Brazil's agricultural expansion
Main crops in Matopiba[1]

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Abstract – This study maps the share of the main temporary and permanent crops in agricultural expansion, based on IBGE data between 1994 and 2019, for the Brazilian mesoregions of Maranhão (MA), Tocantins (TO), Piauí (PI), and Bahia (BA), designated by the acronym "Matopiba". The locational Gini coefficient and modified Hirschman-Herfindahl Index (mHHI) were employed as analysis tools. The results detected cotton as the main crop, followed by soybean. Bahia Center North, Bahia Northeast, Maranhão Center, Maranhão North, Maranhão West, Piauí Center North, and Piauí North can be highlighted for the evaluated temporary crops, and Bahia Extreme West and Bahia Northeast for the permanent ones.

Keywords: agriculture, Gini coefficient, Hirschman-Herfindahl index.

Expansão agrícola brasileira: principais safras no Matopiba

Resumo – Este estudo buscou mapear as participações das principais culturas agrícolas temporárias e permanentes na expansão de área agrícola, com base em dados do IBGE, para as mesorregiões do Maranhão (MA), do Tocantins (TO), do Piauí (PI) e da Bahia (BA), o Matopiba, em 1994–2019. Empregaram-se como ferramentas de análise o coeficiente locacional de Gini e o índice de Hirschmann-Herfindahl modificado (mHHI). Os resultados revelaram o algodão como o principal cultivo, seguido da soja. Para as lavouras temporárias, os destaques foram as mesorregiões do Centro-Norte Baiano, Nordeste Baiano, Centro Maranhense, Norte Maranhense, Oeste Maranhense, Centro-Norte Piauiense e Norte Piauiense; para as safras permanentes, destacaram-se as mesorregiões do Extremo Oeste Baiano e a do Nordeste Baiano

Palavras-chave: agricultura, coeficiente de Gini, índice de Hirschman-Herfindahl.

Introduction

Classical studies of Brazil´s agricultural economics (Castro, 1969; Melo, 1990; Marcondes, 1995) have already discussed the main agricultural functions in the global economic system, which are obtaining foreign exchange from exports, releasing productive factors for other economic activities, supplying food domestically, and supporting internal economic growth.

Between 1930 and 1980, Brazil transitioned from a near monoculture producer (coffee) to a country with diversified agricultural production (Brandão, 2002; Freitas, 2014). To meet the country's food security needs, investments and

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subsidies for research were directed to Brazilian agriculture (Barros, 2002; Marin et al., 2016) and led to a significant production increase during the last 40 years.

In terms of crops, before 1994 (when the Real Plan finally stabilized Brazil's rampant inflation of the past two decades), domestic agricultural production was around 41% of its present level, according to Brasil (2021), as shown in Figure 1.

In the 1980s and 1990s, Brazilian agriculture was negatively affected by high inflation levels and periodic (and ultimately unsuccessful) monetary stabilization plans, including price tabling, distorting the market. Moreover, agricultural sectors were subject to the impact of trade opening between 1986 and 1991 (Barros & Goldenstein, 1997).

Nevertheless, in general terms, local producers obtained support from the National Agricultural Research System (ANRS) and responded to stronger demand for food after the Real Plan, both for the domestic and foreign markets. The ANRS embraced the Brazilian Agricultural Research Corporation (Embrapa), local universities, and public institutes engaged in agricultural research.

These events led to learning and solidarity in the sector, which today is a leading part of the Brazilian economy. However, strategic adjustments had a variety of scattered impacts in distinct regions and on different crops. These processes also converted the country into a remarkable agricultural producer and exporter.

Nowadays Brazil accounts for 5,0% of world agricultural exports by value (WTO, 2018). Moreover, Brazilian agriculture's success in generating surpluses from exports helped to keep inflation rates low in some recent moments (Bacen, 2018). Barros & Goldenstein (1997) and Barros & Barros (2005) cover the specific fundamentals for such achievements.

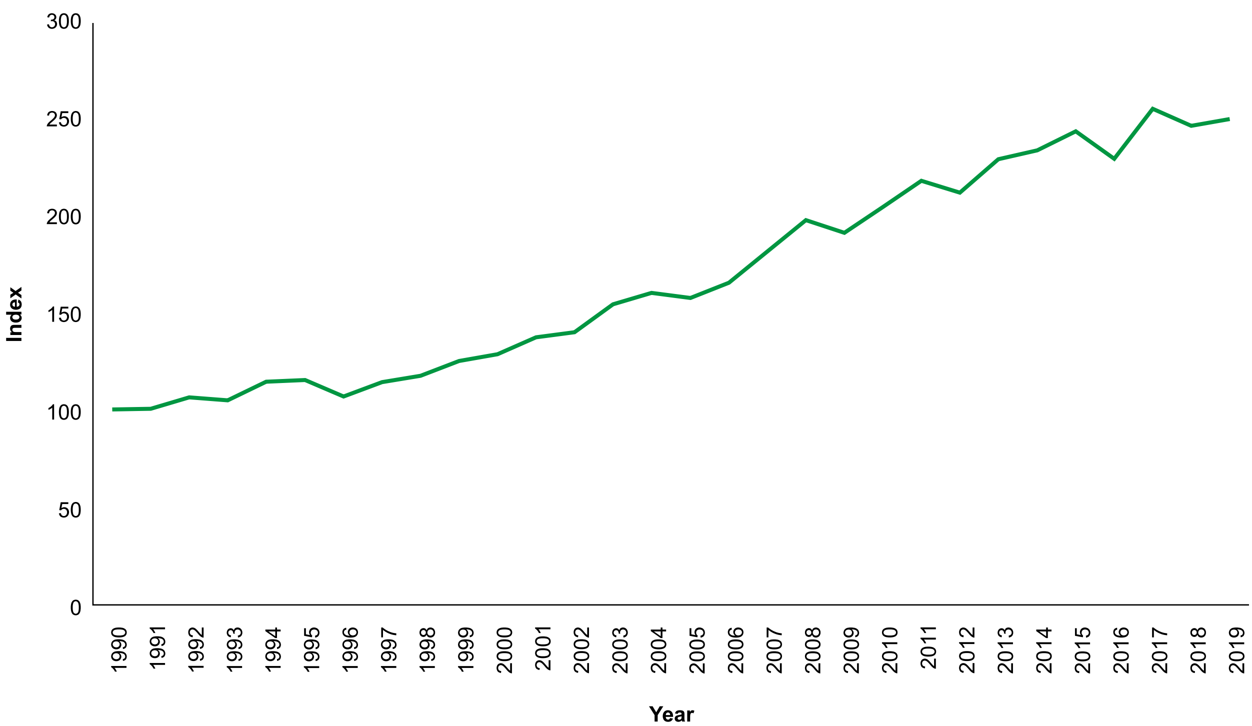

Figure 1. Agricultural Product Index (Laspeyres, 1990=100), 1990-2019.

Source: Brasil (2021).

Indeed, Brazil is not only one of the main sources of food worldwide; this position is projected to strengthen. According to the OECD-FAO… (2014), Brazil would respond to increasing shares of international trade in products like meat and sugar, and the country is already a main supplier for key agricultural importers (Freitas, 2019). At the same time, other analysts (Bruinsma, 2009; Freitas et al., 2014; Modelling land use change in Brazil…, 2015) argue that Brazil is one of the few countries able to expand its agricultural areas.

Brazil´s agricultural expansion: present and prospects

Nowadays, food production remains a central concern for humanity. According to the United Nations (2019), the world population will reach 9.7 billion in 2050, and urbanization is a noted process in the larger developing countries in Africa, as well as China and India. Meanwhile, most of the major food-producing countries (Russia, the United States, Argentina, Canada, the European Union, and Australia) do not have any more land for economically or technically profitable farming.

For Bruinsma (2009), much of the land that is already employed worldwide have some sort of constraints that cannot be easily overcome, such as chemical contamination, physical degradation of soil, endemic diseases, or lack of infrastructure. Some of this land is covered with forests, protected areas, or traditional settlements, for example. Additionally, agricultural systems in Africa and Southeast Asia appear to be vulnerable in terms of changes in agricultural water demand against the backdrop of an evolving climate (Iglesias et al., 2011).

In the Brazilian context, agriculture has expanded from the South region towards the Center-West region since the 1980s and has reached the states of Maranhão, Tocantins, Piauí, and Bahia (MATOPIBA) in the Northeast region and even southern portions of the North region. Accordingly, Gasques et al. (2015) highlighted increasing land prices in Pará, Amazonas, and the Tocantins states, a consequence of the agricultural expansion.

Specific agricultural expansion areas include Tocantins Eastern, Maranhão South, Piauí Southwest, and the Bahia Extreme West. Modelling land use change in Brazil... (2015) indicated those as possibly being responsible for the future expansion of crops in Brazil from 2020 to 2050. Besides MATOPIBA, other analyses (Freitas & Maciente, 2015; Freitas & Mendonça, 2016) identified spaces of agricultural expansion in northern Mato Grosso, southern North region, and Acre and Amapá states.

However, negative environmental impacts exist in this process (Sauer & Leite, 2012), especially those related to soybean and cattle breeding expansion, causing deforestation. Other issues are increasing land prices and questions about foreign property ownership. Other analysts (Sparovek et al., 2016) argue that agricultural expansion can serve both conservationists' and agricultural producers' interests.

In terms of those arguments, the objective of this article is to measure the role played by the main crops in MATOPIBA agricultural expansion. For doing so, the study presents three sections additionally. Section 3 presents the methodology and database. The fourth section discusses the results and offers a subsection about policy implications, and the fifth section presents the final remarks.

Methodology and database

This study employed data from the Brazilian Institute of Geography and Statistics (IBGE 2021a, 2021b) spanning 1994 to 2019. The crops were selected based on Carvalho et al. (2015) and include temporary crops (soybean, corn, cotton, sugarcane, and manioc) and permanent crops (orange and coffee).

Four different tools were used, that is, the locational quotient (*LQ*); the locational Gini coefficient (*LGC*), including the *LGC* time trend;

analysis of variance (ANOVA); and the modified Hirschman-Herfindahl index, as detailed in the following subsections.

Locational Quotient (LQ) and Locational Gini Coefficient

The first stage of the methodological approach used *LQ* and *LGC*. *LGC* was first used by Krugman (1991) to analyze location dynamics, and other studies have highlighted its benefits, namely ease of implementation and data requirements (Bertinelli & Decrop, 2005; Van Den Heuvel et al., 2013). This tool has also been used in studies other than agricultural analyses, for example of regional specialization in China (Lu et al., 2011), industrial reallocations (Ruan & Zhang, 2014), high-tech concentrations (Devereux et al., 2004), and technological concentration (Zitt et al., 1999). Reveiu & Dardala (2011) also applied *LQ* to investigate employment statistics in Romanian counties, while Piet et al. (2012) employed *LGC* to measure inequalities of French farm sizes over time.

Here both *LQ* and *LGC* are used to measure the attraction of soybean, corn, cotton, manioc, sugarcane, orange, and coffee to MATOPIBA agricultural expansion areas, and to identify whether these expansion areas are relatively concentrated in one or more of these crops.

LQ is useful for assessing whether a group of agricultural areas in expansion zones (mesoregions, for example) is specific in certain crops in terms of the used area; that is if a particular mesoregion is relatively more important for specific crops than for all crops. According to Haddad (1989), *LQ* is defined by the following equation, for each mesoregion*i* of Brazilian agricultural expansion areas:

$$LQ_{ij} = (X_{ij}/X_{i*})/(X_{*j}/X_{**}) \qquad (1)$$

Where:

X_{ij} = agricultural area of crop$_i$ (permanent or temporary) in MATOPIBA mesoregions;

X_{i*} = agricultural area of crop$_i$ (permanent or temporary) in Brazilian mesoregions;

X_{*j} = agricultural area of all crops (permanent or temporary) in MATOPIBA mesoregions;

X_{**} = agricultural area of all crops (permanent or temporary) in Brazilian mesoregions.

(X_{ij}/X_{i*}) = MATOPIBA mesoregions' relative importance in crop$_i$' (permanent or temporary) agricultural area;

(X_{*j}/X_{**}) = MATOPIBA mesoregions' relative importance in all crops (permanent or temporary) agricultural area.

Soybean, cotton, corn, manioc, and sugarcane are temporary crops, while orange and coffee are permanent ones. In dealing with major crops, the next step is to organize them by decreasing *LQ* for a chosen variable (share of mesoregion$_j$ in Brazilian permanent or temporary agricultural area, for example). A location curve is then constructed for each analyzed crop, with curve point generators as follows:

- Y coordinates are derived from the accumulated share of the chosen variable (share of mesoregion$_j$ in Brazilian – permanent or temporary – agricultural area) for each assessed crop;
- X coordinates are derived from the accumulated share of the same variable (share of mesoregion$_j$ in Brazilian – permanent or temporary – agricultural area) for all (permanent or temporary) crops.

In both cases, the descending order of the *LQ* defines the order in which the data are calculated. In a hypothetical case of five[3]

[3] MATOPIBA states encompass 18 mesoregions.

mesoregions in MATOPIBA, the final curve would contain five points, as shown in Figure 2.

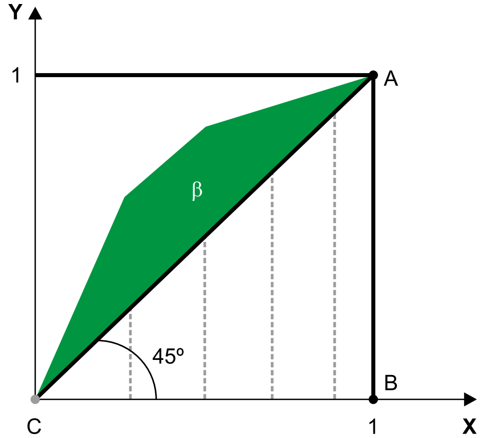

Figure 2. LGC concentration area.

Source: created based on data obtained from Krugman (1991) and Suzigan et al. (2003).

LGC is the ratio between the area represented by β (above) and the area of triangle ABC, which is bounded by a 45º line. Then:

$$LGC = (\beta/0.5) = 2\beta \quad (2)$$

The maximum value of *LGC* = 1, because the maximum value of β is limited by 0.5. Negative values happen when the shaded area (represented by β above) produces points below the 45º line. Then, accumulated proportions on the Y-axis (share of mesoregion*j* in Brazilian agricultural area for each assessed crop) will be below accumulated proportions on the X-axis (share of mesoregion *j* in Brazilian agricultural area for all – permanent or temporary – crops). In such circumstances, the (X, Y) coordinates indicate that MATOPIBA mesoregions are deconcentrating in agricultural area *vis a vis* the total Brazilian agricultural area for the evaluated crops.

According to Suzigan et al. (2003), the closer the value is to 1, the more spatially concentrated the crop being analyzed is, and vice versa. In the context of spatially big MATOPIBA and Brazilian mesoregions, *LGC* will naturally tend to be relatively lower.

ANOVA and LGC time trend

A second approach is to evaluate the *LGC* time trend. Here, the ANOVA table allows conducting the F-test. In this case, according to Sartoris (2003), the F-test permits testing the null hypothesis (H0) of no time trend for the *LGC* series. This stage allows measurement of whether the concentration (or deconcentration) of Brazilian crops in MATOPIBA mesoregions is time consistent if it exists.

Simple linear regression is used as an initial approach, in which time (T) is the explanatory variable of the *LGC* series, in line with Equation 3, where u_t is assumed with classic assumptions about the residuals' behavior in simple linear regression.

$$LGC_t = \beta_0 + \beta_1 T + u_t \quad (3)$$

This approach using a simple linear form establishes an initial step for a better understanding of MATOPIBA mesoregions' attraction in terms of the analyzed crops. Unfortunately, the required data (prices, logistics infrastructure, agricultural credit, etc.) for extending this first approach to multiple regression models[4] were not available for the present study covering the entire series from 1994 to 2019.

From Equation 3, according to Sartoris (2003), it is possible to split the total sum of squares (TSS) into the explained sum of squares (ESS) and the residual sum of squares (RSS), which in terms of each point series is expressed by Equation 4. In Equation 4, lgc_m is the sample mean of the *LGC* series and lgc_{est} is the estimated *LGC* value for every point of the series according to simple linear regression:

[4] An extension of the simple linear model is the multiple regression model, as described in Greene (2000), which can represent further evaluations of other regions, such as northern Brazilian mesoregions.

$$TSS = ESS + RSS = \sum_{t=1}^{T} (lgc_t - lgc_m)^2 = \\ = \sum_{t=1}^{T} (lgc_{est} - lgc_m)^2 + \sum_{t=1}^{T} (e_{est})^2 \qquad (4)$$

This allows investigating the sources of variation and the degrees of freedom contained in each term of Equation 4 and permits calculation of the ANOVA table (Table 1), from which the F-test (F_t) is used to evaluate the statistical significance of the coefficients described in Equation 3.

Modified Hirschman-Herfindahl index

The third methodological approach is to apply the modified Hirschman-Herfindahl index (*mHHI*), based on Crocco et al. (2006). This index identifies the net effect specifically resulting from the MATOPIBA mesoregions in the context of total Brazilian agricultural area, for both temporary and permanent crops.

Equation 5 calculates the *mHHI*.

$$mHHI_{ij} = (X_{ij}/X_{i*}) - (X_{*j}/X_{**}) \qquad (5)$$

The MATOPIBA mesoregions' relative importance in crop$_i$' (permanent or temporary) agricultural area is discounted by MATOPIBA mesoregions' relative importance in all crops (permanent or temporary) area.

This approach partially overcomes a typical *LGC* limitation. It does not detail the level of crop intensity of the distinct Brazilian mesoregions. Therefore, the *mHHI* summarizes the net effects (associated with a surplus of agricultural area) of MATOPIBA mesoregions concerning the analyzed crops. It offers additional information about whether MATOPIBA mesoregions have a relatively large share for a crop$_i$ in the Brazilian agricultural area.

Results and discussion

This section presents analyses for the MATOPIBA mesoregions' share in Brazilian agricultural area for the selected crops. Moreover, it discusses the results of the *LGC*, *LQ* (mesoregions outside MATOPIBA states), ANOVA and *mHHI*. First, Table 2 presents the MATOPIBA mesoregions' share in Brazilian agricultural area for each of the selected crops.

According to Table 2, the selected crops had different performances in terms of MATOPIBA mesoregions' share in Brazilian agricultural area. Firstly, it is possible to highlight the remarkable growth of MATOPIBA mesoregions in soybean area, mostly from 2001 on.

Second, this process also happened for cotton, coffee and orange areas, although in smoother degree. Soil and climate conditions cause coffee and orange production to face some restrictions in MATOPIBA mesoregions, and predominate in the states of São Paulo (orange and coffee), Paraná (coffee) and Minas Gerais (coffee). At the same time, corn and manioc had stable or reduced MATOPIBA share in Brazilian agricultural area.

Table 1. Analysis of variance (ANOVA).

Source (A)	Degrees of freedom (B)	Mean square = (A)/(B)	F-test (F_t)
ESS	1	ESS/1 = MSE	F_t = MSE/MSR
RSS	(n-2)	RSS/(n-2) = MSR	
TSS	(n-1)	TSS/(n-1)	

Source: created with data obtained from Sartoris (2003).

Table 2. Crops' share in Brazilian agricultural area, MATOPIBA mesoregions, 1994-2019.

Year	Temporary (%)					Permanent (%)	
	Soybeans	Corn	Cotton	Sugar Cane	Manioc	Coffee	Orange
1994	8.82	31.68	2.96	1.98	2.63	6.89	3.35
1995	10.20	29.08	3.49	1.91	11.69	7.95	3.57
1996	11.94	27.81	3.46	2.41	9.30	8.04	4.26
1997	13.19	27.47	4.14	2.54	8.85	7.72	4.27
1998	17.37	25.49	2.86	2.85	10.09	7.98	4.33
1999	16.83	26.45	0.98	2.51	9.23	8.59	3.76
2000	17.51	25.69	1.35	2.38	9.82	9.23	3.54
2001	20.49	26.40	1.36	2.19	10.43	10.33	3.55
2002	22.38	25.00	1.58	2.07	10.15	10.54	3.64
2003	23.84	25.76	1.71	2.11	9.59	10.38	3.68
2004	24.68	24.38	3.57	1.97	9.07	10.04	3.55
2005	26.33	22.83	4.13	2.01	11.78	10.01	3.50
2006	27.50	23.19	4.00	2.42	10.16	9.32	3.37
2007	26.66	24.13	4.90	2.53	10.20	9.84	3.39
2008	28.48	23.24	5.13	2.64	10.30	9.75	3.96
2009	29.14	24.65	4.72	2.25	8.08	9.71	3.60
2010	32.31	23.20	4.30	2.50	8.07	9.77	4.05
2011	32.76	22.46	6.33	2.11	7.32	9.60	4.05
2012	37.13	21.88	7.05	2.29	7.58	10.09	4.25
2013	39.66	23.09	4.59	2.16	5.95	10.55	4.26
2014	41.06	23.67	4.70	2.05	5.39	11.16	4.40
2015	45.22	22.48	4.54	1.86	5.15	11.57	5.36
2016	49.64	21.25	4.13	2.06	5.22	11.31	5.58
2017	44.76	23.01	2.96	2.26	3.41	12.03	4.81
2018	52.29	22.10	3.77	2.18	2.82	12.01	12.39
2019	53.59	22.12	4.79	2.27	2.63	11.53	12.68
1994-2019 Average	**28.99**	**24.56**	**3.75**	**2.25**	**7.8**	**9.84**	**4.66**
2007-2019 Average	**39.44**	**22.87**	**4.76**	**2.24**	**6.32**	**10.69**	**5.60**

Source: created with data obtained from IBGE (2021a, 2021b).

MATOPIBA mesoregions' agricultural area expansion: LQ and LGC of main crops

This section presents the *LGC* and *LQ* results for the seven analyzed crops. Table 3 reports the *LGC* results.

According to Table 3, there was strong growth of cotton *LGC*. Such growth exists throughout the time series, but especially from 2005 on. Concurrently, soybean and corn *LGC* seem to be in a positive trend. That is, the corresponding states seem to be slowly concentrating the soybean and corn growing areas in Brazil.

Second, *LGC* results also highlight relatively stable values for manioc, a traditional crop in the MATOPIBA mesoregions, throughout

Table 3. Crops' LGC, MATOPIBA states, 1994-2019.

Year	Temporary					Permanent	
	Soybeans	Corn	Cotton	Sugar Cane	Manioc	Coffee	Orange
1994	-0.078	0.006	0.055	-0.100	0.204	-0.175	-0.168
1995	-0.070	-0.004	0.073	-0.100	0.226	-0.174	-0.172
1996	-0.051	-0.006	0.109	-0.081	0.158	-0.160	-0.156
1997	-0.052	-0.008	0.229	-0.084	0.154	-0.167	-0.159
1998	-0.043	-0.001	0.055	-0.079	0.184	-0.165	-0.158
1999	-0.042	-0.003	-0.035	-0.084	0.181	-0.160	-0.163
2000	-0.042	-0.005	-0.021	-0.086	0.194	-0.164	-0.162
2001	-0.032	-0.006	-0.029	-0.089	0.211	-0.158	-0.159
2002	-0.033	0.001	0.008	-0.091	0.222	-0.154	-0.153
2003	-0.031	0.004	0.037	-0.088	0.247	-0.148	-0.146
2004	-0.035	0.012	0.099	-0.088	0.232	-0.160	-0.156
2005	-0.036	0.014	0.123	-0.092	0.235	-0.162	-0.159
2006	-0.030	0.004	0.197	-0.091	0.244	-0.176	-0.172
2007	-0.027	0.000	0.192	-0.093	0.251	-0.173	-0.174
2008	-0.018	-0.004	0.234	-0.090	0.252	-0.172	-0.162
2009	-0.018	0.008	0.306	-0.094	0.207	-0.169	-0.168
2010	-0.015	0.011	0.263	-0.096	0.207	-0.164	-0.158
2011	-0.012	0.007	0.233	-0.099	0.203	-0.170	-0.158
2012	-0.003	-0.006	0.253	-0.091	0.205	-0.166	-0.148
2013	-0.002	0.001	0.266	-0.092	0.186	-0.163	-0.144
2014	-0.001	0.010	0.245	-0.097	0.179	-0.155	-0.137
2015	0.004	0.005	0.271	-0.099	0.182	-0.153	-0.113
2016	0.010	-0.002	0.225	-0.089	0.188	-0.157	-0.106
2017	0.001	-0.002	0.158	-0.087	0.118	-0.119	-0.105
2018	0.014	0.001	0.170	-0.089	0.088	-0.122	-0.091
2019	0.016	-0.003	0.143	-0.085	0.081	-0.120	-0.090
1994-2019 Average	**-0.024**	**0.001**	**0.148**	**-0.090**	**0.194**	**-0.159**	**-0.148**
2007-2019 Average	**-0.004**	**0.002**	**0.228**	**-0.092**	**0.180**	**-0.154**	**-0.135**

Source: created with data obtained from IBGE (2021a, 2021b).

the time series. Third, negative results for coffee, sugarcane and orange are understandable since these crops have traditionally been concentrated in Brazil´s Southeast and South states. Therefore, the evaluated states in the Northeast continue not attracting those three crops.

In the context of Brazilian savanna areas, the dynamic of agricultural area expansion is partially explained by factors like credit policies for production and sale, minimum price policies (mainly in the 1970s and 1980s), investments in agricultural research, the spillover of new technologies, and the aptness of those areas to mechanization. Not by accident, crop yields (especially corn and soybean) increased more strongly in Center-West states than in other regions. In addition, the agricultural expertise of migrant farmers (of Japanese, Italian and German descendants) was very important for the agricultural expansion in savanna areas.

Next, in some aspects the *LQ* of mesoregions outside MATOPIBA is the MATOPIBA mesoregions LGC counterpart. The corresponding results are presented in Table 4.

These findings reinforce the key role of MATOPIBA mesoregions related to Brazilian agricultural area for manioc and the role of mesoregions outside MATOPIBA related to area for growing coffee (São Paulo, Paraná and Minas Gerais concentration), sugarcane (São Paulo, Pernambuco and Alagoas concentration) and orange (São Paulo concentration).

Table 4. Crops' LQ in other Mesoregions (outside MATOPIBA), 1994-2019.

Year	Temporary					Permanent	
	Soybeans	Corn	Cotton	Sugar Cane	Manioc	Coffee	Orange
1994	1.096	0.997	0.958	1.117	0.785	1.238	1.230
1995	1.087	1.008	0.938	1.117	0.758	1.245	1.242
1996	1.061	1.010	0.897	1.093	0.836	1.216	1.212
1997	1.064	1.011	0.773	1.097	0.840	1.227	1.219
1998	1.053	1.004	0.952	1.090	0.809	1.225	1.218
1999	1.053	1.007	1.045	1.096	0.813	1.217	1.221
2000	1.053	1.010	1.031	1.100	0.798	1.227	1.225
2001	1.043	1.009	1.039	1.102	0.780	1.221	1.222
2002	1.044	1.003	1.001	1.104	0.768	1.214	1.213
2003	1.042	0.999	0.970	1.101	0.743	1.201	1.199
2004	1.045	0.991	0.906	1.102	0.760	1.221	1.219
2005	1.046	0.989	0.881	1.107	0.757	1.226	1.225
2006	1.040	1.000	0.804	1.105	0.748	1.252	1.249
2007	1.037	1.005	0.810	1.107	0.741	1.249	1.253
2008	1.027	1.009	0.765	1.104	0.740	1.250	1.241
2009	1.026	0.995	0.690	1.108	0.787	1.244	1.244
2010	1.024	0.993	0.731	1.110	0.787	1.234	1.229
2011	1.021	0.997	0.765	1.114	0.792	1.244	1.234
2012	1.008	1.010	0.742	1.103	0.792	1.240	1.223
2013	1.007	1.003	0.729	1.105	0.813	1.234	1.216
2014	1.006	0.993	0.752	1.111	0.822	1.223	1.208
2015	1.000	0.999	0.724	1.113	0.820	1.221	1.182
2016	0.992	1.006	0.772	1.101	0.813	1.226	1.174
2017	1.004	1.005	0.842	1.098	0.887	1.158	1.147
2018	0.988	1.003	0.830	1.102	0.918	1.161	1.131
2019	0.985	1.007	0.857	1.096	0.925	1.157	1.129
1994-2019 Average	**1.033**	**1.002**	**0.854**	**1.104**	**0.801**	**1.222**	**1.212**
2007-2019 Average	**1.010**	**1.002**	**0.770**	**1.106**	**0.818**	**1.219**	**1.201**

Source: created with data obtained from IBGE (2021a, 2021b).

Moreover, outside MATOPIBA mesoregions *LQ* results point to a recent (2007-2019 average) concentration of cotton area in MATOPIBA mesoregions. For corn, the results indicate stable performance in agricultural area concentration outside MATOPIBA, both in the long term (1994-2019 average) and medium term (2007-2019 average).

ANOVA and LGC time trend

The performance of the LGC MATOPIBA mesoregions in Brazilian agricultural area has a positive time trend for cotton, soybean, orange and coffee as shown in Table 5. The ANOVA resulted in an F-test score of 439.64 for soybean, 15.60 for cotton, 12.00 for coffee and 31.36 for orange, which indicates a significant time trend at 1% significance level.

In general, this trend can be associated with growing MATOPIBA mesoregion concentration of area for soybean and cotton in the long term (1994-2019). For orange and coffee, the

Table 5. Analysis of variance, LGC time trend, MATOPIBA mesoregions, 1994-2019.

Crop	F test (Ft)	Trend
Soybeans	439.64	significant
Corn	1.04	non significant
Cotton	15.6	significant
Sugar Cane	0.76	non significant
Manioc	5.02	non significant
Coffee	12.0	significant
Orange	31.36	significant

Source: created with data obtained from IBGE (2021a, 2021b).

LGC results also show an ascending value, but in very reduced levels, according to Figure 3. It does not necessarily exclude MATOPIBA states' concentration of Brazilian agricultural area for the other analyzed crops in short term (recent years), like in corn case (Freitas & Mendonça, 2016), since there is a well-known process of soybean-corn intercropping in all areas suitable for these crops.

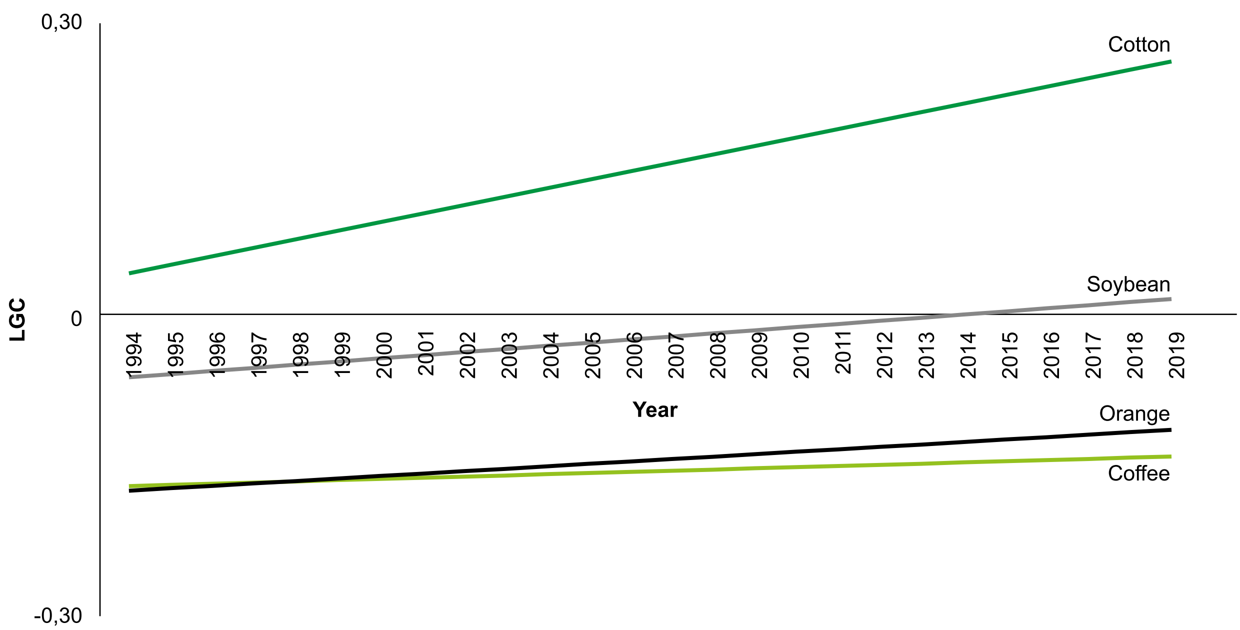

Figure 3. LGC time trend for MATOPIBA mesoregions, 1994-2019.

Source: created with data obtained from IBGE (2021a, 2021b).

Modified Hirschman-Herfindahl index

This section presents the results of the *mHHI* for MATOPIBA mesoregions in terms of temporary and permanent crops. Table 6 shows the mean *mHHI* for the temporary crops (soybean, corn, cotton, sugarcane, and manioc).

Taking only positive mean mHHI values for 2007-2019, they were higher than mean *mHHI* for 1994-2019 for soybean in Piauí Southwest (PI), Tocantins Western (TO) and Tocantins Eastern (TO), for cotton in Bahia Extreme West (BA) and Maranhão South (MA), for corn in Bahia Northeast (BA), Bahia Center North (BA), Maranhão West (MA), Piauí Southeast (PI), Maranhão Center (MA), Maranhão North (MA), Piauí Center North (PI), Bahia San Francisco Valley (BA) and Piauí North (PI), and for manioc in Bahia Northeast (BA), Bahia Center North (BA), Maranhão West (MA), Piauís Southeast (PI), Maranhão Center (MA), Maranhão North (MA), Piauí Center North (PI), Piauí North (PI) and Salvador Metropolitan Area (BA).

Brazilian savanna areas have a well-known dynamic agricultural expansion based on governmental policies, agricultural research investments, and new technologies, mainly developed by Embrapa (Castro, 2003). About it, Freitas & Mendonça (2016) described the Center West-Northwest dynamic route of agricultural expansion in Brazil and highlighted the main role

Table 6. Mean mHHI for temporary crops, MATOPIBA mesoregions, 1994-2019.

Temporary crops	Soybeans		Corn		Cotton		Sugar Cane		Manioc	
	2007-2019	1994-2019	2007-2019	1994-2019	2007-2019	1994-2019	2007-2019	1994-2019	2007-2019	1994-2019
Bahia Extreme West (BA)	0.225	0.285	-0.103	-0.107	0.139	0.086	-0.139	-0.119	-0.014	-0.009
Piauí Southwest (PI)	0.175	0.040	-0.012	0.005	-0.003	-0.009	-0.143	-0.124	-0.018	-0.014
Maranhão South (MA)	0.285	0.294	-0.069	-0.124	0.007	-0.003	-0.106	-0.081	-0.020	-0.022
Tocantins Western (TO)	0.065	-0.045	-0.117	-0.088	-0.016	-0.016	-0.136	-0.121	0.001	0.004
Tocantins Eastern (TO)	0.250	0.174	-0.072	-0.088	-0.009	-0.013	-0.100	-0.089	-0.010	-0.003
Bahia Northeast (BA)	-0.420	-0.368	0.297	0.234	-0.017	-0.018	-0.144	-0.126	0.049	0.049
Bahia Center North (BA)	-0.420	-0.368	0.161	0.084	-0.016	-0.011	-0.142	-0.123	0.064	0.055
Maranhão East (BA)	-0.165	-0.232	-0.014	0.004	-0.016	-0.017	-0.087	-0.086	0.075	0.077
Bahia Center South (BA)	-0.419	-0.368	-0.052	-0.097	0.046	0.084	-0.102	-0.080	0.173	0.185
Maranhão West (MA)	-0.275	-0.296	0.099	0.089	-0.017	-0.018	-0.139	-0.122	0.140	0.119
Piauís Southeast (PI)	-0.419	-0.368	0.222	0.185	-0.011	0.013	-0.144	-0.125	0.039	0.024
Maranhão Center (MA)	-0.359	-0.336	0.128	0.115	-0.017	-0.018	-0.138	-0.120	0.041	0.029
Maranhão North (MA)	-0.420	-0.368	0.001	-0.012	-0.017	-0.018	-0.143	-0.124	0.406	0.380
Piauí Center North (PI)	-0.392	-0.354	0.139	0.120	-0.017	-0.018	-0.069	-0.069	0.037	0.034
Bahia San Francisco Valley (BA)	-0.407	-0.360	0.040	0.026	0.002	0.018	-0.009	-0.004	0.069	0.101
Piauí North (PI)	-0.412	-0.364	0.121	0.098	-0.017	-0.018	-0.137	-0.118	0.127	0.109
Bahia South (BA)	-0.420	-0.368	-0.219	-0.223	-0.017	-0.018	0.121	0.142	0.353	0.410
Salvador Metropolitan Area (BA)	-0.311	-0.314	-0.148	-0.186	-0.017	-0.018	0.066	0.146	0.424	0.404
Other mesoregions	0.003	0.010	0.000	0.001	-0.004	-0.002	0.015	0.013	-0.005	-0.006

Source: created with data obtained from IBGE (2021a, 2021b).

played by soybean in this process. Moreover, the results indicate that some MATOPIBA mesoregions have attracted corn especially in BA, MA, and PI states.

According to Bolfe et al. (2016) expansion of soybean and corn production in agricultural frontiers in BA, MA, PI, and TO is related to the occupation of newly cleared land, mainly from 2002 on. In line with those analysts, such regions have a high potential for the development of intensive agriculture and production. Moreover, they emphasize the need for infrastructure investments with a priority on multimodal transportation in those areas.

At the same time, results for cotton are concentrated in Bahia Extreme West (BA) and Maranhão South (MA), where mean *mHHI* for 2007-2019 were higher than mean *mHHI* for 1994-2019, always in positive terms. For cotton, Freitas (2017) emphasized its performance *vis a vis* soybean and corn related to the expansion of agricultural areas in Brazil from 1994 to 2013, mainly concentrated in areas including BA, TO, MA, and PI mesoregions.

Those results also highlighted mesoregions' specialization in manioc in face of mesoregions outside MATOPIBA.

Table 7 presents the mean *mHHI* for the permanent crops, coffee and orange.

For permanent crops, taking only positive mean *mHHI* values for 2007-2019, few mesoregions had mean *mHHI* for that period higher than the mean *mHHI* for 1994-2019. This happened only for orange in Bahia Northeast (BA) and Salvador Metropolitan Area (BA), and

Table 7. Mean mHHI for permanent crops, MATOPIBA mesoregions, 1994-2019.

Permanent crops	Coffee		Orange	
	2007-2019	1994-2019	2007-2019	1994-2019
Bahia South (BA)	-0.285	-0.308	-0.121	-0.132
Bahia Center South (BA)	0.097	0.114	-0.116	-0.127
Bahia Northeast (BA)	-0.345	-0.352	0.128	0.092
Bahia Center North (BA)	-0.294	-0.278	-0.118	-0.128
Piauí Southeast (PI)	-0.345	-0.352	-0.122	-0.133
Bahia San Francisco Valley (BA)	-0.345	-0.352	-0.119	-0.129
Salvador Metropolitan Area (BA)	-0.344	-0.351	0.249	0.205
Piauí Center North (PI)	-0.345	-0.352	-0.114	-0.121
Piauí North (PI)	-0.345	-0.352	-0.119	-0.130
Piauí Southwest (PI)	-0.345	-0.352	-0.116	-0.126
Bahia Extreme West (BA)	0.321	0.193	-0.092	-0.089
Maranhão East (MA)	-0.345	-0.352	-0.091	-0.093
Maranhão North (MA)	-0.345	-0.352	-0.100	-0.107
Maranhão West (MA)	-0.345	-0.352	-0.112	-0.097
Maranhão Center (MA)	-0.345	-0.352	-0.074	-0.080
Tocantins Western (TO)	-0.345	-0.351	-0.092	-0.103
Tocantins Eastern (TO)	-0.345	-0.351	-0.116	-0.116
Maranhão South (MA)	-0.345	-0.352	-0.059	-0.060
Other mesoregions	0.075	0.078	0.025	0.028

Source: created with data obtained from IBGE (2021a, 2021b).

for coffee in Bahia Extreme West (BA). These results are understandable since the strongest Brazilian production areas for coffee and orange are outside MATOPIBA mesoregions.

For better interpretation, Figure 4 highlights the main results from Tables 6 and 7. It shows the main mesoregions in terms of relative agricultural area concentration in MATOPIBA states according to the measured crops.

Policy implications

The growth of the Brazilian agricultural frontier has one main core in MA, TO, PI, and BA states. Permanent and temporary crops, as the ones mapped here, have different requirements in terms of inputs, agricultural loans, technical assistance, and commercialization policies.

Knowing which kind of crops concentrate such process in those areas is key for improving the corresponding public policies and the logistic infrastructure decisions. Equally, private actors linked to agricultural inputs can also employ such information for modeling their local operation strategies.

Additionally, the regions here featured can benefit from the railways' expansion and consolidation, as the North-South and West-East Integration railways for example. The first one has connections to the MA harbors and the option for multiproduct transportation with the Brazilian South-Southeast industrial areas. Simultaneously, the West-East Integration railway has direct effects on the BA and TO railways corridors and it is also hoped to be integrated into the North-South railway soon.

Studies have emphasized the role of roads in making access to markets easier (Chomitz & Gray, 1996; Cropper et al., 2001). Since railways use to present lower costs of transportation *vis a vis* the roads option, the MATOPIBA railway integration will probably benefit the agricultural development in the highlighted areas.

Final remarks

The objective of this article was to measure the role played by the main crops in MATOPIBA mesoregions' agricultural expansion, that is, soybean, corn, cotton, sugarcane, manioc, coffee, and orange. Then, the study features the following main aspects.

The selected crops had different performances in terms of MATOPIBA mesoregions' share in the Brazilian agricultural area. Mostly, there was impressive growth of MATOPIBA mesoregions in Brazilian agriculture for cotton especially, and soybean. For coffee and orange,

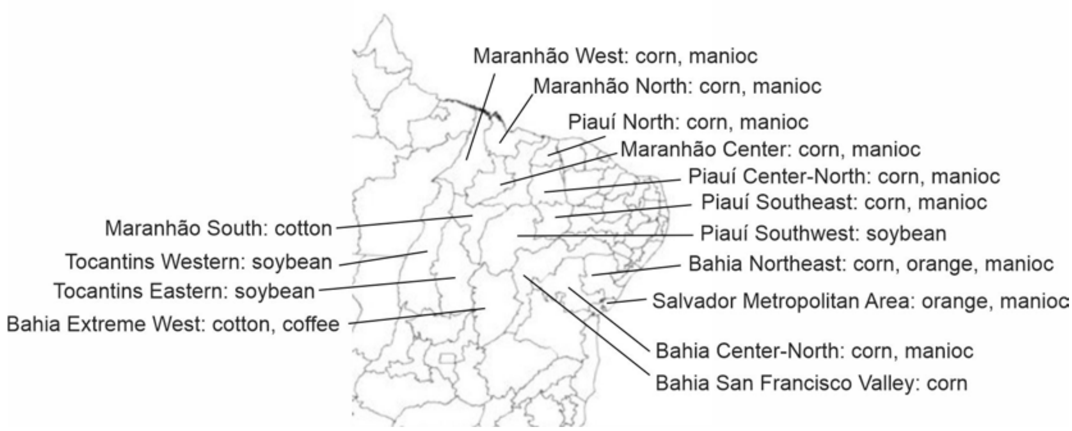

Figure 4. Mesoregions of relative agricultural concentration by crop in MATOPIBA.

Source: created with data obtained from IBGE (2021a, 2021b).

it also happened but on a smaller scale. Soil and climate conditions restrict coffee and orange production in MATOPIBA and concentrate them outside those mesoregions. At the same time, corn sustained a stable share of MATOPIBA mesoregions in the Brazilian corn agricultural area.

The *LGC* results also highlight the growth of MATOPIBA mesoregions in the cotton area. That expansion happened especially from 2004 on, and it is related to structural changes in the Brazilian cotton agribusiness chain since the 1990s. Concurrently, MATOPIBA mesoregions seem to be slowly concentrating the soybean area in Brazil. Furthermore, *LGC* results also highlight stable *LGC* for manioc, a traditional crop in the evaluated states.

The modified Hirschman-Herfindahl index pointed some mesoregions responsible for positive results in two or three crops simultaneously, as Maranhão West (corn, manioc), Maranhão North (corn, manioc), Piauí North (corn, manioc), Maranhão Center (corn, manioc), Piauí Center-North (corn, manioc), Piauí Southeast (corn, manioc), Bahia Northeast (corn, orange, manioc), Bahia Center-North (corn, manioc), and Bahia Extreme West (cotton, coffee).

Knowing which crops concentrate the growth of the agricultural area in frontier lands is crucial for enhancing the associated public policies and the respective infrastructure decisions, asking to map specific agricultural activities, like those highlighted here. Consequently, private actors linked to agricultural sectors can also employ such information for modeling local operation strategies. Concerning this aspect, promising railways in the axis North-South and West-East may permit further agricultural developments in MATOPIBA states.

As a limitation, the study does not encompass soil composition and infrastructure data for the analyzed areas or price data for the crops. Incorporating these aspects could offer new insights about which factors influence the most the dynamic expansion of agricultural areas in MATOPIBA mesoregions and may represent a further step of this study. Further analysis may also explore top-down specifications, at micro-region or municipality levels, and evaluations for crops individually.

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