www.directivepublications.org

Journal of
Environmental And Sciences

ISSN 2836-2551

Research Article

Temporal Dynamics Of Cocoa Growing In Mocajuba, Eastern Amazonia: Environmental And Socioeconomic Implications.

Daniel Fernandes Rodrigues Barroso[1]*, José Francisco Berrêdo[2], Marcia Aparecida da Silva Pimentel[3], Marcelo Cordeiro Thalês[2]; Maria do Perpétuo Socorro Progene Vilhena[4].

[1]*Department of Education, Federal Institute of Maranhão, Campus Itapecuru Mirim, Itapecuru Mirim, MA, Brazil,*
***E-mail:** daniel.rodrigues@ifma.edu.br.*
[2]*Coordination of Earth Sciences and Ecology, Emílio Goeldi Museum of Pará.*
[3]*Institute of Philosophy and Human Sciences, Federal University of Pará.*
[4]*Federal Rural University of Amazonia.*

Abstract

Brazil is the world's seventh largest cocoa producer. This study analyzes the dynamics and socio-economic and environmental relevance of cocoa farming in Mocajuba, using time series and econometric models. Vector error correction (VEC) and autoregressive (VAR) models were applied to assess the impacts of cocoa production. The results indicate that cocoa farming does not contribute to deforestation and has a positive impact on local GDP. Although the VEC model suggests that forest reduction in the past may have influenced cocoa production, the 10-year VAR model indicates no effect on forest cover. The positive correlation between cocoa production, production value and GDP reinforces this relationship. The study confirms the importance of cocoa farming as a driver of economic development in Mocajuba, highlighting its sustainable and relevant role for the local economy.

Keywords : Econometrics, Agricultural Crops, Gross Domestic Product, Deflorestation.

INTRODUCTION

The cacao tree is an evergreen, dicotyledonous arboreal plant belonging to the Sterculiaceae family and to the genus Theobroma and the species Theobroma cacao (Costa et al., 1973). It originated on the American continent and is found in the tropical region of the Amazon basin (Afonso, 1979; Rangel, 1982; Queiroga, et al., 2021). According to Gavrilova (2021), cocoa used to grow only in the tropical forests of the Amazon, but gradually spread to almost all the countries in the sub-equatorial belt. Although the fruit of the cacao tree is used as a raw material for various products, the seeds are most used to produce chocolate (De Araújo & Campos, 1998; Motamayor et al., 2008; Martins & Melo, 2021), a product consumed all over the world.

Brazil is one of the world's largest producers of the fruit, currently occupying seventh place (Brainer, 2021; Batista et al., 2023; ICCO, 2024) and crops can be found in the North, Northeast, Southeast and even Centre-West regions of the country. In the Northeast, the state of Bahia stands out as the second largest national producer, while in the North, the state of Pará stands out as the largest national producer. In the Amazon, plantations are mostly concentrated in areas owned by small producers (TFA, 2022), in dryland environments or in the floodplains of the region's large rivers (Almeida & Brito, 2003).

Production in the state of Pará is concentrated in five main regions: the southeast, northeast, Tocantins River Islands, Transamazon and the west of the state (Mapa, 2022). Crops in the Transamazon region account for 77% of the state's production (Mendes & Mota, 2018). They are produced in monoculture systems, known as full-sun production systems, with intensive use of chemical fertilisers and pesticides, and low biological and genetic diversity (Folhes & Serra, 2023). It is

***Corresponding Author:** **Daniel Fernandes Rodrigues Barroso**, Department of Education, Federal Institute of Maranhão, Campus Itapecuru Mirim, Itapecuru Mirim, MA, Brazil. **Email:** daniel.rodrigues@ifma.edu.br.
Received: 13-June-2025, Manuscript No. JOES - 4934 **; Editor Assigned:** 16-June-2025 **; Reviewed:** 08-July-2025, QC No. JOES - 4934 **; Published:** 18-July-2025, **DOI:** 10.52338/joes.2025.4934.
Citation: Daniel Fernandes Rodrigues Barroso. Temporal Dynamics Of Cocoa Growing In Mocajuba, Eastern Amazonia: Environmental And Socioeconomic Implications. Journal of Environmental And Sciences. 2025 July; 12(1). doi: 10.52338/joes.2025.4934.

in this region of Pará that the municipality of Medicilândia is located, the state's largest producer (Vegro et al., 2014; Santos et al., 2021), known as the national cocoa capital, as it is the largest producer among Brazilian municipalities.

However, there is significant production that is concentrated in the floodplains of rivers, especially in the Amazon, developed by riverside families, with cultivation and traditional practices in native cocoa plantations (Mapa, 2022; Mendes, 2017) or semi-domesticated cocoa plantations of undefined age (Almeida, 1991). This is the case in the municipality of Mocajuba, where cocoa cultivation is concentrated in the floodplains of the Tocantins River, exploited by riverside populations, who produce cocoa beans in a significant way, whose production is aimed at the local and national markets (Viana; Simões & Bastos, 2020).

The Amazon floodplains are important ecosystems that provide raw materials for the regional economy (Junk et al., 2020) and in the floodplains of the Tocantins River, the two main products of the bioeconomy of the state of Pará açaí and cocoa are found forming traditional agroforestry systems (Santos, Miranda; Tourinho, 2004) along with other native species, which are used both to generate income and for family subsistence (Rodrigues; Medeiros, 2024).

Despite several studies reporting the socio-economic and environmental importance of cocoa farming at different spatial scales (Willumsen & Dutt, 1991; Dürr, 2002; Almeida & Brito, 2003; Viana, Simões & Bastos, 2019; Conceição et al., 2020; Gama-Rodrigues et al, 2021; Dos Santos et al., 2023; Dos Santos Batista et al., 2023; Coslovski, 2023; Fernandez-Jeri et al., 2023) few studies measure the implications of this activity at the municipal level and even fewer studies report these implications in the case of floodplain cocoa.

In the context of land use and land cover, cocoa cultivation has been identified as a driver of both deforestation and reforestation (Orozco-Aguilar et al., 2021; Renier et al., 2023; Kalischek et al., 2023), and there are several reasons for this. In the case of the Amazon region, Venturieri et al. (2021) strengthen the argument that cocoa farming is a driver of reforestation, since plantations are concentrated in areas degraded by pasture in the state of Pará, because cocoa plantations are being planted in agroforestry systems (Schroth et al., 2016), transforming previously degraded landscapes. According to Garcia et al. (2024), cacao cultivation is vital for the economies of several developing countries, particularly in Africa and Latin America and In 2022-2023, global production surpassed 4.9 million tons, with major contributions from Ivory Coast (50%), Ghana (17%), and Ecuador (8%). In countries such as Indonesia, cocoa farming has a significant influence on economic growth and has been correlated with gross domestic product - GDP growth in the order of 1% (Silalahi et al., 2024).

The GDP measures the dynamic results of a society's productive activities (Alagoas, 2008) over a given period and is made up of the industrial, trade, services and agricultural sectors. According to Jank et al (2005), agribusiness is one of the most important sources of wealth for Brazil and places the country on a competitive level in the production of commodities and the contribution of the cocoa production chain and the chocolate industry contributed R$20 billion to the country's GDP (Bastos et al., 2017). To illustrate this, Pessoti (2006) analysed the contribution of cocoa to the composition of GDP in the state of Bahia in two different periods and in 1985, cocoa ranked first according to the Gross Value of Production and in 2000, cocoa ranked 7th among agricultural products in the same state (Pessoti, 2006).

It is argued that cocoa production in Mocajuba has positive environmental implications in the context of the dynamics of use and cover, since most cocoa areas are located on the floodplain islands of the Tocantins River (Mendes & Mota, 2018) and therefore agro-extractivist activity does not contribute to the dynamics of municipal deforestation. It is also argued that cocoa farming plays an effective role in the composition of the municipal GDP, contributing to local socio-economic development.

With this in mind, the aim of this study was to analyse the temporal dynamics of cocoa farming in Mocajuba in order to analyse the implications of this agricultural activity for the dynamics of municipal deforestation and the composition of the municipality's GDP, using environmental and socio-economic variables as parameters. It is based on the hypotheses that: i) cocoa farming does not contribute to the dynamics of deforestation because most of the plantations are located in floodplain forest areas of the Tocantins River; and ii) cocoa farming plays a significant role in the composition of the municipality's GDP.

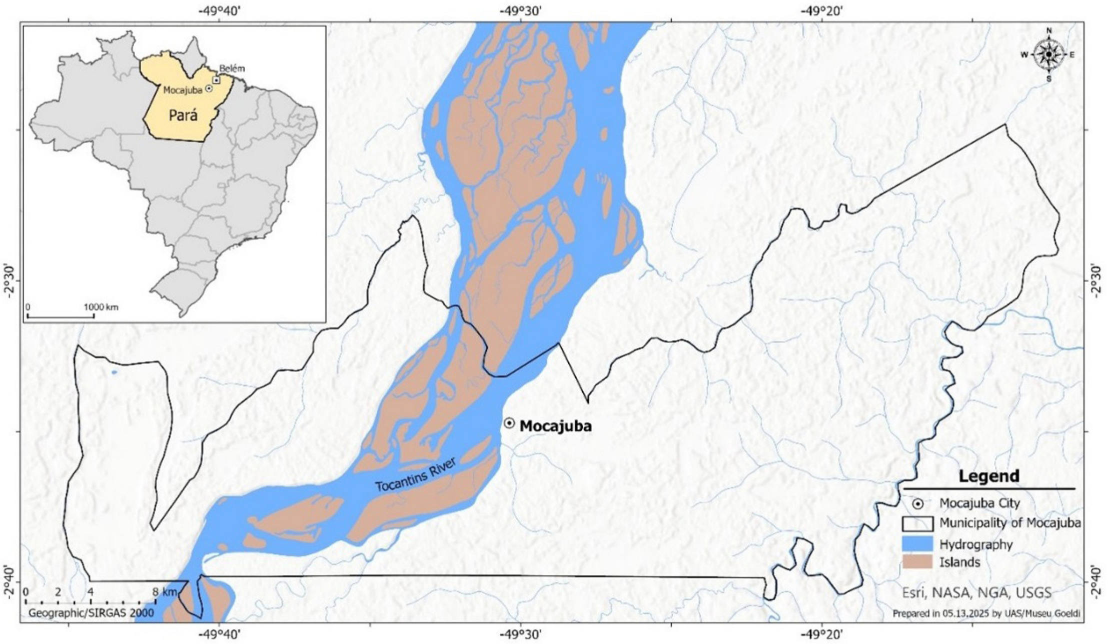
METHODOLOGY

Study area

The study was carried out in the municipality of Mocajuba (**Figure 1**), located on the lower reaches of the Tocantins River in the state of Pará. It belongs to the Intermediate Geographical Region of Belém - RGIB and the Immediate Geographical Region of Cametá - RGIC, along with three other municipalities: Cametá, Limoeiro do Ajuru and Oeiras do Pará (IBGE, 2017). Of the four municipalities that make up the RGIC, Mocajuba is the smallest both in terms of land area, with 871.17 km2 (FAPESPA, 2021), and population, with 27,265 inhabitants (IBGE, 2022), corresponding to 12.09% of the geographical region's population.

According to the Municipal Statistics report (FAPESPA, 2022), the main land-use activities in the municipality of Mocajuba are agriculture, livestock and plant extraction. Among agricultural activities, the most important are annual crops such as rice, beans, manioc and corn, and perennial crops such as açaí, cocoa and black pepper. Cattle, pigs and poultry are the main livestock farming activities. And among extractive activities, the collection of açaí fruit is the most important product.

Figure 1. Location of the study area



Data source

The data used in this study comes from two secondary sources: the first source is the IBGE, which includes a set of variables relating to cocoa farming and Mocajuba's GDP, and the second source is the MapBiomas Project (MapBiomas Project, 2023), which includes land use and land cover variables (**Table 1**). The different sources provide data from different historical periods and, therefore, this difference in time determined the time, in years, of each statistical analysis applied.

Chart 1. Data, variables and units of the Mocajuba cocoa farming variables.

Data*	Variables	Unit of variables
Cocoa1	Area planted/harvested	Hectares (ha)
	Production	Tons (tons.)
	Productivity	Kilograms per hectare (kg.ha-1)
	Production value	R$ 1000
Land use and cover2	Forest area	Percentage (%)
	Agricultural area	Percentage (%)
Gross Domestic Product – GDP3	Municipal GDP	R$ 1000
	Agricultural GDP	R$ 1000

***Data source:** [1]Municipal Agricultural Production; IBGE Automatic Recovery System; [2]MapBiomas Project; [3]National Accounts - IBGE.*

The data on cocoa farming in Mocajuba was extracted from the IBGE Automatic Recovery System - SIDRA and based on the work of Pessoa et al. (2021) four variables were evaluated: (a) Planted/harvested area (ha), which represents the total annual planted/harvested area of the two crops analysed in the municipality of Mocajuba; (b) Production, which represents the annual quantity produced in tonnes (t); (c) Cocoa productivity in kilograms per hectare (kg/ha), described by the ratio between the quantity of dried beans produced and the area of cocoa harvested in the municipality; and (d) Production value (in thousands of R$), calculated by the weighted average of the information on quantity and average current price paid to the producer.

To reduce the impact of inflation on the economic variables used in this study, the data on the value of cocoa production was deflated for the year 2021, using the average annual value of the General Price Index - Internal Availability of the Getúlio Vargas Foundation (FGV-IBRE, 2016) for the period analysed, while the GDP values were deflated using the annual rate of change of the Implicit Deflator of the Gross Domestic Product at current prices of the National Accounts System - SCN (IBGE, 2016).

It should be noted that although data on the value of cocoa production has been available since 1974, these variables were only analysed from 1999 onwards, which coincides with the start of Mocajuba's GDP time series. Similarly, it was only possible to analyse the correlation between the planted/harvested area variables and the land use and land cover variables from 1985 to 2022 (the period in which Mocajuba's land use and land cover data is available). It should also be noted that the data presented in the planted/harvested area variable are different variables within IBGE's SIDRA system, but in the case of Mocajuba, the values for planted area and harvested area (in hectares) are the same, which is why it was decided to aggregate the data into a single variable.

Data analysis

The Mocajuba cocoa farming dataset, consisting of the following variables: planted/harvested area, annual production, productivity and production value, as well as land use and land cover data and economic variables, were analyzed using descriptive statistics to check the average, maximum and minimum values and the standard deviation and were presented in the form of tables, while the annual series of these variables were presented in the form of graphs. To assess the environmental and socio-economic implications of cocoa farming, Spearman's correlation analysis was first applied to verify the relationship between the variables, The strength of the correlation was classified according to Xiao et al (2016) as strong (p-value between -1.0 to -0.5 and 1.0 to 0.5), moderate (p-value between -0.5 to -0.3 and 0.5 to 0.3), weak (p-value between -0.3 to -0.1 and 0.3 to 0.1) and very weak or non-existent (p-value between -0.1 to 0.1). After the correlation analysis, vector autoregressive models (VAR) were developed to analyse the influence of cocoa farming on environmental and socioeconomic variables separately. The first model analysed the influence of cocoa farming on land use through the planted/harvested area variable on the percentages of forest and agriculture for the period 1985 to 2022; while the second model assessed the influence of the value of cocoa production on municipal and agricultural GDPs for the period 1999 to 2022. Table 2 describes the variables, the type of analysis and the sample period used in this work.

Chart 2. Variables, types of analysis and sample period.

Variables	Type of analysis	Sample period (n)
Area planted/harvested	Descriptive Statistics	1974-2022 (n=49)
Production		
Productivity		
Production value		1999-2021 (n=23)
Production	Descriptive Statistics + Spearman Correlation Analysis + Error Correction Model associated with the Autoregressive Vector Model	1985-2022 (n=38)
Area planted/harvested		
Forest area		
Agricultural area		
Production		1999-2021 (n=23)
Production value		
Municipal GDP		
Agricultural GDP		

The Vector Autoregressive Model (VAR) is a statistical approach widely used to model the dynamic interdependence between multiple endogenous variables in non-stationary time series. It consists of multivariate linear autoregressive equations that capture the dynamics of economic variables, identifying structural shocks through restrictions and estimating impulse response functions to analyse the effects of these shocks on the economy. In the case of non-stationary series, i.e. with a unit root, it is desirable to incorporate an error correction vector. Thus, the VEC is an extension of the VAR model, suitable for cointegrated time series, i.e. when the variables under analysis have a long-term relationship with each other and can capture long-term deviations that affect the short term.

To analyse whether the time series are cointegrated, the Extended Dickey-Fuller (DFA) unit root test (Dickey; Fuller, 1979) was applied at significance levels of 1, 5 and 10%, considering the null hypothesis (H0) that the series has a unit root and is therefore non-stationary and the alternative hypothesis (H1) that the series does not have a unit root and is therefore considered stationary. Once the cointegration of the series analysed had been defined, the Johansen cointegration test (Johansen, 1988) was applied to check the number of cointegration vectors. The number of lags in the models was chosen based on the Akaike Information Criterion (AIC); Hannan-Quinn Criterion (HQC); Bayesian Criterion of Gideon Schwartz (SBC); and Final Prediction Error (FPE). The stability of the model was checked using diagnostic tests: Ljung-Box test (Ljung; Box, 1978) for autocorrelation of the residuals; White test (White, 1980) for heteroscedasticity of the residuals and Jarque-Bera test (Jarque; Bera, 1980) for normality of the residuals.

The VEC model was transformed into a VAR to analyse the elasticity of impulse responses for 10 years ahead so that the behaviour of the variables to individual shocks could be assessed, as well as the decomposition of the variance of the model error. All the analyses were carried out using the R Statistical Software (R Core Team, 2022) version 4.2.1 and the ggplot2 package (Wickham, 2016) was used to compose the graphs.

RESULTS AND DISCUSSION

Temporal dynamics of cocoa farming in Mocajuba

Table 1 shows the results of the descriptive statistics for cocoa production in the municipality of Mocajuba, containing the variables planted/harvested area, production, productivity and production value from 1974 to 2022.

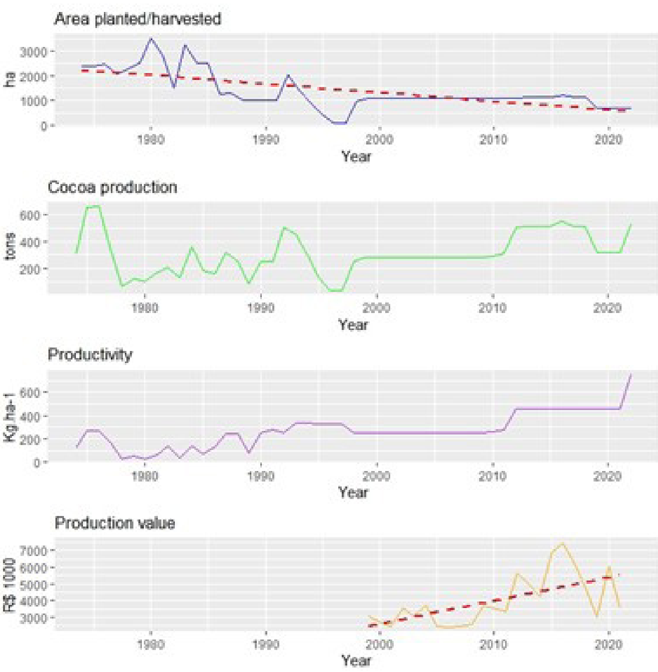
Table 1. Descriptive statistics of the productive aspects of cocoa farming in Mocajuba, containing the sample period (n), maximum and minimum values, means and standard deviations.

Description	Area planted/harvested (ha)	Production (tons)	Productivity (Kg.ha-1)	Production value (R$ 1000)
n	49	49	49	23
Max.	3520	661	750	7476.81
Min.	100	33	29	2406.38
Mean	1383	308	274	3986.83
Standard Deviation	±756	±154	±146	1530.58

The planted/harvested area varied from 3520 ha in 1980 to 100 ha in 1996/97, with an average of 1383 (±756) ha. In 1974, the first year of the historical series, the area of cocoa (planted and/or harvested) in the municipality was 2,400, 73.4% more than the average for the entire historical period. In the second half of the 1990s, there was a significant reduction in the planted/harvested area, reaching 400 ha in 1995, a reduction of 83.33% compared to the first year of the historical series, and in the following years (1996 and 1997) the reduction was even greater, falling to 100 ha with a reduction rate of 95.83%. From 1999 onwards, the cocoa production area rose to 1105 ha, remaining at this level until 2018 (with 1125 ha), reducing to 700 ha in the last four years of the historical series (Table1).

Dry almond production during the sample period averaged 308 tons per year, ranging from 661 to 33 tons in 1976 and 1996/97, respectively. In terms of productivity, the historical average was 274 Kg.ha-1 with the lowest productivity in 1978 with only 28 Kg.ha-1, while the highest productivity was achieved in 2022 with 750 Kg.ha-1. The value of cocoa production (in values of R$ 1000), measured from 1999 onwards, deflated by the General Price Index - Domestic Availability (IGP-DI) for the year 2021, ranged from R$ 2406.00 in 2006 to R$ 7476.81 in the year 2021, with an average of R$ 3986.83.

Figure 2. Time series with trend lines for cocoa farming in Mocajuba from 1974 to 2022, containing: planted/harvested area, production, productivity and production value.



The results show that, over time, the size of the planted/harvested area has reduced, but there is a tendency for growth in the quantity produced (of dried almonds), in productivity and in the value of production. The reduction in the cocoa area between 1974 and 2022 in Mocajuba contrasts with the results of the work by Landau, Silva and Moura (2020), who observed a trend towards an increase in the area of cocoa cultivation in the northern region of Brazil, but agrees with the same authors with regard to production and productivity, since in that work, these variables increased over time. The upward trend in the value of cocoa production coincides with the pattern of increase observed for the quantity produced and productivity.

It is important to remember that until the 1980s, Brazil was the world's second largest cocoa producer, second only to Côte d'Ivoire (Coslovsky, 2023) and the reduction in planted/harvested area from the 1980s onwards may be associated with the crisis faced by the cocoa sector caused by infestations of witches' broom in the plantations of Bahia, which culminated in regional economic destabilization (Trevisan, 1998: Carvalho et al., 2007) with direct consequences for Brazilian cocoa exports (Conceição, Soares & Lisboa, 2022), 2007) with direct consequences for Brazilian cocoa exports (Conceição, Soares & Lisboa, 2022) or the increasing presence of potential and actual competitors (Carvalho et al., 2007). Furthermore, in the Amazon, since 1996, the Executive Commission of the Cocoa Plantation Plan - CEPLAC has imposed a requirement that new plantations be made in anthropized areas (Gama-Rodrigues et al., 2021), discouraging new plantations in floodplain environments.

The relationship between cocoa farming and the dynamics of land use and cover and Mocajuba's GDP

Table 2 shows the land use and land cover variables, more specifically the forest cover and farming data for Mocajuba from the MapBiomas Project. Using this data, it is possible to assess the growth of agricultural activities and correlate them with the production and areas of cocoa plantations in the municipality. For analysis purposes, only the following land use categories were considered: forest percentage (which includes forest formation, savannah formation and flooded forest) and agriculture (which includes pasture and temporary and perennial agriculture), which were correlated with the variable cocoa production and planted/harvested area in the sample period (1985-2022).

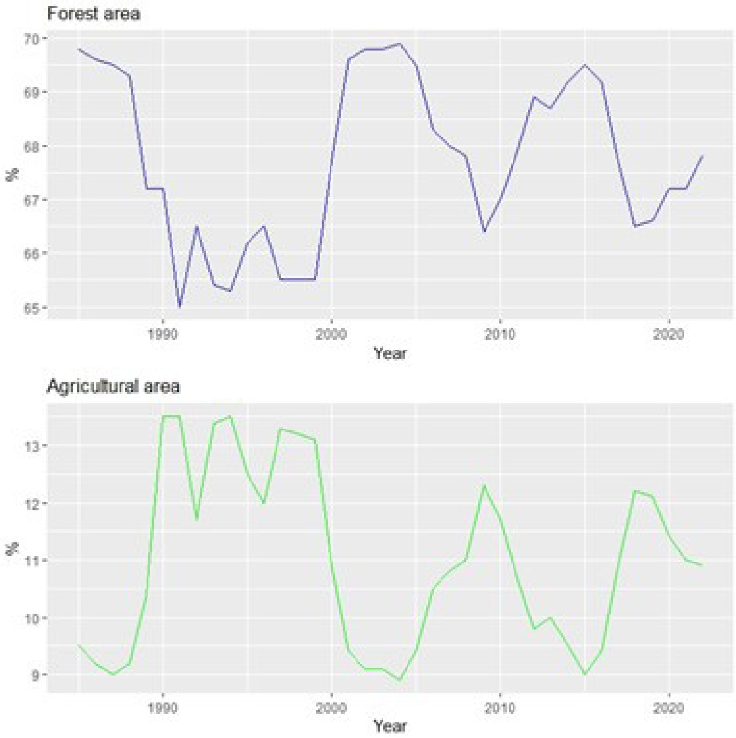
Table 2. Descriptive statistics for Mocajuba's land use and land cover variables, containing the sample period (n), maximum, minimum, average and standard deviation values for the area and percentage of forest and agriculture.

Description	Forest (ha)	Agriculture (ha)	Forest (%)	Agriculture (%)
n	38	38	38	38
Max.	60914.33	11784.89	69.90	13.50
Min.	56592.44	7788.63	65.00	8.90
Mean	59002.59	9563.93	67.74	10.97
Standard Deviation	1347.22	1347.00	1.55	1.55

Source: *prepared by the authors (2025) based on data from the MapBiomas Project.*

The results show that there was a reduction in forest cover throughout the 1990s with an increase in the percentage of agricultural land, since in 1985, the percentage of forest was 69.8% (60760.3 ha), falling to 65.5% (57059.61 ha) in 1999. In the same period, the percentage of agriculture was 9.5% (8,302.83 ha) in 1985 and rose to 13.1% (1,043.2 ha) in 1999. Between the years 2000 and 2022, the area devoted to agricultural activities fluctuated, remaining above or close to the percentage at the start of the historical series. These results are corroborated by Spearman's correlation analysis (Figure 5a), which showed a significant inverse correlation ($\rho = -0.95$; $p<0.01$) between the two variables. Among agricultural activities, cattle ranching was the main driver of deforestation in the municipality, since, since the beginning of the historical series, the pasture area has increased by more than 18% (MapBiomas (2023), occupying 10.82% of the entire municipal area. These results indicate that the increase in agricultural areas is a determining factor in the increase in deforested areas in Mocajuba, following the same trend as the increase in deforestation observed for the Amazon region, which is widely cited in scientific literature, with agricultural activities and livestock farming, especially cattle farming, as vectors (Maranhão et al., 2024; Delazeri, 2016; Lima, Skutsch & Medeiros Costa, 2011).

Figure 3. Time series with the percentages of forest cover and agricultural use in Mocajuba from 1985 to 2022.



Source: *prepared by the authors (2025) based on data from the MapBiomas Project.*

On the contrary, the statistical analysis showed a moderate positive correlation between the variables cocoa production area and percentage of forest area (ρ= 0.44 and p<0.006) and a negative correlation with the percentage of agricultural area (ρ= -0.44 and p<0.001) (Figure 5a), indicating a directly proportional relationship between cocoa and forest areas. It is important to note that the municipality of Mocajuba is located in the Tocantins region, where the practice of cocoa growing is traditionally in floodplain cultivation (Folhes & Serra, 2023), whose plantations are located in the understory of floodplain forests of the Tocantins River forming traditional agroforestry systems (Santos, Miranda; Tourinho, 2004) consortium with native species, especially açaí. Because they are located in the understory of floodplain forests, the cocoa forests of the Tocantins River are not identified as agricultural crops, but rather as forests in the context of land use and occupation.

Table 3 shows the results of the descriptive statistics for the econometric variables: the value of cocoa production and the total GDP and GDP of the agricultural sector in Mocajuba. In relation to Mocajuba's GDP (Total GDP), measured between 1999 and 2021, it can be seen (in values of R$ 1000) that it varied from R$ 397881.23 in 1999 to R$ 3361204.01 in 2021, while the GDP of the agricultural sector (Agricultural GDP) varied from R$ 152015.51 to R$ 1373960.11 in 1999 and 2021. The share of the agricultural sector's GDP in total GDP averaged 35.61% over this period, ranging from 26.62% in 2004 to 47.37% in 2013. The share of the value of cocoa production in the municipality's total GDP over the period analyzed averaged 0.30%, ranging from 0.03% in 2019 to 0.93% in 2003, while the share of the agricultural GDP averaged 0.90%, ranging from 0.09% to 3.27% in 2019 and 2003, respectively.

Table 3. Descriptive statistics for Mocajuba's econometric variables, containing the sample period (n), maximum, minimum, average and standard deviation values for the area and percentage of forest and agriculture.

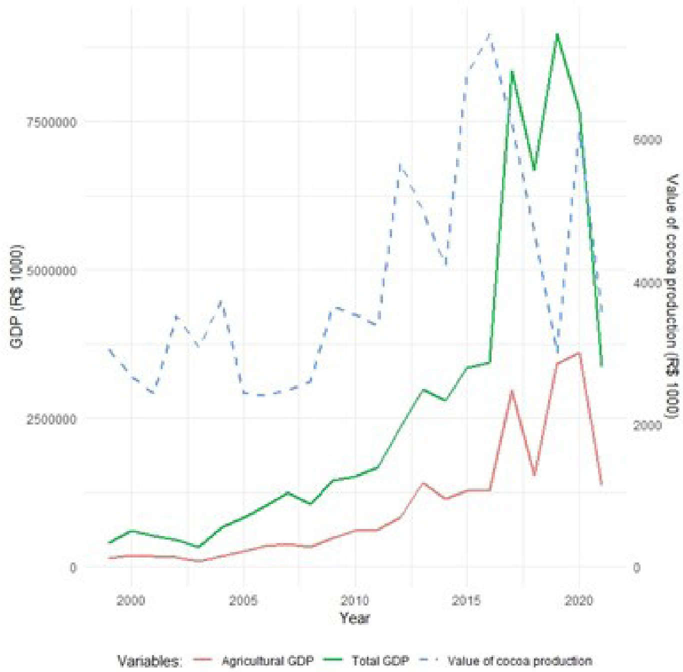
Description	*Value of Cocoa Production (R$ 1000)	**Total GDP (R$ 1000)	**Agricultural GDP (R$ 1000)	¹Participation (%)	²Participation (%)	³Participation (%)
n	23	23	23	23	23	23
Max.	7476.81	8975055.81	3616825.22	47.37	0.30	0.90
Min.	2406.38	330307.38	94001.04	23.04	0.93	3.27
Mean	3986.83	2684123.74	994246.40	35.61	0.03	0.09
StandardDeviation	±1530.58	±2678350.14	±1042825.97	±5.75	±0.24	±0.80

Source: *prepared by the authors (2025) based on IBGE data. *Inflated by the average value of the IGP - DI for the year 2021; **Inflated by the Implicit GDP Deflator; 1Participation of the agricultural sector's GDP in relation to the municipality's total GDP; 2Participation of VP_Cacao in relation to total GDP; and 3Participation of VP_Cacao in relation to agricultural GDP.*

Figure 4 shows the time series of Mocajuba's total GDP and agricultural GDP values, comparing them with the municipality's cocoa production values. The result shows similar behavior between the economic variables: cocoa production value, total GDP and agricultural GDP over the period analyzed.

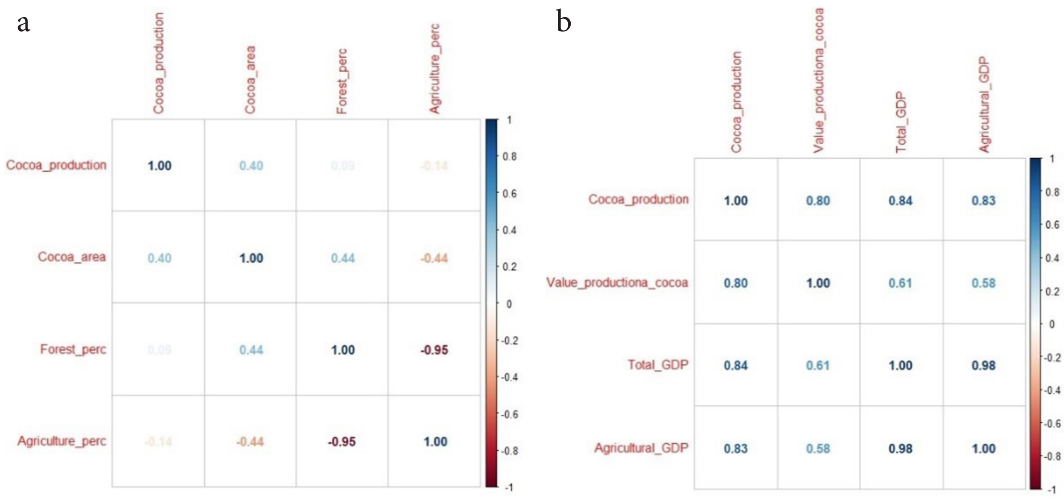
This behavior is corroborated by the Spearman correlation analysis between these variables (Figure 5b), which showed positive, strong and significant correlations. The value of cocoa showed a correction coefficient of ρ= 0.61 and $p<0.05$ with total GDP; and ρ= 0.58 and $p<0.05$ with the GDP of the agricultural sector. Similarly, the correlations between Mocajuba's total and agricultural GDP values were strong, direct and significant with the cocoa production variable, (ρ= 0.84 and $p<0.001$) and (ρ= 0.83 and $p<0.001$), respectively. The correlation between cocoa production and the value of production was ρ= 0.80 and $p<0.01$. These statistical relationships show that an increase in cocoa production in Mocajuba is a determining factor in raising the value of the municipal GDP and agree with the results of the studies by Breisinger et al (2008), Pérez, Cevallos and Campoverde (2022), Alain (2024) and Silalahi et al. (2024).

Figure 4. Time series containing the value of cocoa production and the values of Mocajuba's total and agricultural GDP from 1999 to 2021.



Source: *prepared by the authors (2024) based on data from IBGE's Municipal Agricultural Production and Federal Accounts.*

Figure 5. Results of Sperman's correlation analysis between the variables: a) cocoa production, planted/harvested area, percentage of forest cover and percentage of agricultural use in the period from 1985 to 2022; and b) cocoa production, value of cocoa production, total GDP and GDP of the agricultural sector in the period from 1999 to 2021.



	Cocoa_production	Cocoa_area	Forest_perc	Agriculture_perc
Cocoa_production	1.00	0.40	0.09	-0.14
Cocoa_area	0.40	1.00	0.44	-0.44
Forest_perc	0.09	0.44	1.00	-0.95
Agriculture_perc	-0.14	-0.44	-0.95	1.00

	Cocoa_production	Value_productiona_cocoa	Total_GDP	Agricultural_GDP
Cocoa_production	1.00	0.80	0.84	0.83
Value_productiona_cocoa	0.80	1.00	0.61	0.58
Total_GDP	0.84	0.61	1.00	0.98
Agricultural_GDP	0.83	0.58	0.98	1.00

Vector Error Correction Model - VEC associated with the Vector Autoregressive Model – VAR

The VEC associated with the VAR was applied in this work to analyze the implications of cocoa farming on land use and land cover and socioeconomic variables in Mocajuba. To this end, two models were tested: Model I analyzed the implications of cocoa production on the area under cocoa cultivation, as well as on the percentages of forest area and area under agricultural activities in the municipality. The second model (Model II) assessed the implications of cocoa production on the value of cocoa production and on the values of Mocajuba's total GDP and the GDP of the agricultural sector.

The unit root test in a VAR model is necessary to check whether the time series is stationary or not. We tested models without a constant and without a trend (None); with a constant and without a trend (Drift); and with a constant and with a trend (Trend). **Table 4** shows the results of the level test, indicating that the series are stationary, since the critical values are greater than the t-statistic values.

Table 4. Augmented Dickey-Fuller unit root test for the time series analyzed: cocoa production, planted/harvested area, percentage of forest cover and percentage of agricultural use in Mocajuba from 1985 to 2021 for models I and II.

Variáveis	Model I					
	None		Drift		Tend	
	*Critical value	t-statistic	*Critical value	t-statistic	*Critical value	t-statistic
LNCocoa_Production	-1.95	0.039	-2.93	-3.258	-3.50	-4.066
LNCocoa_Area	-1.95	-0.375	-2.93	-3.699	-3.50	-3.645
LNPerc_Forest	-1.95	-0.265	-2.93	-2.484	-3.50	-2.597
LNPerc_Agriculture	-1.95	-0.266	-2.93	-2.484	-3.50	-3.285
	Model II					
cocoa_production	-1.95	0.09	-3.00	-1.47	-3.60	-1.37
value_ production	-1.95	0.34	-3.00	-1.56	-3.60	-1.97
total_GDP	-1.95	1.15	-3.00	-0.93	-3.60	-2.80
agriculture_GDP	-1.95	1.43	-3.00	-0.72	-3.60	-3.37

**at the 5% significance level*

The first difference test was carried out (**Table 5**) and the result showed that model I does not have a unit root and is therefore non-stationary, since the values of the statistical tests (t-statistic) are lower at the 5% significance level.

Table 5. Augmented Dickey-Fuller unit root test in first difference for the time series analyzed: cocoa production, planted/harvested area, percentage of forest cover and percentage of agricultural use in Mocajuba from 1985 to 2021 for models I and II.

Variables	Model I					
	None**		Drift		Tend	
	* Critical value	t-statistic	* Critical value	t-statistic	* Critical value	t-statistic
d_LNCocoa_Production	-1.95	-2.64	-3.00	-2.57	-3.60	-2.62
d_LNCocoa_Area	-1.95	-4.20	-3.00	-4.15	-3.60	-4.14
d_LNPerc_Forest	-1.95	-2.15	-3.00	-2.35	-3.60	-2.08
d_LNPerc_Agriculture	-1.95	-3.28	-3.00	-4.04	-3.60	-3.76
	Model II					
d_cocoa_production	-1.95	-2.64	-3.00	-2.57	-3.60	-2.62
d_value_ production	-1.95	-4.20	-3.00	-4.15	-3.60	-4.14
d_total_GDP	-1.95	-2.15	-3.00	-2.35	-3.60	-2.08
d_agriculture_GDP	-1.95	-3.28	-3.00	-4.04	-3.60	-3.76

**At 5% significance level; **Best-fit model.*

The series in the None model (**Table 5**) are stationary in first difference and therefore integrated, so the Johansen cointegration test was carried out to check the number of cointegration vectors. The result of the trace test (**Table 6**) showed three cointegration vectors at a 5% significance level in both models, demonstrating the existence of long-term relationships between the variables analyzed.

Table 6. Results of the Johansen Cointegration test for Models I and II

Null hypothesis	Model I			
	Trace test	Critical value (1%)	Critical value (5%)	Critical value (10%)
r ≤ 3	10.54	11.65	8.18	6.50
r ≤ 2	38.76	23.52	17.95	15.66
r ≤ 1	87.08	37.22	31.52	28.71
r = 0	139.53	55.43	48.28	45.23
	Model II			
r ≤ 3	4.34	11.65	8.18	6.50
r ≤ 2	13.98	23.52	17.95	15.66
r ≤ 1	38.15	37.22	31.52	28.71
r = 0	72.65	55.43	48.28	45.23

Table 7 shows the results for choosing the number of lags in the VAR model, according to the Akaike (AIC), Schwarz (SC), Hannan-Quinn (HQ) and Error Prediction Function (EFF) criteria. For Model I, the AIC criterion suggested five lags, the SC criterion suggested only one lag and the HQ and FPE criteria suggested two lags. For Model II, all the criteria suggest three lags. We therefore opted for the HQ criterion with two lags for Model I and three lags for Model II, since this criterion increases the accuracy of multivariate time series analysis, effectively capturing complex dependencies between variables, leading to better forecasting and classification performance in hierarchical structures (Prado et al., 2005).

Table 7. Results for the number of lags in the VAR model, based on the Akaike (AIC), Schwarz (SC), Hannan-Quinn (HQ) and Error Prediction Function (EFF) information criteria.

Lag	Model I			
	AIC	HQ	SC	FPE
1	-2.124840e+01	-2.100547e+01	-2.051553e+01*	5.945960e-10
2	-2.187278e+01	-2.138693e+01*	-2.040705e+01	3.308086e-10*
3	-2.167753e+01	-2.094876e+01	-1.947893e+01	4.491315e-10
4	-2.125859e+01	-2.028689e+01	-1.832711e+01	8.686015e-10
5	-2.229464e+01*	-2.108001e+01	-1.863030e+01	4.936039e-10
	Model II			
1	-1.145530e+01	-1.132070e+01	-1.065998e+01	1.086752e-05
2	-1.160458e+01	-1.133539e+01	-1.001395e+01	1.140750e-05
3	-1.311564e+01*	-1.271185e+01*	-1.072969e+01*	4.950776e-06*

Table 8 shows the diagnostic tests applied to the VEC model converted to VAR. These tests assess the adequacy of the model's residuals to the assumptions of independence, homoscedasticity and normality. The results of the tests indicate that both models meet the main assumptions: there is no evidence of autocorrelation, the residuals are homoscedastic and follow a normal distribution, and are therefore suitable for the analyses carried out, since the p-value was greater than 0.05 in all the tests.

Table 8. Diagnostic test results for models I and II.

Test	Model I			
	Type	Statistics	Degrees of freedom	p-valor
Autocorrelation	Ljung-Box Test	224.67	228	0.5499
Heteroscedasticity	White's Test	300	500	1.0000
Normality	Jarque-Bera Test	8.8807	8	0.3525
	Model II			
Test	Type	Statistics	Degrees of freedom	p-valor
Autocorrelation	Ljung-Box Test	234.65	212	0.1367
Heteroscedasticity	White's Test	140	500	1.0000
Normality	Jarque-Bera Test	12.007	4	0.09406

Vector Error Correction Model - VEC of Model I

The coefficients of the long-term equations, represented by the beta matrix (β) of the VEC, are shown in **Table 9**. The cocoa production (d_producao_cacau.l2), cocoa planted/harvested area (d_area_cacau.l2) and percentage of forest area (d_floresta_perc.l2) variables have normalized coefficients (β = 1) in their respective long-term equations. However, the percentage of agricultural area shows a positive relationship with these variables in the long-term dynamics, as indicated by the correction error coefficients (ECT1 = 2.883; ECT2 = 3.249; ECT3 = 0.162). Specifically, the coefficient of 2.883 (ECT1) suggests that the percentage of agricultural area has a positive impact on cocoa production in the long term. Similarly, the positive impact of the percentage of agricultural area on the area planted/harvested with cocoa is more expressive, as evidenced by the coefficient ECT2 = 3.249. Finally, the influence of the percentage of agricultural area on the percentage of forest area is also positive and significant, albeit to a lesser extent (ECT3 = 0.162).

Table 9. Model I long-term equation

Variables	ECT1	ECT2	ECT3
d_producao_cacau.l2	1.000	0.000	0.000
d_area_cacau.l2	0.000	1.000	-0.000
d_floresta_perc.l2	0.000	0.000	1.000
d_agropecuaria_perc.l2	2.883	3.235	0.162

The positive relationship between cocoa production and the area of cocoa cultivation with the percentage of agricultural land indicates that the expansion of agricultural activities in the municipality of Mocajuba is partly directed towards cocoa farming, directly impacting cocoa production in the long term. This suggests that new agricultural areas may be earmarked for cocoa cultivation. In addition, it is possible that the expansion of cocoa farming will occur in forest areas, especially through agroforestry systems, which can minimize the impacts of this activity on ecosystems.

Table 10 shows the regression coefficients of Model I of the VEC for the cocoa production variable (d_producao_cacau), containing the Error Correction Terms (ECTs) and the coefficients of the short-term dynamics. The ECT1 (-2.35) and ECT2 (1.49299) terms are statistically significant ($p < 0.001$) and ($p < 0.01$) with negative ECT1 indicating that when there is a deviation from the long-term equilibrium, cocoa production decreases to correct this imbalance and positive ECT2 suggesting that long-term imbalances increase cocoa production.

Table 10. Error correction terms and short-term relationships in Model I.

Variables	Estimate	Standard Error	t-valor	p-valor
ECT1	-2.35437	0.49267	-4.779	0.000055***
ECT2	1.49299	0.47349	3.153	0.00393**
ECT3	-24.86740	26.98139	-0.922	0.36487
Constante	0.09009	0.08570	1.051	0.30249
d_producao_cacau.dl1	-0.88032	0.37996	-2.317	0.02834*
d_area_cacau.dl1	0.38080	0.38468	0.990	0.33101
d_floresta_perc.dl1	-45.83318	21.20619	-2.161	0.03970*
d_agropecuaria_perc.dl1	-6.64106	3.28376	-2.022	0.05314.

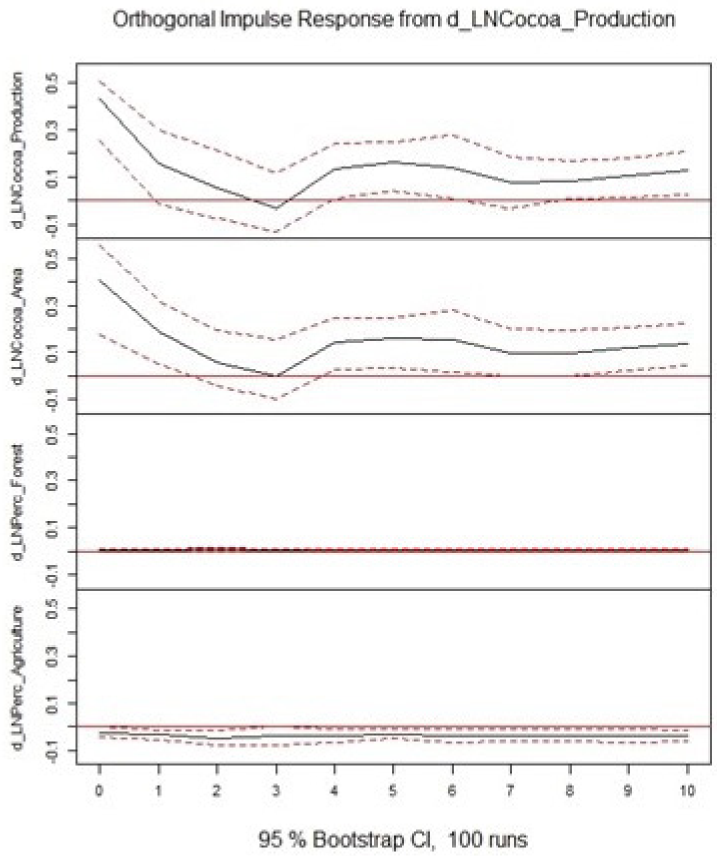
Codes Significance: (***) = 0.001; (**) = 0.01; (*) = 0.05; (.) = 0.1; ( ) = 1

The coefficients of the short-term variables highlight the influence of previous variations on current dynamics. At the previous lag, cocoa production influences its own current production (β = -0.88 and $p< 0.00$), the percentage of forest area also has a negative and significant effect on current cocoa production (β = -0.45 and $p< 0.05$), and the percentage of agricultural area has a negative and marginally significant effect (β = - 0.64 and $p < 0.01$). These values mean that an increase of 1 unit in the change in cocoa production in the previous lag reduces current production by approximately 0.88 tons; a 1% reduction in forest cover in the previous period is associated with an increase of approximately 45.83 tons in cocoa production in the current period; and a 1% increase in agricultural area reduces the change in cocoa production by around 6.64 tons.

The reduction in cocoa production in the current period may be related to various factors, including climatic and seasonal factors, since cocoa can be influenced by annual variations in the climate (Mbo et al., 2023). In addition, the reduction of forests may be being converted into new areas of cocoa plantations with positive responses on cocoa production in the medium and long term. On the other hand, the reduction in cocoa production with the increase in agricultural areas is an indication that the expansion of these agricultural areas is not necessarily for the implementation of cocoa farming, indicating diversity in land use in Mocajuba.

Figure 6 shows the impulse response (IRF) of the VEC model converted to VAR, analyzing the impact of cocoa production on the planted/harvested area and the percentages of forest and agricultural area over a 10-year horizon. The initial shock to cocoa production has a positive effect in the first year (1.15), persisting over time, although it becomes negative in the third period. The cocoa area responds positively to the shock, starting at 0.19 and remaining positive until the tenth period (0.13). The percentage of forest area shows a minimal positive response (0.0045), which is practically constant over time. The percentage of agricultural area reacts negatively (-0.035 in the first period), but this effect is slightly reduced over time (-0.036 in the tenth period).

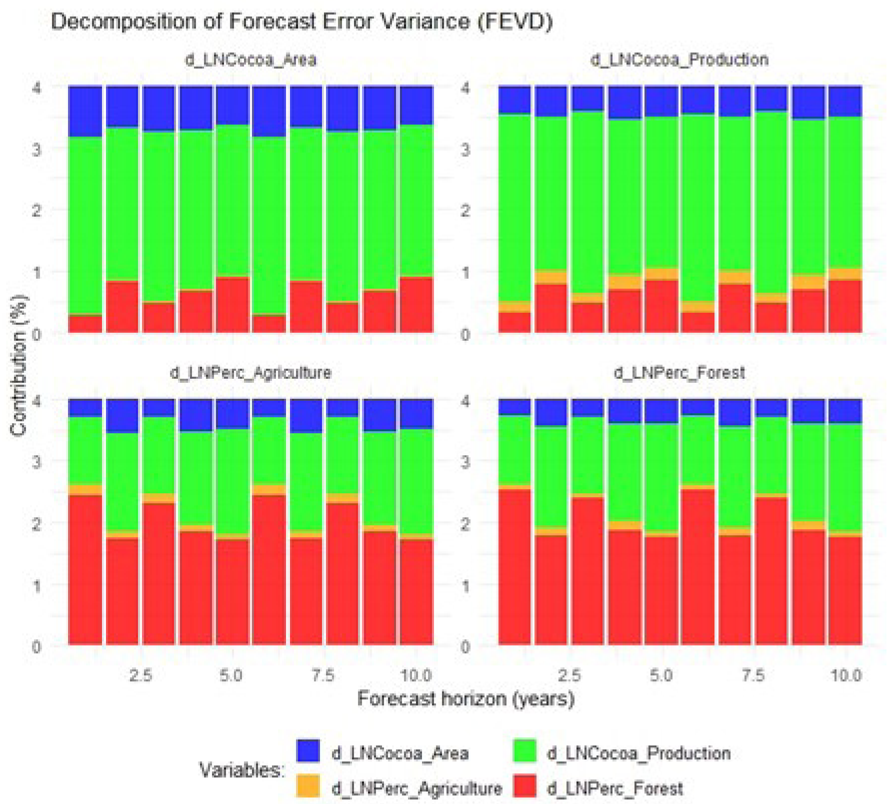
Figure 6. Impulse Response Function (IRF) of cocoa production on the planted/harvested area of cocoa and on the percentages of forest and agricultural area.



The increase in cocoa production drives its own growth over time, reflecting economic incentives and investments in the crop. This growth expands the planted area, but the effect is reduced over time due to physical, environmental or economic limitations. Despite the higher production, there is no significant impact on forest cover, indicating that cocoa farming in Mocajuba occurs mostly in agroforestry systems on the floodplains of the Tocantins River. In addition, cocoa production slightly reduces the percentage of agricultural activities, suggesting a partial substitution of land uses, although this effect stabilizes over time.

The graph in Figure 4 shows the decomposition of the forecast error variance. Initially, cocoa production is explained almost 100% by itself. In the medium term (5 periods), its influence decreases, being shared with the cocoa area (12%) and the percentage of forest (20%). In the long term (10 periods), cocoa production still dominates (60%), but the influence of the other variables increases, especially forest area (23%) and cocoa area (12%).

Figure 7. Decomposition of the forecast error variance (FEVD) of cocoa production on the area planted/harvested and on the percentages of forest and agricultural area for ten years ahead of Model I.



The results indicate that, in the short term, cocoa production depends mainly on internal factors, such as technology and investments. In the medium and long term, the variation in production is influenced by the area of cocoa and the percentage of forest, suggesting that the expansion of farming is essential for sustainable growth. The greater influence of forest indicates a possible association with agroforestry systems. The low influence of the agricultural area suggests that cocoa farming is consolidating as an independent activity, possibly replacing other land uses.

Vector Error Correction Model - VEC of Model II

Table 11 shows the coefficients of the long-term equations, represented by the beta matrix (β) from the VEC model. Cocoa Production (d_producao_cacau), Value of Cocoa Production (d_vp_cacau) and Total GDP (d_pib_total) have normalized coefficients (β = 1) in their respective long-term equations. However, Agricultural GDP shows a negative relationship with the other variables in the long-term dynamics. The Coefficient of -0.080 (ECT1) of agricultural GDP has a small and negative impact on the long-term relationship with cocoa production. The negative impact of agricultural GDP from ECT2 (-0.248) is more relevant in the long-term relationship with the value of cocoa production. While agricultural GDP has a higher negative influence on the long-term relationship with total GDP (ECT3= - 0.934).

Table 11. Model II long-term equation between the variables: cocoa production, plant/harvested area, total GDP and GDP of the agricultural sector in Mocajuba.

Variável	ECT1	ECT2	ECT3
d_producao_cacau.l3	1.000	0.000	0.000
d_vp_cacau.l3	0.000	1.000	0.000
d_pib_total.l3	0.000	0.000	1.000
d_pib_agrop.l3	-0.080	-0.248	-0.934

Table 12 shows the coefficients of the ETCs for the cocoa production equation and the coefficients of the short-term equation, which measures the current dynamics of cocoa production in relation to the lagged periods. ETCs 1 and 3 are negative and significant, indicating that when there are deviations from the long-term equilibrium, cocoa production decreases to correct these deviations (ECT1= -1.38860, $p < 0.05$; and ECT3=-1.83847, $p < 0.05$).

The short-term coefficients (**Table 12**) show the impact of past variations on current dynamics. At the first lag, only agricultural GDP shows a positive and marginally significant effect ($\beta = 0.55431$; $p < 0.1$). At the second lag, cocoa production is negatively impacted by its own production ($\beta = -1.02428$; $p < 0.05$) and by total GDP ($\beta = -1.35500$; $p < 0.05$). On the other hand, agricultural GDP has a significant positive effect ($\beta = 1.15566$; $p = 0.0177$). These coefficients indicate that an increase of 1 ton in the variation of cocoa production in the second lag reduces current production by approximately 1.02 tons and a R$ 1000.00 reduction in Mocajuba's total GDP in the two previous periods is associated with an approximate loss of 1.35 tons of dried cocoa beans in the current period. In contrast, an increase of R$ 1000.00 in the GDP of the agricultural sector in two previous periods is associated with an increase in cocoa production of around 1.15 tons in the current period.

Table 12. Error correction terms and short-term relationships in Model II between the variables: cocoa production, plant/harvested area, total GDP and GDP of the agricultural sector in Mocajuba.

Variável	Estimativa	Erro Padrão	t-valor	p-valor
ECT1	-1.38860	0.54323	-2.556	0.0378*
ECT2	0.30435	0.37819	0.805	0.4474
ECT3	-1.83847	0.65492	-2.807	0.0263*
Constante	0.03343	0.03596	0.930	0.3834
d_producao_cacau.dl1	-0.68132	0.39698	-1.716	0.1298
d_vp_cacau.dl1	-0.14466	0.18805	-0.769	0.4669
d_pib_total.dl1	-0.53817	0.31595	-1.703	0.1323
d_pib_agrop.dl1	0.55431	0.24677	2.246	0.0595.
d_producao_cacau.dl2	-1.02428	0.40198	-2.548	0.0382*
d_vp_cacau.dl2	0.08459	0.24057	0.352	0.7355
d_pib_total.dl2	-1.35500	0.39593	-3.422	0.0111*
d_pib_agrop.dl2	1.15566	0.37456	3.085	0.0177*

Codes Significance: (***) = 0.001; (**) = 0.01; (*) = 0.05; (.) = 0.1; ( ) = 1

Figura 8. Função Impulso-Resposta (IRF) do modelo II da produção de cacau sobre as variáveis valor da produção de cacau, PIB Total e Agropecuário para o período de 10 anos.

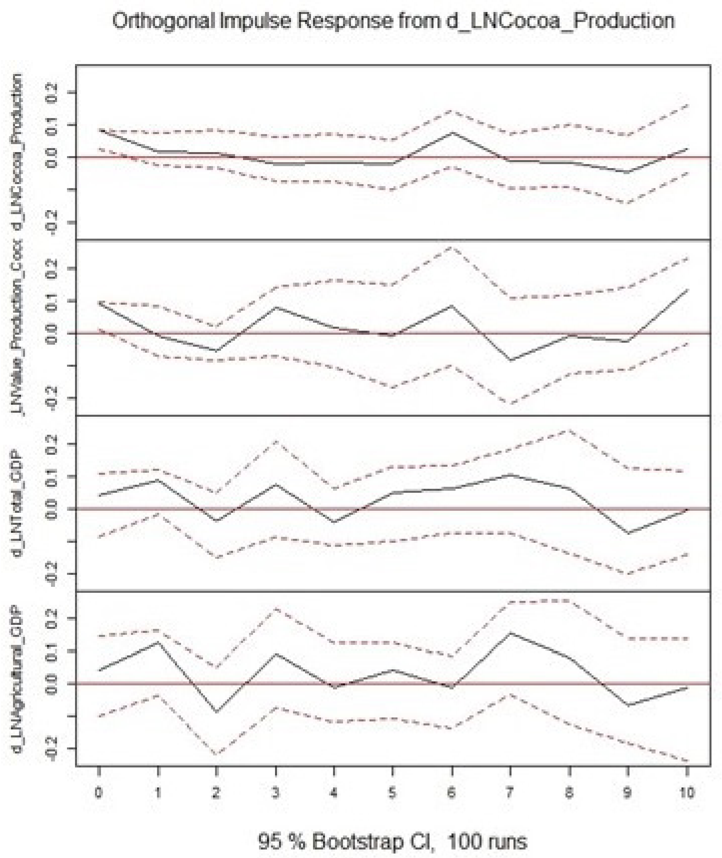


Figure 8 shows the impulse response function of the VEC model converted to VAR over a 10-year horizon. Initially, a shock to Cocoa Production (0.088) generates a positive impact on itself (0.015), a small negative effect on the value of production (-0.007) and positive impacts on total GDP (0.087) and agricultural GDP (0.127). In the following periods, the responses oscillate between positive and negative. In the medium term (5 years), a negative shock to cocoa production (-0.020) reduces the value of production (-0.009), while total GDP (0.0481) and agricultural GDP (0.043) respond positively. In the long term (10 years), cocoa production recovers (0.023), boosting the value of production (0.132), but negatively impacting total GDP (-0.005) and, to a greater extent, agricultural GDP (-0.010).
The results suggest that a shock to cocoa production has mixed effects over time. In the short term, there are benefits for the economy, but instability in production can lead to fluctuations in the value of production and GDP. In the long term, the recovery in production strengthens the sector, but can generate negative effects on the general economy, perhaps due to the reallocation of resources or structural changes in the agricultural sector. This may be a reflection of the market behavior in the cocoa chain, which increases the price of the product in years of lower agricultural production, caused by external factors such as climatic dynamics, positively impacting on the value paid to the producer and also reflecting on GDP figures.

Figure 9. Decomposition of the variance of cocoa production on the variables production value, total GDP and agricultural GDP for the 10-year period.

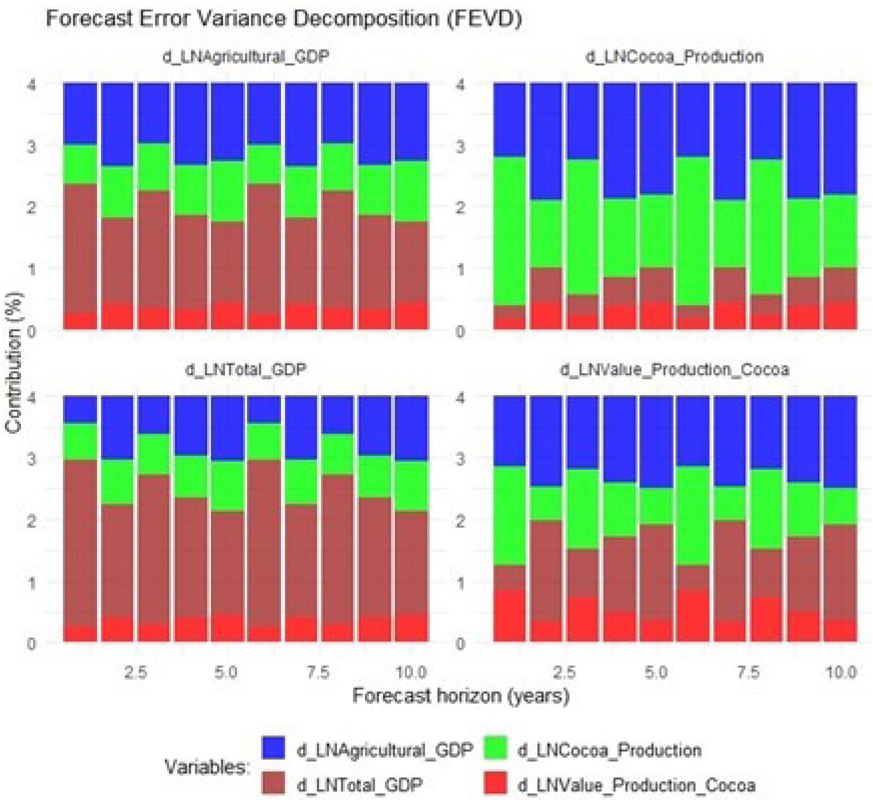


Figure 9 shows the variance decomposition for 10 years in Model II. In the short term (1 year), cocoa production explains 100% of the variance. In the medium term (5 years), this contribution drops to 26%, while agricultural GDP accounts for 48% and the other variables (Value of Production and Total GDP) for 12%. In the long term (10 years), cocoa production explains 29% of its variance, while agricultural GDP accounts for 45%, the value of production 12% and total GDP 14%.
The FEVD analysis in the VAR model showed that the value of cocoa production is initially explained by itself, but the role of the other variables increases significantly over the 10-year forecast horizon, with a greater impact of the GDP of the agricultural sector in the medium and long term and a lesser impact of total GDP and the value of production, suggesting a strong interdependence between these variables.

CONCLUSION

The temporal analysis of the dynamics of cocoa farming in Mocajuba showed a tendency for production and productivity to increase, even with a reduction in the area planted/harvested over the course of the historical series analyzed.

Based on the results of the statistical correlation analyses and the regression models used, the study confirmed the hypotheses tested that cocoa farming does not contribute to deforestation in Mocajuba and that this activity contributes effectively to the composition of Mocajuba's GDP. Although the VEC regression model shows that the reduction of forest in past periods suggests an increase in cocoa production in the present in the historical period analyzed, the VAR forecast model for the 10-year horizon points to a null effect of cocoa production on the percentage of forest cover in Mocajuba. The positive correlation between cocoa production, production value and GDP values corroborated the results of the VEC model, which showed an increase in production with an increase in GDP, strengthening the second hypothesis of this study and confirming the socio-economic importance of cocoa growing in Mocajuba as a driver of local development. Given the environmental and socio-economic importance of cocoa farming in Mocajuba, future studies are recommended that incorporate socio-economic and environmental variables at different spatial scales in order to understand how these factors may be influencing cocoa production in Mocajuba. Such studies are fundamental to understanding natural or anthropogenic threats to cocoa production in Mocajuba.

Acknowledgments

The authors would like to thank the Fundação Amazônia de Amparo à Pesquisa e Estudos - FAPESPA for funding the "Cacau das Ilhas de Mocajuba" project, which provided financial support for this work; to the Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão - FAPEMA for awarding a doctoral scholarship to the first author.

REFERENCES

1. Afonso, F. M. A. (1979). O cacau na Amazônia: Boletim Técnico I. Comissão Executiva do Plano da Lavoura Cacaueira: MAPA: Itabuna, 39 p.

2. Alagoas (Estado). (2008). Produto Interno Bruto. 8 (8). Maceió: Secretaria de Estado de Planejamento e Orçamento.

3. Alain, B.K. Economic impact of cocoa culture in Ivory Coast and in Ghana from 1980 to 2015. Journal of Historical Archaeology and Anthropological Sciences, 8(2), 62-67. https://doi.org/10.15406/jhaas.2024.09.00308.

4. Almeida, C. M. C. V. (1991). Correlação entre caracteres no estádio adulto e possibilidades de seleção precoce em híbridos de cacau (Theobroma cacao L.). 194 f. Tese (doutorado) – ESALQ/USP, Piracicaba.

5. Avadi, A. (2023). Environmental assessment of the Ecuadorian cocoa value chain with statistics-based LCA. The International Journal of Life Cycle Assessment. 28, 1495–1515. https://doi.org/10.1007/s11367-023-02142-4.

6. Bastos, E., Furtado, E, M., Cardoso, F., Brandão, J., Freire, R. M., & Maynart, J. (2017). Aposta na retomada do cacau. AgroANALYSIS, 37(9), 31-35.

7. Brainer, M.S. de C.P. (2022). Cacauicultura - Ações para o desenvolvimento da atividade. Caderno Setorial ETENE; Banco do Nordeste, Ano 7, n. 239.

8. Breisinger, C., Diao, X., Kolavalli, S., & Thurlow, J. (2008). The role of cocoa in Ghana's future development. Ghana Strategy Support Program. Disponível em: https://cgspace.cgiar.org/server /api/core/bitstreams/6e22dde5-679e-4f1d-98e5-74cc88bf414d/content.

9. Carvalho, D. F., Ribeiro, M. R., Santana, A. C. de, Carvalho, A. C. (2007). Analise dos testes de cointegração e de correção de erro nos preços de café e do cacau no mercado internacional de futuros e opções. Novos Cadernos NAEA, v. 10, n. 1. P. 45-70.

10. Conceição, R. L. C. da, Soares, N. S., & Lisboa, G. J. (2022). Oferta brasileira de exportação de derivados de cacau, 1961-2016. Novos Cadernos NAEA, 25(1).

11. Coslovsky, S. (2023). Oportunidades para aprimoramento da cacauicultura. Infloresta, n. 55.

12. Costa, A. da S.; Frazão, D. A. C.; Tourinho Filho, E. & Daguer, A. R. F. (1973). Cultura do cacau. Belém, IPEAN/ACAR-PA.

13. Costa, F. A., Ciasca, B. S., Castro, E. C., Barreiros, R. M., Folhes, R. T., Bergamini, L. L., Sobrino, A. S., Cruz, A., Costa, A., Simões, J., Almeida, J. & Souza, H. M. (2021). Bioeconomia da sociobiodiversidade no estado do Pará. Brasília, DF: Brasília, DF: The Nature Conservancy. BID.

14. De Almeida, L. C., & De Brito, A. M. (2003). Manejo do cacaueiro silvestre em várzea do estado do Amazonas, Brasil. Agrotrópica 15 (1): 47 - 52.

15. De Araujo, A. C., & Campos, R. T. (1998). Análise da evolução e da elasticidade de transmissão dos preços do cacau. Revista de Economia e Sociologia Rural, 36(1), 131-148.

16. Delazeri, L. M. (2016). Determinantes do desmatamento nos municípios do arco verde-Amazônia Legal: uma abordagem econométrica. Revista Economia Ensaios, 30(2), 11-34.

17. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American statistical association, 74(366a), 427-431. https://doi.org/10.1080/01621459.1979.10482531.

18. Dos Santos Batista, H., Schwertner, J. J. G., de Souza, F. R., da Silva, R. A., & Coronel, D. A. (2023). Análise da matriz competitiva das exportações estaduais brasileiras de chocolate e derivados do cacau. Economia & Região, 11 (2), 294-312.

19. Dos Santos, G. G., Neris, J. P. F., de Freitas, T. P. M., dos Santos, M. G., da Narusawa, I. D. S., da Silva, B. K. S.; de Souza, J. S., & Silva, V. S. (2021). Identificação e análise espacial das aglomerações produtivas do cacau na mesorregião do Sudoeste Paraense. In. Mendonça, M. de S. Agronegócio: técnicas, inovação e gestão. 1º ed. v. 1, p. 271-286.

20. Dos Santos, M. A. S., da Silva, S. A. S., da Silva Farias, V. D., da Silva, G. B., & Hamid, S. S. (2023). Demandas tecnológicas da cadeia produtiva do cacau no Território do Xingu, Estado do Pará. Revista Agronomia Brasileira. v. 7. doi: 10.29372/rab202320.

21. Dos Santos, S. R. M., de Souza MIRANDA, I., & Tourinho, M. M. (2004). Análise florística e estrutural de sistemas agroflorestais das várzeas do rio Juba, Cametá, Pará1. Acta Amazônica, 34, 251-263.

22. Dürr, J. (2014). Agro-extractivist value chains and regional development: the case of the Lower Tocantins River in the Brazilian Amazon. Novos Cadernos NAEA, 17(2).

23. Fernández-Jeri, A., Mori-Zabarburú, R., Cruzalegui-Fernández, R., Julca-Otiniano, A., & Fernández-Jeri, L. (2023). Sustainability of native cocoa producing farms in the Bagua Province, Peru. Tropical and Subtropical Agroecosystems 26.

24. Folhes, R. T., & Serra, A. B. (2023). Os efeitos da concorrência de trajetórias tecnológicas na economia cacaueira paraense sobre as promessas de sustentabilidade do setor: um estudo a partir da transamazônica, Pará, Brasil (Paper 555). Papers do NAEA, 1(1).

25. Fundação Amazônia de Amparo a Estudos e Pesquisas. (2021). Barômetro da sustentabilidade do município de Mocajuba. FAPESPA: Belém.

26. Fundação Amazônia de Amparo a Estudos e Pesquisas. (2022). Estatísticas Municipais Paraenses: Mocajuba./ Diretoria de Estatística e de Tecnologia e Gestão da Informação. – Belém, 69 p.

27. Fundação Getúlio Vargas/ Instituto Brasileiro de Economia. (2016). Índice Geral de Preços – Disponibilidade Interna: metodologia. FGV; IBRE.

28. Gama-Rodrigues, A. C., Müller, M. W., Gama-Rodrigues, E. F., & Mendes, F. A. T. (2021). Cacao-based agroforestry systems in the Atlantic Forest and Amazon Biomes: an ecoregional analysis of land use. Agricultural Systems, 194, 103270.

29. García, L.C., Zambrano, E., Maddela, N.R., García, M.S., & Gavilanes, F.Z. (2024). Cacao agribusiness in a global contexto. In García, L.C., Maddela, N.R., Gavilanes, F.Z., & Duarte, C.A (Eds.). Sustainable cacao cultivation in Latin America 3-15. https://doi.org/10.4324/9781003381761-2.

30. Gavrilova, N. G. (2021). Contemporary global production and consumption of cocoa: An assessment. In IOP Conference Series: Earth and Environmental Science (Vol. 839, No. 2, p. 022095). IOP Publishing.

31. Gomes, C. V. A. (2018). Ciclos econômicos do extrativismo na Amazônia na visão dos viajantes naturalistas. Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas, 13, 129-146.

32. Gomes, C., Garcia, E., Alves, E., Queiroz, M., & Oliveira, F. P. (2015). Cocoa agroforestry system as an alternative for degraded pastureland restoration, food security and livelihoods development among smallholders in a Brazilian Amazon agricultural frontier. Enhancing Food Security through Forest Landscape Restoration: Lessons from Burkina Faso, Brazil, Guatemala, Viet Nam, Ghana, Ethiopia and Philippines. Gland, Switzerland: IUCN, 42-69.

33. Instituto Brasileiro de Geografia e Estatística. (2016). Sistema de Contas Nacionais: Brasil: ano de referência 2010/ IBGE, Coordenação de Contas Nacionais. – 3. ed. - Rio de Janeiro: IBGE. 236 p.

34. Instituto Brasileiro de Geografia e Estatística. (2017). Divisão Regional do Brasil em Regiões Geográficas Imediatas e Regiões geográficas Intermediárias: 2017. Coordenação de Geografia. – Rio de Janeiro.

35. Instituto Brasileiro de Geografia e Estatística. (2022). Prévia da população calculada com base nos resultados do Censo Demográfico 2022 até 25 de dezembro de 2022. Diretoria de Pesquisas - DPE - Coordenação Técnica do Censo Demográfico – CTD: IBGE.

36. Instituto Brasileiro de Geografia e Estatística. (2022). Produção Agrícola Municipal. Sistema IBGE de Recuperação Automática.

37. International Cocoa Organization. (2024). Production of cocoa beans (Thousand tonnes). In: Quarterly Bulletin of Cocoa Statistics, Vol. L, No. 1, Cocoa year 2023/24.

38. Jank, M. S., Nassar, A. M., & Tachinardi, M. H. (2005). Agronegócio e comércio exterior brasileiro. Revista USP, (64), 14-27.

39. Jarque, C. M., & Bera, A. K. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. Economics letters, 6(3), 255-259.

40. Johansen, S. (1988). Statistical analysis of cointegration vectors. Journal of economic dynamics and control, 12(2-3), 231-254.

41. Junk, W. J., Piedade, M. T. F., Wittmann, F., Schöngart, J. (2020). Manejo e uso múltiplo da várzea: uma síntese In. Junk, W. J., Piedade, M. T. F., Wittmann, F., Schöngart, J. Várzeas Amazônicas: Desafios para um Manejo Sustentável. – Manaus: Editora do INPA, p. 242-263.

42. Kalischek, N., Lang, N., Renier, C., Daudt, R. C., Addoah, T., Thompson, W., ... & Wegner, J. D. (2023). Cocoa plantations are associated with deforestation in Côte d. Ivoire and Ghana.

43. Landau, E. C., da Silva, G. A., & Moura, L. (2020). Evolução da produção de cacau (Theobroma cacao, Malvaceae). In: Landau, E. C.; Silva, G. A. da; Moura, L.; Hirsch, A.; Guimarâes, D. P. (Ed.). Dinâmica da produção agropecuária e da paisagem natural no Brasil nas últimas décadas: produtos de origem vegetal. Brasília, DF: Embrapa, v. 2, cap. 17, p. 529-555.

44. Lima, M., Skutsch, M., & de Medeiros Costa, G. (2011). Deforestation and the social impacts of soy for biodiesel: perspectives of farmers in the South Brazilian Amazon. Ecology and Society, 16(4).

45. Ljung, G. M., & Box, G. E. (1978). On a measure of lack of fit in time series models. Biometrika, 65(2), 297-303.

46. Mapa. (2022). Cacao de Brasil. Ministerio de Agricultura y Ganadería: Brasília.

47. Maranhão, R. L. A., Guimarães, R. F., Hermuche, P. M., Gomes, R. A. T., Peripolli, V., Tanure, C. B., ... & McManus, C. (2024). Growth and acceleration analysis of the soybean, sugar cane, maize and cattle production in Brazil. Environment, Development and Sustainability, 1-46.

48. Martins, de C.D., & Melo, A. L. S. (2021). A Mercantilização do Fruto de Ixcacao: o Cacau do Grão-Pará e o Consumo do Chocolate na Europa (Séculos XVII e XVIII). Locus: Revista de História, 27(1), 229-251.

49. Mendes, F. A. F. (2017). State of Pará, Brazil: an option for the global supply of cocoa. In: 2017 International Symposium on Cocoa Research (ISCR), Lima, Peru, 13-17.

50. Mendes, F. A. F., Mota, A. T., Silva, J. W. (2018). O cultivo do cacaueiro no estado do Pará.

51. Motamayor, J. C., Lachenaud, P., Da Silva e Mota, J. W., Loor, R., Kuhn, D. N., Brown, J. S., & Schnell, R. J. (2008). Geographic and genetic population differentiation of the Amazonian chocolate tree (Theobroma cacao L). PloS one, 3(10), e3311.

52. Orozco-Aguilar, L., Lopez-Sampson, A., Cerda, R. H., Casanoves, F., Ramirez-Argueta, O., Diaz Matute, J., ... & Somarriba, E. (2024). CacaoFIT: the network of cacao field trials in Latin America and its contribution to sustainable cacao farming in the region. Frontiers in Sustainable Food Systems, 8, 1370275.

53. Pérez, O.A.V., Cevallos, H.A.V., Campoverde, J.M.Q. Análisis comparativo del impacto económico del cultivo del cacao en Ecuador del primer semestre 2019 versus el primer semestre 2020. Revista Metropolitana de Ciencias Aplicadas, 4(2), 169-179.

54. Pessoa, G. G. F. de A., Alves, A. K. S., Dantas, Érico dos A., Almeida, L. J. M. de, Silva, J. de A., Araújo, J. R. E. S., Silva, D. A. M. da, & Santos, J. P. de O. (2021). Dinâmica temporal da produção de cana-de-açúcar em um município do Brejo Paraibano, Brasil (1995–2019). Scientific Electronic Archives, 14 (11).

55. Pessoti, G. C. (2006). Uma leitura da economia baiana pela ótica do PIB–1975/2005. RDE-Revista de Desenvolvimento Econômico, 8(14).

56. Prado, R., Molina, F., & Huerta, G. (2006). Multivariate

time series modeling and classification via hierarchical VAR mixtures. Computational Statistics & Data Analysis, 51(3), 1445-1462.

57. Projeto MapBiomas (2023). Cobertura e transição municípios (v. 8.0) da Série Anual de Mapas de Uso e Cobertura da Terra do Brasil, 2021. Disponível em: https://brasil.mapbiomas.org/estatisticas/

58. Queiroga, V. de P.; Gomes, J.P.; Melo, B.A. de; Albuquerque, E.M.B. de (2021). Sistema produtivo do cacau (Theobroma cacao, L.) orgânico sombreado. In: Queiroga, V. de P.; Gomes, J. P.; Melo, B. A. de; Albuquerque, E. M. B. de. (ed.). Cacau (Theobroma cacao, L.) orgânico sombreado: Tecnologias de plantio e produção da amêndoa fina. 1ª ed. – Campina Grande: AREPB. 386 f.: il. color.

59. R CORE TEAM. (2022). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.Rproject.org/.

60. Rangel, J. F. (1982). Ceplac/cacau ano 25 (Vol. 16). IICA Biblioteca Venezuela.

61. Renier, C., Vandromme, M., Meyfroidt, P., Ribeiro, V., Kalischek, N., & Zu Ermgassen, E. K. (2023). Transparency, traceability and deforestation in the Ivorian cocoa supply chain. Environmental Research Letters, 18(2), 024030.

62. Rodrigues, R. P., & Medeiros, M. (2024). Atividades socioprodutivas e tipologias de Unidades de Produção Familiar de camponeses-ribeirinhos em várzea do Baixo Tocantins. Revista de Economia e Sociologia Rural, 62(2), e264420. https://doi.org/10.1590/1806-9479.2022.264420.

63. Schroth, G., Garcia, E., Griscom, B. W., Teixeira, W. G., & Barros, L. P. (2016). Commodity production as restoration driver in the Brazilian Amazon? Pasture re-agro-forestation with cocoa (Theobroma cacao) in southern Pará. Sustainability Science, 11, 277-293.

64. Silalahi, Y.D.A., Andika, R., Damayanti, E., Qisthi, N.M., Husain, M.A., Nurlel, & Ayu, D. (2024). Analisis Pengaruh Produksi Kakao Terhadap Pertumbuhan Ekonomi di Indonesia. Jurnal Ekonomi Bisnis dan Manajemen (JISE) 3, 80-88. https://doi.org/10.59024/jise.v2i3.770.

65. Trevisan, S. D. (1998). A Society-Nature Relationship: The Cocoa Crisis and the Social Movement for Land in Southern Bahia (Brazil) in the 1990s. Revista de Economia e Sociologia Rural, 36(3), 193-210.

66. Tropical Forest Alliance. (2022). Amazon Origin: Sustainable Cocoa, TFA.

67. Venturieri, A., Oliveira, R.R.S., Igawa, T.K., Fernandes, K.A., Adami, M., Oliveira Júnior, M.C.M., Almeida, C.A., Silva, L.G.T., Cabral, A.I.R., Pinto, J.F.K.C., Menezes, A.J.A. and Sampaio, S.M.N. (2022). The Sustainable Expansion of the Cocoa Crop in the State of Pará and Its Contribution to Altered Areas Recovery and Fire Reduction. Journal of Geographic Information System, 14, 294-313.https://doi.org/10.4236/jgis.2022.143016.

68. Viana, A. L. N, Simões, A., & Bastos, R. Z. (2020). O cacau de várzea: saberes e práticas ribeirinhos. Revista Agroecossistemas. v. 12, n. 1, p. 135 – 150, ISSN online 2318-0188.

69. White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica: journal of the Econometric Society, 817-838.

70. Willumsen, M. J., & Dutt, A. K. (1991). Café, cacau e crescimento econômico no Brasil. Brazilian Journal of Political Economy, 11, 362-381.

71. Xiao, C., Ye, J., Esteves, R. M., & Rong, C. (2016). Using Spearman's correlation coefficients for exploratory data analysis on big dataset.. Concurrency and Computation: Practice and Experience, 28(14), 3866-3878.

72. M'bo, A. A. K., Cherif, M., Kouadio, K., Adolphe, M. G., Bamba, A., Toure, E. N. D., Okou, A. K., Brunelle, R., Rouseau, Y & Koné, D. (2023). Climate Variability and Outlook of Cocoa Production in Côte D'ivoire under Future Climate. In Shifting Frontiers of Theobroma Cacao-Opportunities and Challenges for Production. IntechOpen.