meet that standard? Who coordinates the arrangement? How will the result be measured?

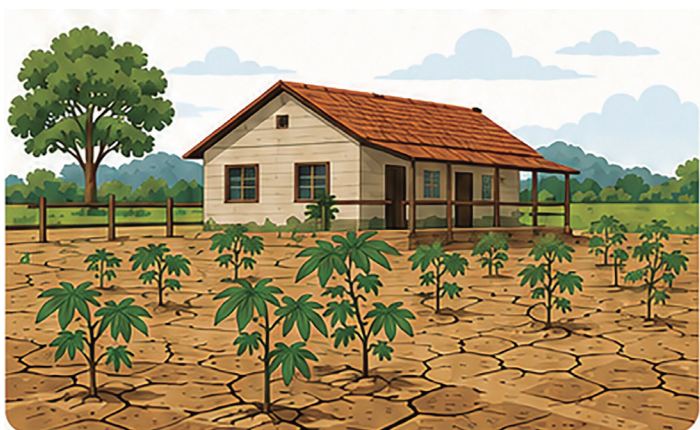


Figure 5. Arrangements associated with increased cassava productivity in Rondônia.

HOW RONDÔNIA INCREASED CASSAVA PRODUCTIVITY

Productivity gains resulted from research, rural extension, soil correction, financing, and public procurement—not a single policy.

1 STARTING POINT: BOTTLENECKS ON THE FARM



In addition to acidic, low-fertility soils:

-  **81.8%** sold through middlemen
-  **64.9%** received no technical assistance
-  **7.4%** had access to financing

In the 2000s, cassava was important to family farming, but **productivity was limited by poor soils, limited credit, scarce technical assistance, and market access difficulties.**

2 DIAGNOSIS AND RESEARCH



The Brazilian Agricultural Research Corporation (Embrapa) identified constraints in soils, farm management, and markets



Tests of clones and varieties identified planting materials **more productive and suitable for flour production, table consumption, and industrial processing.**



The Rondônia Technical Assistance and Rural Extension Agency (Emater-RO) and Embrapa **disseminated cassava stem cuttings and cultivars** such as BRS 1668, with potential yields of up to 25 t/ha.

ROLE OF RESEARCH



Adapt varieties



Improve farm management



Reduce dependence on informal planting material.

3 RURAL EXTENSION + INPUTS + FINANCING



A

A. Rural extension



Emater-RO advised producers on soil preparation, fertilization, planting, harvesting, and organizing farms.



Field days, the multiplication of cassava stem cuttings, and support for producer associations **helped disseminate technology.**



AGRICULTURE IN THE LEGAL AMAZON

3 RURAL EXTENSION + INPUTS + FINANCING

b State support through Pró-Leite

The **Pró-Leite Fund** originated from efforts to find a state-level solution to the shortcomings and limitations of regional development instruments.

To address this gap, **Rondônia created its own arrangement**: part of the tax incentive granted to dairy processors was used to finance Pró-Leite.

Although it was created for the dairy value chain, **the fund supported the mixed farming systems** of family farms and financed part of the logistics for limestone distribution.



In the 1990s and 2000s, regional incentives and policies, including those of the Superintendency for the Development of the Amazon (Sudam), did not provide stable and sufficient support to modernize family farming.

1999:

Part of the tax incentive granted to dairy processors began financing Pró-Leite.

2009:

Complementary Law No. 547 formally established the Pró-Leite Fund.

2010:

Decree No. 15,513 regulated the fund.



c Limestone and soil correction



Limestone corrected soil acidity, reduced aluminum toxicity, and increased fertilizer efficiency.

This also benefited pastures, corn, and cassava.

2020: Free transportation of **12,000 metric tons** to **433 producers** in **35 municipalities**.

2021: More than **10,000** metric tons delivered to **318 producers**; target of **50,000** metric tons for more than **2,000 farmers**

Related target: restore approximately **16 thousand hectares**.

THE COST OF LIMESTONE

3.1 t/ha

Estimated application rate

~R\$ 599/ha

Government logistical support

~R\$ 203/ha

Cost borne by the producer



In remote areas, freight costs could equal **or exceed** the cost of the product itself.

Pró-Leite financed a significant share of limestone transportation under the **Mais Calcário**

4. GUARANTEED MARKET: PUBLIC PROCUREMENT

National School Feeding Program (PNAE)

- School meals created stable demand for family farming.
- Rondônia encouraged municipalities to allocate at least **40%** of procurement funds to local purchases, above the minimum legal requirement of **30%**.
- Cassava and cassava products gained a place in institutional markets.

Food Acquisition Program (PAA/PAA-RO)

- The program purchased products from family farmers for simultaneous donation.
- **First half of 2024:** 558 individual producers and 12 cooperatives served.
- **State funding during the period:** R\$3 million.

5 RESULT: INCREASED PRODUCTIVITY



17.4 t/ha

2007



~20 t/ha

2014



~23-24 t/ha

2021

Average cassava yield in Rondônia, metric tons per hectare.



6.4 Appendix 4. Catrapovos: Public Procurement Adapted for Traditional Foods and Isolated Small Producers

Catrapovos is relevant to this report because it demonstrates how public procurement can work in territories where family farmers, Indigenous peoples, quilombola communities, riverine populations, and forest extractivists face barriers related to documentation, scale, logistics, technical assistance, and sanitary compliance. The available evidence best supports a more specific conclusion: Catrapovos created a method of institutional coordination to turn PNAE's legal priority into feasible procurement in traditional territories.

The experience began in Amazonas with Catrapoa, organized from 2016 onward through an initiative of the Federal Public Prosecutor's Office to enable the purchase of locally produced food for school meals. Catrapovos Brasil was later structured to replicate the practice in other states. The MPF describes the initiative as a coordination among governments, social movements, Indigenous and traditional leaders, and civil society organizations to adapt school meals to local realities (Ministério Público Federal [MPF], n.d.-a). An academic article based on documentary research records the creation of Catrapovos Brasil in 2020, while institutional sources indicate national consolidation in 2021; the safest formulation is therefore to treat 2020-2021 as the period of national structuring (Rocha, Leite, & Dias, 2024; MPF, n.d.-a).

The legal framework of the National School Feeding Program established that at least 45% of resources transferred by FNDE must be used to purchase food from family farming, with priority for agrarian-reform settlements, Indigenous communities, and quilombola communities (Brasil, 2025c). The rule does not, however, guarantee implementation. Many traditional producers lack the required documentation, regular delivery scale, transportation, packaging, technical assistance, or a sanitary classification compatible with conventional public calls.

Catrapovos' principal contribution is to address this bottleneck. The mechanism combines dialogue among the MPF, FNDE, education departments, nutritionists, sanitary-surveillance authorities, CECANEs, Funai, community organizations, and local managers. In practice, the commission helps adapt procurement notices, recognize traditional foods in menus, guide documentation, organize suppliers, and reduce barriers so that communities can sell to PNAE. FNDE Technical Note No. 3744623/2023 represented a concrete advance: it advised executing entities to accept the Social Identification Number (NIS), linked to the Unified Registry (Cadastro Único – CadÚnico, Brazil's Unified Registry for Social Programs) when family farmers from traditional peoples and communities do not have a valid Pronaf Eligibility Declaration (DAP) or active National Family Farming Registry (CAF) (FNDE, 2023a, 2023b).

According to the MPF, implementation has advanced. Between 2019 and 2024, more



than R\$11 million was allocated to purchasing traditional foods for school meals in different states and municipalities. In Amazonas, there were more than 30 public calls, more than 200 schools served, about 20,000 students benefiting, and more than 1,000 supplying families. In Pará, 57 schools and about 4,400 students were recorded; in Oriximiná, since 2022, approximately R\$1 million has been allocated to purchase about 100 metric tons of local foods, including flour, fish, and regional fruit pulps (MPF, 2025).

These figures demonstrate implementation but are insufficient to establish the final impact. The MPF reports an evaluation by the Federal University of Amazonas that shows a reduction in nutritional deficits in three Indigenous schools compared with data from 10 years earlier. The finding is relevant but should be treated as preliminary evidence because the report does not present the complete methodology, a comparison group, detailed indicators, or a peer-reviewed publication (MPF, 2025). The same caution applies to income: the possibility of up to R\$40,000 per year per Indigenous family farmer in Amazonas should be read as a ceiling, not an average among suppliers (MPF, 2025).

The coordination experience reveals the potential mechanism. Catrapovos reduces barriers to entering PNAE; PNAE creates more predictable demand; demand justifies the organization of production, technical assistance, quality improvement, and delivery planning; part of public procurement income remains in the territory; and schools can receive food that is more consistent with local dietary habits. This mechanism is consistent with the report's central thesis: productivity and resilience depend on markets, assistance, logistics, appropriate rules, and institutional coordination, rather than on isolated instruments.

Important gaps remain. There is no consolidated national public database reporting amounts contracted and paid by municipality, product, supplier, school, people or community, quantity delivered, price, delivery regularity, and implementation problems. Independent evaluations are also lacking on suppliers' net income, menu composition, student acceptance, reduction in ultra-processed foods, logistics costs, nutritional indicators, and effects on traditional production systems.

Despite these challenges, the initiative provides lessons for improving the capacity of isolated rural producers in the Amazon. First, public procurement from this population requires preparation before the procurement notice: documentation, technical assistance, price formation, supply organization, packaging, transportation, sanitary guidance, and accounting.

Second, policy should finance delivery capacity, not only the food purchased. In many territories, the bottleneck is river transportation, basic processing, storage, refrigeration, digital access, invoice issuance, and ATER.

Third, sanitary rules should be proportional to risk. Food safety is indispensable, but industrial requirements can exclude small-scale traditional products without necessarily improving sanitary quality. The approach adopted by Catrapoa and Catrapovos Brasil is consistent with the principle of risk-proportionate regulation advocated by



FAO and the Codex Alimentarius, under which sanitary controls should be based on risk assessment and adjusted to product and production-system characteristics, avoiding disproportionate requirements that hinder the inclusion of family farmers, Indigenous peoples, and traditional communities in institutional markets (FAO & WHO, 2022; FAO & WHO, 2003).

Simplified sanitary inspection through the Municipal Inspection Service (Serviço de Inspeção Municipal - SIM), a local sanitary inspection system for animal-origin food products marketed within the municipality, illustrates risk-proportionate regulation strictly for local trade (Ministério da Agricultura, Pecuária e Abastecimento, Confederação Nacional de Municípios, Rede Nacional de Consórcios Públicos & Serviço Brasileiro de Apoio às Micro e Pequenas Empresas, 2021). This regulatory arrangement simplifies complex structural and infrastructure requirements for foods with low epidemiological risk or short supply chains, such as honey from small apiaries and fresh, short-maturation cheeses sold directly at open-air markets (Prefeitura de São José do Sul, 2024). The rationale is that distribution limited to the municipality sharply reduces the reach and dispersion of potential outbreaks, facilitates immediate epidemiological tracing by local surveillance, and avoids the stringent controls required for road or interstate trade (Confederação Nacional de Municípios, 2021). If a small producer expands sales beyond municipal boundaries, however, the regulatory risk changes immediately, and the business must migrate to national equivalence systems (Ministério da Agricultura, Pecuária e Abastecimento, Confederação Nacional de Municípios, Rede Nacional de Consórcios Públicos, & Serviço Brasileiro de Apoio às Micro e Pequenas Empresas, 2021).

Fourth, Catrapovos should be treated as a method of territorial coordination. It does not replace ATER, logistics, credit, inspection, or school management; it connects these elements so that PNAE can purchase from suppliers that would otherwise remain outside the institutional market.

The program can be improved through monitoring that includes the following: amounts contracted and paid, product quantity and quality, price, supplier, community, school, students served, delivery frequency, and implementation problems.



Table 9. Catrapovos: Progress and Challenges

Issues	Documented progress	Challenges for scale and evaluation
Institutional basis	National coordination inspired by Catrapoa/AM; commissions and working groups in several states; participation of MPF, FNDE, managers, communities, and social organizations (MPF, n.d.-a; Rocha, Leite, & Dias, 2024).	Lack of comparable data by state and municipality.
Procurement rule	PNAE prioritizes family farming, Indigenous peoples, and quilombola communities; Law No. 15,226/2025 raised the minimum to 45% beginning in 2026 (Brasil, 2009, 2025).	Legal priority alone does not solve documentation, logistics, sanitary, and delivery-capacity constraints.
Documentation	FNDE Technical Note No. 3744623/2023 advised acceptance of NIS when DAP or CAF is unavailable (FNDE, 2023a).	Municipalities and states still need to apply the guidance consistently.
Implementation	More than R\$11 million in purchases between 2019 and 2024; robust data for Amazonas and Pará (MPF, 2025).	No public annual series with amounts paid, products, suppliers, and schools.
Products	Inclusion of cassava, flour, fish, fruit, pulps, tubers, eggs, poultry, and other traditional foods (MPF, n.d.-b; MPF, 2025).	No database with quantities by product, delivery regularity, and participation in menus.
Impacts	Preliminary evidence on income and nutrition in specific cases (MPF, 2025).	Insufficient independent evaluation to conclude broad impacts on income, health, the environment, or climate resilience.

6.5 Appendix 5. Agricultural Climate Risk Zoning by Management Level: Mechanism and Gaps for the Amazon

ZarcNM is based on the premise that agricultural risk depends not only on climate and soil but also on management. Soils with better cover, more organic matter, greater infiltration, and less compaction retain more water and reduce the probability of losses during dry spells. ZarcNM therefore differentiates management levels and enables rural insurance policies to reward producers who reduce risk through verifiable practices (MAPA, 2026; Embrapa, 2026a).

The expansion announced by MAPA in 2026 included soybeans in new states, second-crop corn, and subsidies of up to 50% in areas with the best management levels. For the Amazon, the gaps are both technical and institutional. Technical gaps include



calibrating indicators for humid tropical soils, areas with heavy cloud cover, integrated systems, perennial crops, cassava, and agroforestry systems (SAFs). Institutional gaps include the creation of accredited operators, laboratories, ATER, data platforms, and mechanisms accessible to small producers (MAPA, 2026; Embrapa, 2026a; IPCC, 2022).

The recommendation is to begin Amazon pilots with three objectives: validate indicators, reduce data collection costs and measure whether insurance incentives change practices. Without this, the instrument may remain limited to producers already integrated into formal systems, excluding those who most need adaptation (MAPA, 2026; Pereira & Castro, 2021; World Bank, 2018).

Table 10. Gaps in Adapting Agricultural Climate Risk Zoning by Management Level to the Legal Amazon

Gap	Risk	Proposed response
Calibration for Amazonian soils	Incorrect risk classification.	Embrapa and university trials by crop and soil.
Heavy cloud cover	Difficulty with remote monitoring.	Combine radar, field data, and historical series.
Low ATER coverage	Producers cannot improve management.	Accredit public agencies, cooperatives, and community technicians.
Low access to insurance	Benefits concentrated among integrated producers.	Pilots for family farming and public procurement.

Source: Authors' own elaboration based on MAPA (2025, 2026), Embrapa (2026), Pereira and Castro (2021), and World Bank (2018).

6.6 Appendix 6. Sectoral Funds in the Design of Agricultural Extension Systems

Discussion of sectoral funds in Brazilian agriculture often begins with financing, but it should begin with the problem to be solved. Funds are not, by themselves, instruments of productive transformation; they merely expand or stabilize resources. Impact occurs when these resources are integrated into extension and innovation systems that translate knowledge into production decisions. This integration is the link connecting technology, management, credit, and markets, and it helps explain why productivity gains in Brazil have been more consistent where innovation, technical assistance, and education were combined. Evidence shows that producers with access to technical assistance achieved significantly higher land productivity - in some cases up to two-thirds higher - than those without such support (Arias et al., 2017).

In the Amazon, this logic is even more relevant. The region combines low average productivity, great heterogeneity among producers, infrastructure constraints, and



growing environmental pressure. In this context, isolated policies tend to produce incomplete or even counterproductive results. Credit without technical guidance can increase indebtedness; infrastructure without territorial governance can stimulate disorderly expansion; and traceability requirements without technical support can exclude smaller producers. The challenge is therefore not simply to provide more financing, but to organize existing instruments more effectively around extension systems that function as an integrating axis.

Contemporary rural extension cannot be understood as simple technology transfer. It must operate as a producer decision-support system, addressing technical and managerial dimensions simultaneously. Technical support includes soil management, animal and plant health, adapted production systems, restoration of degraded areas, and climate adaptation. Managerial support includes planning, cost control, access to credit, risk management, and marketing strategies. Technology adoption depends on both productive knowledge and the capacity to make informed economic decisions.

Extension must also perform an institutional coordination function. The World Bank's concept of "extension-plus" describes services that go beyond traditional technical assistance to include access to markets, credit, and information, as well as coordination among actors (World Bank, 2012). In practice, extension agents act as bridges between producers and banks, buyers, public agencies, and research institutions. Without this connecting function, public policies tend to operate in a fragmented manner, reducing effectiveness.

Financing these systems requires a combination of public and private sources. Services with strong public-good characteristics—such as productive inclusion, environmental sustainability, sanitary protection, and climate adaptation—are unlikely to be supplied adequately by markets and therefore require public financing (World Bank, 2012). Services with more direct private returns can be co-financed by producers, agro-industries, and other value chain actors. This combination produces pluralistic systems in which public, private, and cooperative providers operate in complementary ways.

International experience shows that such arrangements can be effective when accompanied by appropriate governance and evaluation mechanisms. Peru's INCAGRO illustrates how competitive funds can stimulate demand for extension services by requiring producer cofinancing and merit-based selection. The program mobilized significant cofinancing and reached tens of thousands of farmers, demonstrating that organizing demand can improve the efficiency of public spending (World Bank, 2012).

Brazil has relevant examples of sectoral funds operating with different degrees of integration with extension systems. Funcafé (Brasil, 1986; Ministério da Agricultura e Pecuária, 2026) and Fundecitrus (Fundecitrus, 2025) show that sectoral resources can be effective when associated with technical governance and clear objectives.

Experiences such as ProLeite (Rondônia, 2009; Rondônia, 2025) show that a lack of institutional stability can undermine policy continuity and impact. A critical issue, however, is that Brazil has little systematic measurement of the cost-effectiveness and



efficiency of these funds. Unlike countries such as New Zealand, where organizations such as DairyNZ regularly evaluate return on investment (DairyNZ, 2025), Brazilian funds rarely have robust metrics that allow results to be compared and future decisions to be guided.

SENAR is financed through compulsory contributions from the rural sector: 0.2% of sales for individual producers, 0.25% for legal entities, or 2.5% of payroll for agro-industries. However, we found no broad analyses of the cost-effectiveness and effectiveness of resource allocation. A SENAR study focused on Technical and Managerial Assistance (ATeG) in dairy production in Espírito Santo found positive income effects (Dantas & Lacruz, 2024), although because it concerns a single value chain and region and because of its methodology, it cannot yet support generalization or precisely separate the effect from other factors.

What is still missing is an independent, nationwide evaluation that directly compares the benefits generated with the cost of the resources applied. Oversight bodies such as the Federal Court of Accounts verify the regularity and transparency of spending - including recognition that the S System[13] "survives essentially on public resources" (Tribunal de Contas da União [TCU], 2021) - but this type of oversight does not measure economic returns (TCU, 2022).

Because these are substantial resources (R\$818 million in 2025 - Table 11) and are public in nature, SENAR contributors themselves would benefit from broader, independent evaluations. Studies using comparison groups and measuring costs and benefits would help demonstrate the value of work already performed and guide even more efficient use of resources.

This evaluation gap limits institutional learning. Without consistent cost-effectiveness data, it is difficult to identify which arrangements work best, which should be adjusted, and which should be discontinued. In complex systems such as those in the Amazon, this limitation is particularly important because it increases the risk of inefficient resource allocation where needs are extensive, and resources are limited.

**Table 11. Budget Executed by the National Rural Learning Service in the States of the Legal Amazon, 2025**

States	Income spent (R\$)	% of the total in the Legal Amazon
Mato Grosso	471,351,360	58%
Pará	90,200,945	11%
Maranhão	84,300,000	10%
Tocantins	60,972,117	7%
Rondônia	56,877,004	7%
Amazonas	23,489,238	3%
Acre	12,461,506	2%
Amapá	11,690,179	1%
Roraima	7,206,427	1%
Total	818,548,776	100%

Data source: SENAR. Transparency Portal (data by the Regional Administration). transparencia.senar.org.br

Segmentation of extension services is another central element. Large producers tend to demand more sophisticated services and have greater capacity for cofinancing. Medium-sized producers represent the main potential for productivity gains because they often have sufficient scale but face constraints in management and access to services (Arias et al., 2017). Small producers, in turn, require more integrated and subsidized approaches focused on income, food security, and productive inclusion. This differentiation is essential to ensure that extension systems are both efficient and equitable.

At the same time, it is essential to improve the measurement of results. The absence of systematic cost-effectiveness evaluations in Brazil limits the capacity to improve policies and learn from experience. Countries that have adopted more rigorous evaluation practices have been better able to align investment with productive and environmental outcomes. Incorporating this dimension into the design of Brazilian sectoral funds is an essential step toward improving efficiency and ensuring that they contribute effectively to sustainable agricultural development in the Amazon.

Accumulated experience suggests that sectoral funds can play an important role in agricultural financing, but their impact depends on how they are integrated with extension and innovation systems. In the Amazon, where productive and environmental challenges are particularly complex, this integration is even more necessary. Policy design should begin with the concrete problems faced by producers and build institutional arrangements that connect financing, knowledge, and markets.



Table 12. Funds and Financing Arrangements in the Context of Extension Systems

Fund or institutional arrangement	Inception year	Root cause for creation	Extension role	Funding source	Source of information
Funcafé (Coffee Economy Defense Fund)	1986	Created to stabilize the coffee sector in the face of international price volatility and the need to coordinate credit and marketing.	Integrates credit with training and productive-support actions.	Public-sectoral	Brasil (1986); Ministério da Agricultura e Pecuária (2026)
Fundecitrus (Citrus Defense Fund)	1977	Created to address sanitary externalities, especially diseases requiring coordinated collective action among producers.	Sanitary coordination, applied research, and technical training.	Private contribution	Fun-decitrus (2025)
SENAR (National Rural Learning Service)	1991	Created to address a structural deficit in training and technical assistance in rural Brazil.	Continuous technical and managerial assistance.	Parafiscal	Brasil (1991)
GRDC (Grains Research and Development Corporation)	1990	Established to promote innovation and competitiveness in Australia's grain sector through coordinated investment in research.	Research, development, and extension with return-on-investment evaluation.	Public	Grains Research and Development Corporation (2022)
DairyNZ (New Zealand dairy-sector organization)	2001	Created to coordinate investments in productivity, sustainability, and competitiveness in the dairy sector.	Extension, data, and technical support with strong producer governance.	Mandatory levy	DairyNZ (2025)
FUNDERSUL (Mato Grosso do Sul Road System Development Fund)	1999	Created to finance logistics infrastructure essential to moving agricultural production.	Indirect productivity support through lower logistics costs.	Public	Mato Grosso do Sul (1999)
FUNDEMS (Fund for the Development of Corn and Soybean Crops in Mato Grosso do Sul)	2010	Created to support development and competitiveness in corn and soybean production, including research, plant health, and productive development.	Finances research, technical assistance, and development of corn and soybean value chains.	State	Mato Grosso do Sul (2010)
ProLeite (Rondônia Dairy Farming Development Fund)	2009	Created to raise dairy productivity in a context of low productive efficiency.	Supports sectoral policies and technical assistance.	State	Rondônia (2009); Rondônia (2025)
INCAGRO (Peruvian Agricultural Innovation and Competitiveness Program)	2001	Developed to correct market failures in the supply of innovation services and stimulate organized producer demand.	Competitive funds for contracting extension services.	Cofinancing	World Bank (2012)
Public extension	Various	Need for productive inclusion and provision of public goods not supplied by the market.	Basic technical-assistance and coordination services.	Public	World Bank (2012)



6.7 Appendix 7. Pre-Salt Social Fund: Potential Use for Climate Adaptation, Food Security, and Forest Protection in the Amazon

The Pre-Salt Social Fund (FS) can finance climate adaptation, food security, and forest protection in the Amazon. Law No. 12,351/2010 created the fund to convert part of oil revenues into social and regional development and authorized expenditures on the environment and climate adaptation. Law No. 15,164/2025 expanded eligible purposes to include social infrastructure, social housing, water infrastructure, food and nutrition security, and protection of the rights and interests of Indigenous peoples (Brasil, 2010, 2025a).

Allocating part of the FS specifically to the Amazon would require competition for resources not already earmarked. Law No. 12,858/2013 allocates 50% of resources received by the FS to public education and health until the targets of the National Education Plan are met. Law No. 15,164/2025 created an additional temporary allocation of 5% to education and health for five fiscal years. Complementary Law No. 223/2025 excluded these temporary expenditures from primary-expenditure limits and fiscal targets (Brasil, 2013, 2025a, 2025b). The Amazon, therefore, needs to compete for the remaining share through the Social Fund Annual Resource Application Plan (Plano Anual de Aplicação de Recursos do Fundo Social - PAAR FS), the budget proposal organized by the Ministry of Planning and Budget (MPO), and the Annual Budget Law (LOA) approved each year by the National Congress (CDFS, 2026b)[14].

The financial scale makes this competition important. Pré-Sal Petróleo S.A. (PPSA), the state-owned company linked to the Ministry of Mines and Energy that represents the federal government in managing and commercializing oil and gas from production-sharing contracts, reported revenue of R\$10.32 billion in 2024 and projected R\$69 billion in 2030 and R\$506 billion cumulatively through 2034 (PPSA, 2025). For 2027, the Social Fund Deliberative Council (CDFS) estimated revenue of R\$56.4 billion: R\$43.6 billion from oil and gas production, R\$7.8 billion in unrestricted own resources, and R\$5 billion in other financial revenue. Programming allocated R\$21.8 billion to education, R\$2.8 billion to health, and R\$31.8 billion to social housing and the energy transition (CDFS, 2026b). In 2026, the CDFS also proposed a R\$20 billion supplemental appropriation for reimbursable operations under the Minha Casa, Minha Vida housing program (CDFS, 2026a). These figures indicate financial capacity but also intense budget competition.

The Amazon combines climate, logistics, food security, and environmental vulnerabilities directly related to the FS's legal purposes. The Amazon forest recycles between 30% and 50% of the rainfall within its own basin and exports moisture to other regions of South America (Science Panel for the Amazon, 2025). Deforestation reduces rainfall at the regional scale and can lower agricultural productivity and revenue as forest loss accumulates across the territory; Leite-Filho et al. (2021) estimate that avoiding defor-



estation could prevent agricultural losses of up to US\$1 billion per year in the southern Brazilian Amazon. Severe droughts also interrupt river transportation, isolate riverine communities, and limit access to food, fuel, medicines, health care, and education (Santos de Lima et al., 2024).

Amazon-specific allocation depends on institutional design. The CDFS has the authority to approve the PAAR FS, publish the fund's annual report, define forms of resource execution, and assess financial conditions for credit lines (CDFS, 2025). Based on these powers, allocation should use public criteria such as climate vulnerability, food insecurity, dependence on river transportation, fire risk, presence of Indigenous peoples and traditional communities, deficits in environmental enforcement, and the importance of protected areas for water, fisheries, extractivism, and rural production.

The Annual Budget Law should translate these criteria into identifiable actions. Examples include climate adaptation in Amazonian communities, community water infrastructure, protected-area management, forest-fire prevention, technical assistance for agroforestry systems, and food-security logistics. A specific FS window for the Amazon should be based on technical criteria rather than fixed regional quotas. The presidential veto of Law No. 15,164/2025 rejected mandatory percentages for the Northeast, North, and Center-West on the grounds that rigid quotas would reduce allocative efficiency (Senado Federal, 2025).

Financial design should combine direct expenditure and credit in line with the nature of the intervention. The World Bank classifies adaptation measures into the provision of public goods, resilient infrastructure, promotion of private adaptation, and safety nets for vulnerable populations (World Bank, 2010). In the Amazon, enforcement, fire prevention, monitoring, public technical assistance, regularization of protected areas, and community infrastructure require direct expenditure. Productive restoration, agroforestry systems, sustainable management, low-impact irrigation, local storage, and farm adaptation can be combined with subsidies, technical assistance, and credit.

Law No. 15,164/2025 allows the FS to finance credit lines linked to public funds or public policies, provided that the resources are not used as collateral and the federal government does not assume the risk of the operations. When specific legislation does not establish conditions, the CDFS proposes, and the National Monetary Council (CMN) approves charges, terms, and fees (Brasil, 2025a). In the Legal Amazon, this structure can be linked to the Constitutional Financing Fund for the North (FNO), operated by Banco da Amazônia; the Constitutional Financing Fund for the Northeast (FNE), operated by Banco do Nordeste and relevant to Maranhão; and the Constitutional Financing Fund for the Center-West (FCO), created by Law No. 7,827/1989, coordinated within the Superintendency for the Development of the Center-West (Sudeco), and operated by Banco do Brasil, with relevance to Mato Grosso (Banco da Amazônia, 2024; Banco do Nordeste, n.d.; Banco do Brasil, n.d.; Sudeco, n.d.). Brazil's Constitutional Financing Funds provide subsidized regional development credit: FNO for the North, FNE for the Northeast, and FCO for the Center-West.

Implementation should have public targets. FS legislation requires quantitative and



qualitative evaluation of programs, with monitoring of effective impacts on beneficiary populations and regions (Brasil, 2010, 2025a). For the Amazon, indicators should include families less exposed to drought-related isolation, communities with secure supplies, effectively managed protected areas, reduced fires, restoration of degraded productive areas, and increased income for family farmers and forest extractivists.

There is a legal basis, financial scale, and technical justification for directing part of the Pre-Salt Social Fund to climate adaptation, food security, and forest protection in the Amazon. The bottleneck is budgetary and political. Without public criteria in the CDFS, specific actions in the Annual Budget Law, a technical allocation rule, and results monitoring, the contestable share will remain concentrated in the best-organized priorities. With these instruments, Brazil can convert temporary oil revenue into permanent protection of water, production, and food security in the region most strategically important to the country's climate.



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Endnotes

[1]The Brazilian Institute of Geography and Statistics (IBGE) is Brazil's national statistical agency.

[2]In Brazil, "family farming" is a legally defined category used to determine eligibility for specific rural credit, procurement, and support policies; it does not simply refer to any farm operated by a family.

[3]Authors' calculations based on MapBio-mas (2026) data available in Appendix 1.

[4]Based on the estimate by Vale (2020).

[5]Catrapoa and its national-scale successor, Catrapovos Brasil, are interinstitutional initiatives designed to facilitate public procurement of traditional foods from Indigenous peoples and other traditional communities.

[6]Brazil's Federal Public Prosecutor's Office (MPF) is an autonomous institution with responsibilities that extend beyond criminal prosecution to include the protection of constitutional, collective, environmental, Indigenous, and other public-interest rights.

[7] The Brazilian Agricultural Research Corporation (Embrapa) is the country's federal agricultural research agency.

[8]A federal system that identifies lower-risk planting windows by crop, municipality, and soil conditions and is used in agricultural credit and insurance policies.

[9]Quilombola communities are Afro-Brazilian communities descended from groups that historically formed autonomous settlements, including communi-

ties established by people who escaped slavery. Brazil's Constitution recognizes specific territorial rights for these communities.

[10] According to the National Department of Transport Infrastructure (DNIT), the "right-of-way" is the physical base upon which a highway rests, comprising the traffic lanes, medians, engineering structures, shoulders, signage, and lateral safety strips, with boundaries defined according to the highway's executive design, public utility decrees, or DNIT projects (2020).

[11]SENAR is part of Brazil's employer-funded vocational training system and provides rural vocational education as well as technical and managerial assistance. It is financed primarily through compulsory sectoral contributions.

[12]Extractive Reserves are a Brazilian category of protected area intended to safeguard the livelihoods and cultures of traditional populations while allowing the sustainable use of natural resources.

[13]Brazil's "S System" is a network of sector-specific, privately administered nonprofit organizations that are financed primarily through compulsory contributions and provide vocational training, technical assistance, and other services. SENAR is its rural-sector component.

[14]Brazil's Constitutional Financing Funds provide subsidized regional development credit: FNO for the North, FNE for the Northeast, and FCO for the Center-West.



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