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REGULAR ARTICLE

Sugarcane expansion in the microregion of Araraquara: a shift-share analysis

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Abstract

Sugarcane is one of the main crops in Brazilian agribusiness, covering a vast planted area that expands annually. Based on this, it is important to understand how the dynamics of this expansion occurred, to visualize whether there was the replacement of other crops or the incorporation of new areas. The objective of this research, therefore, was to analyze the sugarcane expansion by changes in land use. To this end, the shift-share method was applied, which, assuming a proportionality in the change in land use, allowed visualizing the main crops that incorporated and lost land, both in terms of planted area and new areas. Sugarcane was the main crop that incorporated land, but it was followed by soybeans, peanuts, and cassava. All other crops grown in the region lost land, including oranges, a traditional and important crop in the region. This may be due to more stability on returns of sugarcane and disease in the orange fields. There was also a reduction in the pastureland, which may be caused by competition with more intensive use of the land by some crops, such as sugarcane, and cheaper land in the northern region of the country. The results can contribute to the formulation of public and private policies regarding land use management.

Keywords

Araraquara; Sugarcane; Land cover change; Shift-share.

Introduction

Sugarcane is one of the most important crops in the Brazilian economy. Its production value reached over 93 billion reais (R$) in 2022. In 9.8 million hectares, more than 724 million tons were harvested in more than 171 thousand farms. The average yield per ha nationwide was 73,393 kg, demonstrating the sector's efficiency. The center-south region of the country, driven by a favorable climate and a solid logistics infrastructure, has a significant concentration, with 31.5% of the national total, and the state of São Paulo is the main producer, followed by Minas Gerais, Goiás and Paraná (IBGE, 2024).

Furthermore, Brazil's Gross Domestic Product (GDP) in 2021 was about 9 trillion reais (R$), a substantial increase of 422.2% compared to 2003, which was about 1.7 trillion reais (R$). This result was caused by variables such as increased productivity, economic diversification, and population growth. São Paulo's GDP in 2021 was 2.7 trillion reais (R$), an increase of 361.5% compared to 2003, which was 591 billion reais (R$). Strong industrialization, growth in the service sector, and the concentration of large companies contributed to this increase. Finally, Araraquara's GDP in 2021 was 25 billion reais (R$), an increase of 333.2% compared to that of 2003, which was about 5.9 billion reais (R$). The expansion of the services sector, agribusiness growth, and local economy diversification contributed to this increase (IBGE, 2021). In addition, Brazil's agribusiness exports reached US$11.7 billion in January 2024, an increase of 14.8% compared to the same period in 2023. The 21.5% increase in Brazilian exports was driven by other sectors, despite a 3.6% drop in international prices for agricultural products and a 17.4% drop in grain prices. The agribusiness trade balance had a total surplus of US$10.0 billion, while the other sectors had a deficit of US$3.5 billion. The main exported product was soybean, with a value of US$1.5 billion, followed by raw cane sugar, corn, soybean meal, and fresh beef (CNA, 2024). In the 2023/24 sugarcane harvest in São Paulo, there were some notable points. The harvest, completed in December 2023 in most mills, was delayed compared to the usual schedule due to the large volume of cane in the fields and the rains during the harvest season. Favorable weather conditions, especially at the beginning of the plant cycle, contributed to good crop development and high productivity, one of the highest in the state's historical series. This productivity offset the reduction in the amount of total recoverable sugar (TRS) due to rains during

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ripening and lower sunlight. Furthermore, harvesting younger sugarcane resulted in a higher TRS than the previous harvest (CONAB, 2024).

Considering the importance of sugarcane to the Brazilian economy and its expansions throughout the years, it is important to analyze its impacts on other crops. From this premise, there is the central question of this work: how does the sugarcane expansion affect other crops in terms of land use? To answer this, the objective of this research is to analyze the expansion of sugarcane by the change (incorporation and transfer) in land use in the microregion of Araraquara.

Materials and methods

The geographic scope adopted in this study is the so-called central region of the state of São Paulo, here considered as the integration of the microregion of Araraquara (Figure 1).

To examine the increase in sugarcane cultivation in this location, the Municipal Agricultural Survey of the IBGE Automatic Recovery System (PAM/SIDRA) was used as a reference. The time frame of the data used in this research was the years 2003 and 2022 (IBGE, 2023a). Based on the decomposition of the area variation, it becomes possible to determine the Scale Effects (EE) and Substitution Effects (ES) of the main activities under study. The expression that represents the analytical model used can be found in equation (1) (Lourenzani & Caldas, 2014).

$$A_{i2} - A_{i1} = (\alpha A_{i1} - A_{i1}) + (A_{i2} - \alpha A_{i1}) \quad (1)$$

$A_{i2} - A_{i1}$ = Variation of the area cultivated with an activity “i”, between period 1 and 2;

$(\alpha A_{i1} - A_{i1})$ = Scale effect;

$(A_{i2} - \alpha A_{i1})$ = Substitution effect.

$$a = {A_{t2}}/{A_{t1}} \qquad A_{t1} = \sum_{i1} A_{i1} \qquad A_{t2} = \sum_{i2} A_{i2}$$

where: A_{i1} and A_{i2} are the total areas occupied by the “n” agricultural activities of a region, respectively, in years 1 and 2.

The Scale Effect (EE) refers to the change in the area of an activity due to a change in size, keeping a constant proportion of participation in this activity. The Substitution Effect (ES) measures the relative participation of an activity within a system, thus being able to perceive whether this activity was replaced by another (Souza; Wander, 2014).

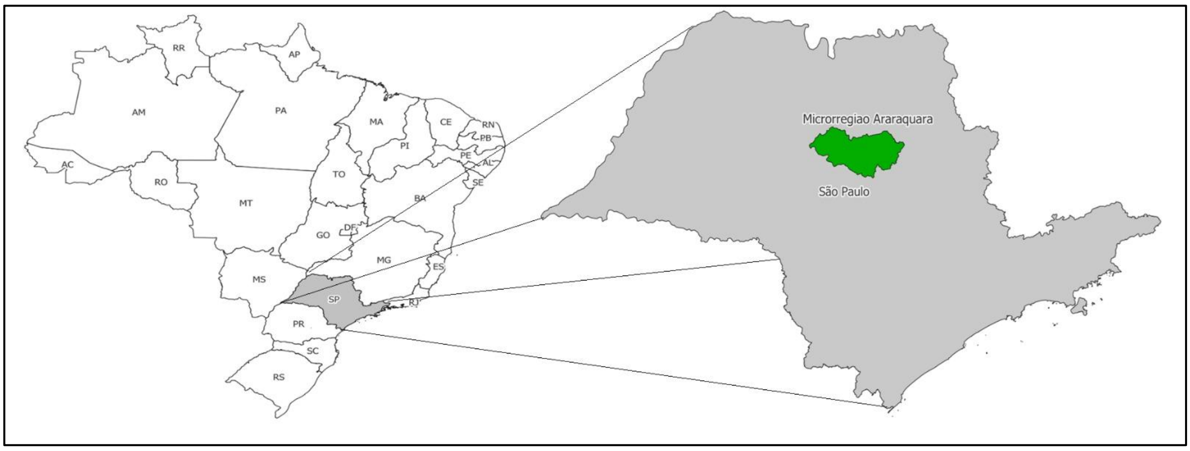

Figure 1. Geographical scope of the research.

Results and discussion

Characterization of agricultural and livestock activity in the Araraquara microregion

In the Araraquara microregion, the planted area underwent an expansion between 2003 and 2022, except for three municipalities, namely Gavião Peixoto, Motuca and Nova Europa, as shown in Figure 2. This may be associated with the economic growth of the country, especially the region, over the period analyzed.

The data reveal both increases and decreases in agricultural land use over the two decades, reflecting diverse trends in local farming practices. Each municipality presents a unique pattern, shedding light on potential shifts in land management, crop choices, or external influences such as policy changes, economic factors, or environmental constraints.

Itápolis emerges as a prominent case, showcasing a remarkable expansion in planted areas, indicating increased agricultural activity. Conversely, Motuca displays a significant reduction in planted areas, which could signify changes in agricultural focus, urban expansion, or challenges such as resource limitations or economic disincentives. Other municipalities, such as Boa Esperança do Sul and Nova Europa, exhibit relative stability in their planted areas, suggesting consistency in their agricultural strategies over time.

Smaller municipalities like Trabiju and Santa Lúcia show relatively low levels of planted areas in both years, hinting at limited agricultural operations or possibly a focus on specific, less land-intensive crops. These variations across municipalities underscore the complex dynamics of agricultural land use and hint at broader factors influencing these patterns.

All municipalities, except for Itápolis, have undergone a process of reducing the number of cattle, as shown in Figure 3. This may be associated with the displacement of cattle from the Southeast region to the North. With the increase in the price of pastureland in the region, competing with cheaper areas in other geographic regions of Brazil, the tendency is for replacement by areas with greater agricultural intensity and potential for commoditization (Teixeira & Hespanhol, 2015).

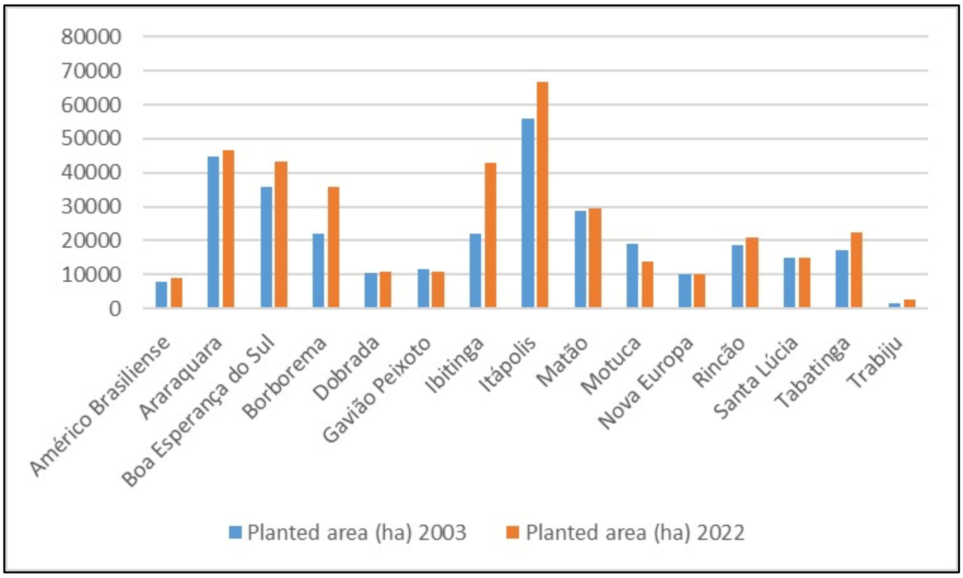

Figure 2. Planted area in the Araraquara microregion by municipality.

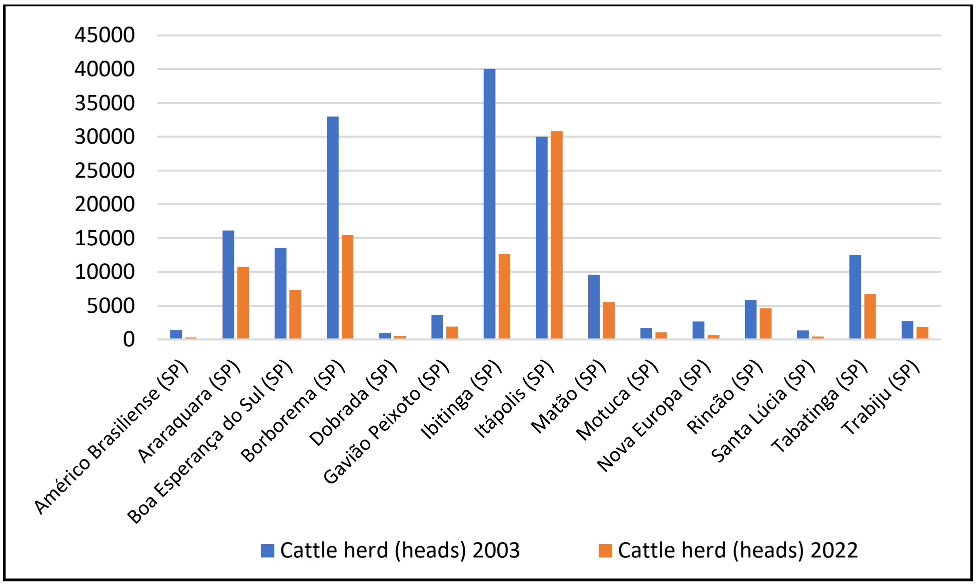

Figure 3. Cattle herd in the Araraquara microregion by municipality.

This migration movement of livestock is related to the adoption of extensive production systems and the introduction of new technologies from the 1970s onwards, such as using salt in feed and controlling diseases such as foot-and-mouth disease. Brazilian livestock productivity increased in the 1990s and consolidated an integrated industry in the country (Freitas Junior & Barros, 2021).

Furthermore, three feeding regimes currently coexist: advanced technology and intensive use of high-quality cultivated and confined pastures; low-quality native pastures with extensive production; and semi-intensive with supplemental feeding. The increase in the consumption of agro-industrial by-products such as corn, soybeans, and sugarcane bagasse has increased capital turnover and reduced fattening time. The modernization of cattle farming is also impacted by the uneven availability of rural credit, especially PRONAF. However, the expansion of livestock farming has caused significant deforestation in the Atlantic Forest, Cerrado, and Amazon biomes (Freitas Junior & Barros, 2021).

Considering a stocking area of 1.08 heads/ha, according to IBGE (2019), it is possible to estimate the area of cattle pasture in the Araraquara microregion in the period analyzed, as shown in Figure 4. It is understood that there are limitations to this estimate, as the stocking rate changes over time, but to standardize the analysis, this is the rate selected.

Over the two-decade period, there is a clear downward trend in pasture area, accompanied by a decline and subsequent stabilization in the cattle herd size. During the initial years, from 2003 to around 2012, both the pasture area and the cattle herd experienced significant reductions.

This parallel decline suggests a possible correlation, where reductions in available pastureland may have directly influenced the capacity to sustain large herds. However, from 2013 onward, the trends diverge slightly. While the pasture area continues to decrease or stabilize at lower levels, the cattle herd size shows a slight recovery and steady growth from 2015 onwards. This divergence in trends may indicate the adoption of more intensive or efficient cattle farming practices, such as improved pasture management, technological advancements, or a shift toward feedlot systems. Such changes would allow for maintaining or increasing herd sizes despite reductions in available pastureland. Alternatively, this pattern could reflect economic and policy shifts.

Regarding the expansion of sugarcane, Figure 5 shows that there was a strong expansion in the planted area, except for the municipality of Motuca. This crop has been gaining importance in Brazilian production, especially in meeting the domestic market, both for sugar and ethanol. Ethanol has stood out due to the demand for renewable energy, sustainability, and energy security. Both as an additive to gasoline and as a fuel on its own, it has been strategic geopolitically for Brazil (Guevara et al., 2017).

The production of ethanol from sugarcane has been an important part of the Brazilian economy, especially in terms of sustainability and energy security. In meeting the growing demand for renewable energy, ethanol is useful both as a stand-alone fuel and as an additive to gasoline. However, the 2024/25 harvest is expected to have major problems, as initial estimates show that, compared to the previous harvest, there was a decrease in total sugarcane production, which may have a direct effect on the volume of ethanol produced. The forecast for Brazil is 27.3 billion liters of ethanol, a drop of 8% in relation to the 2023/24 harvest. In addition, the estimated production for this harvest is 13.5 billion liters in São Paulo, which is one of the main producing states, having a drop of 6.3% compared to the previous year. This decline is attributed to two factors: a reduced availability of raw materials and decreased competitiveness of this biofuel compared to sugar, due to the rising prices of this natural sweetener in the international market (CONAB, 2024).

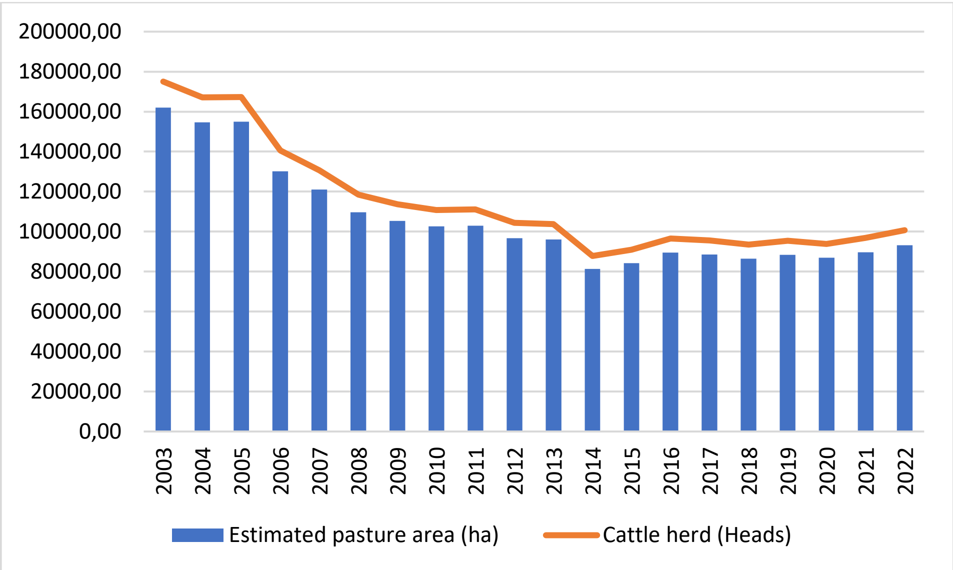

Figure 4. Comparison of the cattle herd with the estimated pasture area in the Araraquara microregion.

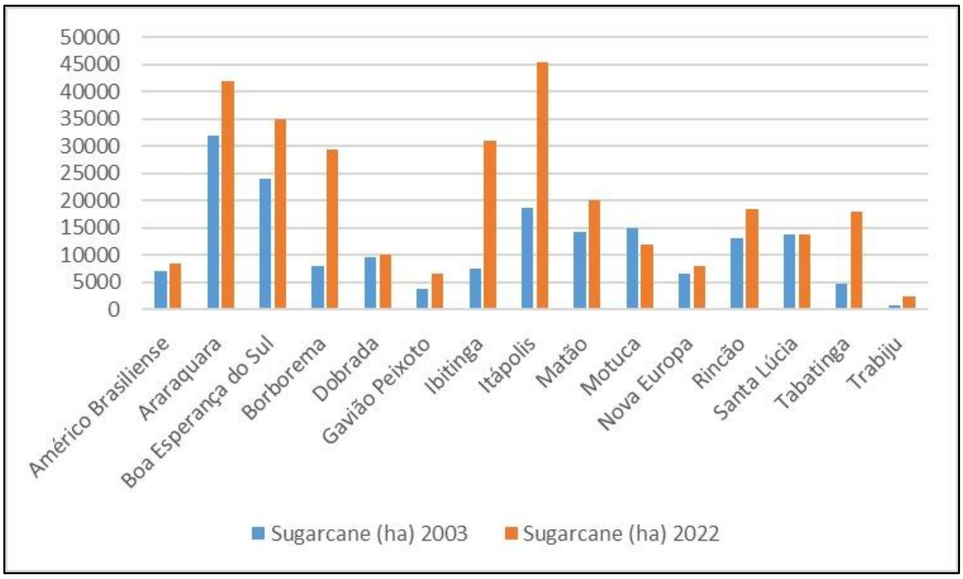

Figure 5. Sugarcane in the Araraquara microregion by municipality.

Figure 6 shows a comparison between sugarcane (temporary crop) and oranges (permanent crop). The area planted with temporary crops, including sugarcane, has increased considerably over the years. On the other hand, the area planted with oranges has remained relatively constant with small fluctuations, showing a slight downward trend after 2015.

Sugarcane exhibits a steady increase in cultivated areas, particularly after 2008, when it surpasses 250,000 hectares, eventually reaching over 300,000 hectares by 2017. This growth reflects the expanding demand for sugarcane, likely driven by biofuel production (ethanol), sugar export opportunities, and its role as a cash crop in São Paulo's agricultural economy. In contrast, land dedicated to permanent crops shows a relatively consistent decline over the same period. This suggests a shift in agricultural priorities, possibly moving resources away from long-cycle crops to focus on more profitable or strategic crops like sugarcane.

Temporary farming (excluding sugarcane), on the other hand, maintains a smaller but stable presence, with small fluctuations over the years. This stability implies a steady demand for non-perennial agricultural products, though they remain secondary to sugarcane in terms of land use.

Orange cultivation, traditionally a significant agricultural activity in São Paulo, shows a gradual decrease in area. This reduction may be attributed to challenges such as citrus greening disease, market fluctuations, or competition with expanding sugarcane plantations.

In this case, the greening disease also known as huanglongbing (HLB), affected 38.06% of orange groves in 2023. In the Araraquara microregion, many orange producers have faced challenges in controlling the disease, which has led many of them to choose to reduce or even exchange orange groves for other crops, such as sugarcane, which have fewer phytosanitary problems and greater financial stability (Fundecitrus, 2023).

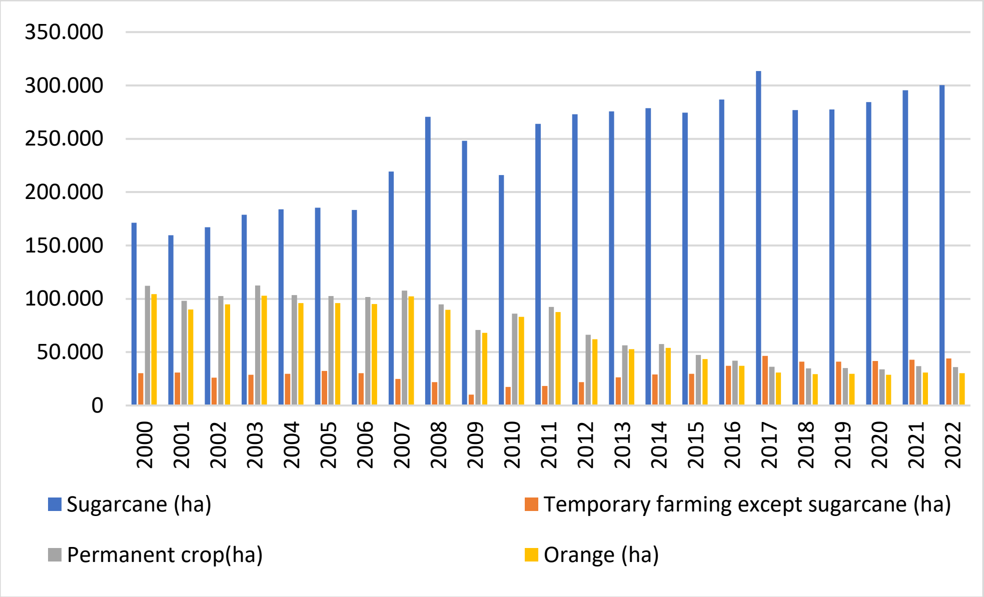

Figure 6. Comparison of sugarcane with oranges in the Araraquara microregion.

Shift-share analysis

Observing the change in land use in the Araraquara microregion (Table 1) between 2003 and 2022, it is possible to identify an increase in the cultivable area of approximately 60 thousand hectares, that is, an increase of 19% in the agricultural production area of the microregion.

Sugarcane stands out as the primary crop, with its cultivated area increasing by 121,385 hectares—a 68% rise. This expansion is attributed to two key factors: the scale effect, which added 33,716 hectares through the incorporation of new areas, and the substitution effect, which contributed 87,669 hectares by replacing land previously used for other crops. This shift underscores the economic prioritization of sugarcane, likely driven by its role in biofuel production and broader market demand. Other crops, such as soybeans, peanuts, and cassava, also experienced substantial growth, with soybeans expanding by 294% and peanuts by 195%. Cassava, while smaller in scale, saw an impressive 493% increase in its cultivated area.

Conversely, several traditional crops faced significant reductions in cultivated areas. Oranges, a historically important crop in the region, declined by 72,719 hectares, representing a 71% drop. Similarly, corn and coffee saw decreases of 47% and 85%, respectively. These losses were predominantly absorbed by the expanding sugarcane cultivation, as evidenced by the substitution effect, where sugarcane alone accounted for 80% of the reallocated land.

Regarding the Substitution Effect (Table 2), it was found that sugarcane was responsible for 80% of the incorporation of areas of other crops, and the crops that lost the most area were: oranges, corn, and coffee. Oranges alone lost 73,800 hectares to sugarcane, underscoring the crop's dominance. Other crops, such as rice, rubber, and beans, also contributed smaller portions of their land to this transition.

Table 1. Scale Effect (EE) and Substitution Effect (SE) of the microregion of Araraquara, between 2003 and 2022.

Product of temporary and permanent crops	Cultivated area (ha)		Area variation		EE	SE
	2003	2022	(ha)	%	(ha)	(ha)
Sugarcane	178,895	300,280	121,385	68%	33,716	87,669
Soybeans (grain)	4,740	18,660	13,920	294%	893	13,027
Peanuts (in-shell)	4,415	13,045	8,630	195%	832	7,798
Cassava	201	1,192	991	493%	38	953
Other crops	972	1,146	174	18%	183	-9
Fruits (except oranges)	4,823	5,693	870	18%	909	-39
Beans (grain)	488	80	-408	-84%	92	-500
Rubber (coagulated latex)	1,011	460	-551	-55%	191	-742
Rice (husk)	810	0	-810	-100%	153	-963
Coffee (grain) Total	3,676	539	-3,137	-85%	693	-3,830
Corn (grain)	17,015	8,990	-8,025	-47%	3,207	-11,232
Oranges	103,004	30,285	-72,719	-71%	19,413	-92,132
Total	**320,050**	**380,370**	**60,320**	19%	60,320	0

Table 2. Substitution effect (ES) attributed to products that lost area, in hectares, in the Microregion of Araraquara, between 2003 and 2022.

Lost area	Incorporated Area				
	Sugarcane	Soybeans (grain)	Peanut (in-shell)	Cassava	Total
Other crops	7	1	1	0	**9**
Fruits (except oranges)	31	5	3	0	**39**
Beans (grain)	400	60	36	4	**500**
Rubber (coagulated latex)	594	88	53	6	**742**
Rice (husk)	771	115	69	8	**963**
Coffee (grain) Total	3,068	456	273	33	**3,830**
Corn (grain)	8,997	1,337	800	98	**11,232**
Orange	73,800	10,966	6,564	802	**92,132**
Total	**87,669**	**13,027**	**7,798**	**953**	

Therefore, these results show a clear picture of the agricultural transformation in the Araraquara microregion, emphasizing the centrality of sugarcane in reshaping land use patterns. While the economic incentives driving sugarcane expansion are evident, the reduction in diversity raises concerns about ecological balance and long-term sustainability. The decline of staple and traditional crops such as oranges and corn suggest shifts in market dynamics, policy priorities, and possibly challenges like disease or climate impacts.

Overall, the data reflects a strategic reallocation of resources favoring sugarcane at the expense of crop variety. While this shift likely bolsters economic returns, it also highlights the need for balanced land-use policies that ensure environmental resilience, food security, and sustainable agricultural practices.

The data highlight sugarcane's dominant role in reshaping the agricultural landscape, as it absorbed most of the land transitioned from other crops, incorporating 87,669 hectares, which accounts for 80% of the total substitution effect. This dominance reflects its strong economic appeal, likely driven by its use in biofuel production and its ability to generate higher economic returns compared to other crops. Oranges experienced the largest loss, with 73,800 hectares redirected to sugarcane alone, further emphasizing the magnitude of this shift.

Other crops such as corn, coffee, and rice also contributed significant land to sugarcane cultivation, losing 8,997, 3,068, and 771 hectares, respectively. These shifts highlight a broader trend of prioritizing sugarcane over traditional crops, with significant implications for agricultural diversity and ecosystem balance.

While sugarcane absorbed most of the reallocated land, other crops such as soybeans and peanuts also gained ground, albeit on a smaller scale. Soybeans incorporated 13,027 hectares, with notable contributions from oranges, corn, and coffee. Peanuts gained 7,798 hectares, sourced from similar crops, reflecting their growing importance in the region's agricultural mix. Cassava saw modest gains, incorporating 953 hectares, which, while smaller, signifies its niche role in the broader agricultural landscape.

The redistribution of land highlights a clear pattern: high-value, high-demand crops such as sugarcane, soybeans, and peanuts are systematically replacing traditional staples and perennial crops like oranges, coffee, and corn. This reflects shifts in market dynamics, technological advancements, and possibly policy incentives favoring these crops.

However, the data also raise concerns about the environmental and social implications of such concentrated agricultural practices. The reduction in crop diversity may increase vulnerability to market fluctuations, pests, and diseases, while also impacting soil health and long-term sustainability. Moreover, the significant loss of land for staple crops such as corn and coffee could have socioeconomic repercussions for local farming communities.

Conclusions

The results reveal a significant transformation in the agricultural landscape of the Araraquara microregion between 2003 and 2022. The most striking observation is the dramatic expansion of sugarcane cultivation. This expansion was primarily driven by the substitution effect, which highlights the dominant role of sugarcane in reshaping agricultural priorities, likely influenced by its economic importance for biofuel production and its alignment with broader market trends.

While sugarcane flourished, other crops such as soybeans, peanuts, and cassava also experienced notable growth, with cassava leading the way. However, these gains are overshadowed by the significant losses experienced by traditional crops such as oranges, corn, and coffee. Oranges, a historically prominent crop in the region, saw a drastic reduction. Corn and coffee also experienced sharp declines. This pattern underscores a strategic reallocation of land away from these crops, further emphasizing the centrality of sugarcane.

This aggressive change highlights the economic pressures and incentives favoring sugarcane, while also raising questions about the long-term sustainability of such land-use shifts, which leads to a broader trend of agricultural specialization in the region, potentially at the expense of crop diversity and ecological balance. While the economic drivers of this shift are evident, the environmental and socio-economic implications warrant closer examination. The loss of traditional crops like oranges and coffee could have cascading effects on biodiversity, soil health, and the livelihoods of farmers dependent on these crops. Moreover, the concentration of agricultural resources in sugarcane may expose the region to risks associated with monoculture, such as vulnerability to pests, diseases, and market volatility.

Furthermore, the reduction in pastureland aligns with broader agricultural trends, where land previously dedicated to livestock grazing has probably been converted to crop cultivation, especially for high-value crops like sugarcane.

In conclusion, the results highlight the transformative impact of sugarcane on the agricultural dynamics of the Araraquara microregion. While the economic benefits of this shift are apparent, they are accompanied by significant trade-offs, including reduced crop diversity and potential ecological challenges. A balanced approach that considers economic, social, and environmental goals will be crucial to ensuring the long-term resilience of the region's agricultural systems.

Finally, this research provides significant insights into land use and the economic and socioeconomic impacts of sugarcane expansion. Furthermore, the results obtained during the research can assist in formulating public policies aimed at the sustainable management of agricultural resources and environmental preservation.

References

CNA. (2024). *Boletim do Comércio Exterior do Agronegócio*. https://cnabrasil.org.br/publicacoes/boletim-do-comercio-exterior-do-agronegocio-janeiro-2024

CONAB. (2024). *Boletim da Safra de cana-de-açúcar*. https://www.conab.gov.br/info-agro/safras/cana/boletim-da-safra-de-cana-de-acucar

Freitas Junior, A. M. de, & Barros, P. H. B. de. (2021). A expansão da pecuária para a Amazônia legal: externalidades espaciais, acesso ao mercado de crédito e intensificação do sistema produtivo. *Nova Economia*, *31*(1), 303–333. https://doi.org/10.1590/0103-6351/5064

Fundecitrus. (2023). *Levantamento da incidência das doenças dos citros*. Fundecitrus. https://www.fundecitrus.com.br/levantamentos

Guevara, A., Silva, O., Hasegawa, H., & Venanzi, D. (2017). Evaluation of Sustainability of Brazilian Ethanol Production: A model in System Dynamics. *Brazilian Business Review*, *14*(4), 435–447. https://doi.org/10.15728/bbr.2017.14.4.5

IBGE. (2019). *Censo Agropecuário 2017*. IBGE. https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=73096

IBGE. (2021). *Produto Interno Bruto dos Municípios*. https://sidra.ibge.gov.br/pesquisa/pib-munic/tabelas

IBGE. (2023a). *Produção Agrícola Municipal*. https://sidra.ibge.gov.br/pesquisa/pam/tabelas

IBGE. (2023b). *Produção da Pecuária Municipal*. https://sidra.ibge.gov.br/pesquisa/ppm/quadros/brasil/2023

IBGE. (2024). *Produção Agropecuária: cana-de-açúcar*. https://www.ibge.gov.br/explica/producao-agropecuaria/cana-de-acucar/br

Lourenzani, W. L., & Caldas, M. M. (2014). Mudanças no uso da terra decorrentes da expansão da cultura da cana-de-açúcar na região oeste do estado de São Paulo. *Ciência Rural*, *44*(11), 1980–1987. https://doi.org/10.1590/0103-8478cr20140186

Teixeira, J. C., & Hespanhol, A. N. (2015). A TRAJETÓRIA DA PECUÁRIA BOVINA BRASILEIRA. Caderno Prudentino De Geografia, 2(36), 26–38. Recuperado de https://revista.fct.unesp.br/index.php/cpg/article/view/2672