LAND USE TRANSFORMATIONS IN THE PAMPA BIOME: IMPACTS OF AGRICULTURAL INTENSIFICATION AND IMPLICATIONS FOR ENVIRONMENTAL MANAGEMENT

1 INTRODUCTION

The global demand for food is expected to increase between 60% and 70% by 2050, requiring intensified land use and expansion into new agricultural areas (van Dijk et al., 2021). In Brazil, the Pampa biome has traditionally supported extensive livestock farming, while recent decades have seen the expansion of agricultural activities, particularly soy and irrigated rice cultivation (CONAB, 2017). These land use changes have been driven by economic, social, and environmental factors, as well as by the pursuit of increased productivity (Marin et al., 2022).

However, this intensification has resulted in the progressive loss of natural grassland formations, altering ecosystem services and landscape dynamics (Lima et al., 2020; Caumo et al., 2021). Understanding the balance between increased food production and conservation of natural areas is essential for sustainable management in the region.

Therefore, the objective of this study is to analyze land use changes in the Brazilian Pampa biome between 1985 and 2021 and assess their effects on the production of soy, rice, and beef cattle, with a focus on gains in protein and calorie output.

2 THEORETICAL FRAMEWORK

Land use change is closely linked to agricultural intensification, influencing both productivity and environmental sustainability. Anthropogenic activities in Brazilian biomes have led to significant modifications in natural landscapes, affecting soil quality, water availability, and greenhouse gas emissions (EMBRAPA, 2022). These transformations highlight the need to evaluate how intensification strategies impact ecosystem functions and long-term agricultural viability.

Intensification in the Pampa biome has involved shifts from extensive livestock grazing to more productive land uses, including crop cultivation. Such transitions are influenced by historical land management practices, technological adoption, and socio-economic pressures (MMA, 2022). The integration of livestock and crop systems can provide opportunities for improved efficiency in protein and calorie production, but may also generate trade-offs in terms of biodiversity conservation and landscape integrity (FAO, 2017).

Recent analyses demonstrate that reductions in natural grasslands due to land use change have implications for ecosystem services and regional Sustainability. Therefore, understanding the environmental consequences of agricultural intensification is essential for developing management strategies that balance productivity, conservation, and sustainable land use. These insights inform policy decisions, planning, and implementation of practices that support both food security and ecological resilience.

3 MATERIALS AND METHODS

The study was conducted in the Pampa Biome, which spans four South American countries and covers 2.3% of Brazil's national territory, concentrated in the state of Rio Grande do Sul. The region exhibits high biodiversity, with approximately 2,817 plant species and 956 animal species, some of which are at risk of extinction. The climate is humid subtropical, with average temperatures ranging from 12.1°C to 23.7°C and monthly precipitation between 116 and 195 mm. Native vegetation formations include grasslands, forests, wetlands, shrublands, and rocky outcrops, providing the ecological context for assessing the environmental impacts of land-use changes.

The activities evaluated encompassed agriculture and livestock farming, focusing on soybean and rice cultivation and beef cattle production. Historical data from 1985 to 2021 were obtained from MapBiomas and the Brazilian Institute of Geography and Statistics (IBGE), while information on beef cattle was available from 1997 onwards. Estimates of cattle slaughter and meat production in the region were derived from state-level cattle populations, enabling calculation of productivity, annual production, and the protein and caloric content of soybean, rice, and beef, based on previous studies. For the analysis, the systems were categorised into native grassland livestock systems, integrated crop-livestock systems, and combined systems, allowing comparison of environmental impacts across different land-use approaches. Natural (forest and non-forest formations) and anthropic (croplands and pastures) variables were quantified and included in the assessment.

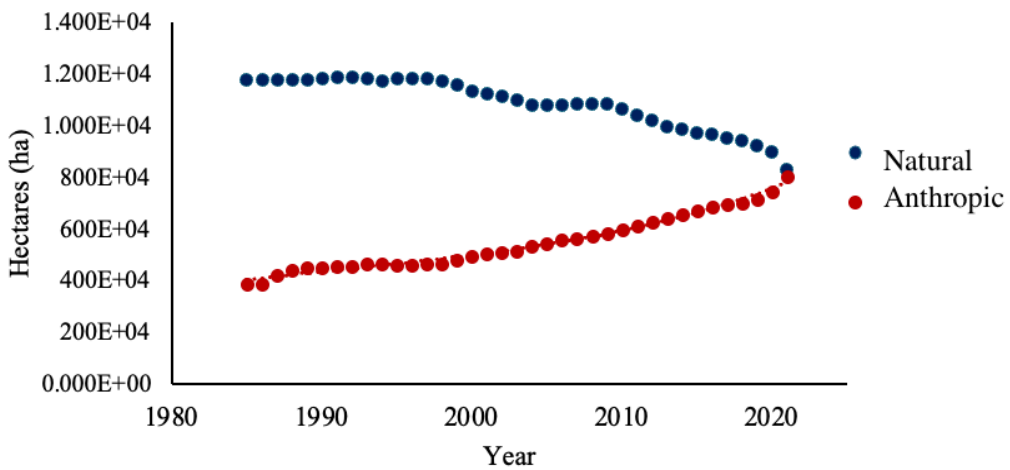
Data processing was carried out using IBM SPSS Statistics 20.0, with analysis of variance (ANOVA) followed by Scheffé's test at a 5% probability level. Time series were segmented into comparable periods (four for agriculture and three for livestock) to evaluate differences in mean values across intervals. This statistical approach allowed the identification of trends and effects of land-use changes, contributing to the assessment of environmental impacts in the Pampa Biome resulting from the conversion of native grasslands into integrated crop-livestock systems, as well as comparisons among the different system types.

The time series was segmented into four distinct periods for the creation of four intervals of comparable duration, with three periods consisting of 9 years each, and the last one comprising 10 years. This segmentation was designed to facilitate comparisons and ascertain the presence or absence of differences in the average values of the variables across these intervals. The periods were designated as P1 (1985-1993), P2 (1994-2002), P3 (2003-2011), and P4 (2012-2021). Regarding the variables specific to beef cattle farming, three periods were delineated, named P1 (1997-2002), P2 (2003-2011), and P3 (2012-2021).

4 ANALYSIS AND DISCUSSION OF RESULTS

Land use in the Brazilian Pampa biome experienced substantial transformation between 1985 and 2021, with natural formations decreasing by 29.55% (-3,488,619.57 ha) and anthropogenic formations increasing by 107.54% (4,179,169.01 ha)(Figure1).

Figure 1 – Variation in natural formation and anthropogenic formation in the Pampa biome between 1985 and 2021



Grasslands, crucial for local biodiversity, declined by 26.28%, while agricultural activities intensified, notably through the expansion of soy (+172.77%) and rice (+111.49%) cultivation, alongside increased beef production despite reductions in grazing áreas (Table 1).

Table 1 – Average of anthropic formation variables

Description	Variable	P1 1985-1993	P2 1994-2002	P3 2003-2011	P4 2012-2021	Sig*
Anthropic Formation (ha)						
Rice	A1	367,520.19^{b}	315,415.53^{b}	488,712.02^{b}	777,286.67^{a}	0.000
Soybean	A2	1,958,131.56^{b}	2,617,667.45^{b}	4,501,102.70^{a}	5,341,144.65^{a}	0.000
Other Temporary Crops	A3	1,881,554.20^{a}	1,575,042.69^{a}	219,536.85^{b}	148,702.42^{b}	0.000
Pasture	A4	0.50^{a}	0.28^{ab}	0.32^{ab}	0.23^{b}	0.023
Forest Plantation	A5	145,651.49^{d}	292,328.55^{c}	446,184.67^{b}	690,659.98^{a}	0.000

Note: ha: Hectares. ANOVA test with significance at the 5% probability level ($p < 0.05$). Lines with means followed by different letters differ in the F and Scheffé's tests ($P \leq 0.05$).

Protein and calorie production followed a consistent upward trend. Soy increased by 319.09% and rice by 112.97%, while beef production grew by 48.15%, despite reduced pasture áreas (Table 1). Positive correlations were observed between land use change and protein and calorie outputs for crops, contrasting with beef production, where efficiency gains in smaller areas resulted in a negative correlation. These patterns indicate that agricultural intensification has enhanced productivity and food supply, yet significantly altered natural ecosystems (Table 2).

Table 2 – Average of total annual production of protein and calorie

Description	P1 1985-1993	P2 1994-2002	P3 2003-2011	P4 2012-2021	Sig*
Soybean					
Protein (t)	6.63E+08^{b}	6.11E+08^{b}	1.21E+09^{b}	2.78E+09^{a}	0.000
Calorie (j)	3.10E+13^{b}	2.86E+13^{b}	5.64E+13^{b}	1.30E+14^{a}	0.000
Rice					
Protein (t)	3.23E+08^{c}	4.02E+08^{c}	5.81E+08^{b}	6.87E+08^{a}	0.000
Calorie (j)	5.65E+13^{c}	7.04E+13^{c}	1.02E+14^{b}	1.20E+14^{a}	0.000
Beef Cattle		**P1 1997-2002**	**P2 2003-2011**	**P3 2012-2021**	**Sig***
Protein (t)		4.94E+07^{b}	6.61E+07^{a}	7.32E+07^{a}	0.000
Calorie (j)		2.31E+12^{b}	3.09E+12^{a}	3.42E+12^{a}	0.000

Note: t: Tonnes. **J**: Joules. ANOVA test with significance at the 5% probability level ($p < 0.05$). Lines with means followed by different letters differ in the F and Scheffé's tests ($P \leq 0.05$).

Intensification focused on former pastures, relying on higher inputs of nitrogen and phosphorus fertilisers, irrigation, and improved management, which enhanced yields but also posed environmental risks, including soil degradation, water eutrophication, and increased greenhouse gas emissions (Theisen et al., 2017; Vasconcelos et al., 2018b; Zimmer et al., 2020). Flood irrigation for rice contributed to productivity gains, though mismanagement could disrupt hydrological balance, increase soil acidification, and release methane (Caumo et al., 2021; Overbeck et al., 2022).

The expansion of the agricultural frontier also promoted integrated crop-livestock-forestry systems, offering opportunities for risk mitigation, economic diversification, and partial conservation of natural areas (Conceição, 2022). Nevertheless, conversion of natural landscapes into intensified production areas continues to raise concerns regarding biodiversity loss and environmental degradation. Compliance with environmental legislation, including the Forest Code and the Rural Environmental Registry (CAR), remains essential but insufficient alone to mitigate the impacts of agricultural expansion.

Systematic environmental assessment using tools such as Life Cycle Assessment (LCA) and Emergy Assessment (EA) is crucial to quantify impacts, evaluate sustainability, and guide sustainable intensification (Garofalo et al., 2022). These methodologies help identify the most environmentally efficient systems and inform management strategies that balance productivity with conservation, supporting a more sustainable agro-productive development in the Pampa biome.

5 FINAL CONSIDERATIONS

This study demonstrates that land use changes in the Pampa biome, particularly the expansion of soy and rice cultivation, have contributed to significant increases in protein and calorie production, alongside gains in beef cattle productivity. These improvements were achieved with partial land conservation, highlighting the role of technological advancements and management practices in enhancing agricultural output. Other factors, such as economic growth, societal demands, political incentives, and international trade, may also have influenced these production gains.

While integrated production systems are widely promoted for sustainability, the Pampa presents a distinct scenario where crop cultivation occurs alongside native pastures. In this context, the expansion of anthropogenic formations, particularly for soy, has reduced grassland areas, potentially impacting biodiversity.

The findings underscore the trade-offs between increased food production and conservation of natural landscapes. By presenting these results, stakeholders can assess priorities and make informed decisions regarding the balance between productivity and environmental preservation, acknowledging that no system is without limitations.

REFERENCES

CAUMO, M., et al. (2021). Grassland community structure in Permanent Preservation Areas associated with forestry and livestock in the Pampa biome, Southern Brazil. *South African Journal of Botany, 139*, 442–448.

CONCEIÇÃO, J. C. P. R. da. (2022). *Integração pecuária-lavoura: avanços e principais desafios*. http://repositorio.ipea.gov.br/handle/11058/11261

CONAB. (2017). *A produtividade da soja: Análise e perspectiva*. http://www.conab.gov.br

EMBRAPA. (2022). *Bioma Pampa - Portal Embrapa*. https://www.embrapa.br/contando-ciencia/bioma-pampa

FAO. (2017). *Biodiversidade Brasileira | FAO*. https://www.fao.org/family-farming/detail/fr/c/469801/

GAROFALO, D. F. T., et al. (2022). Land-use change CO2 emissions associated with agricultural products at municipal level in Brazil. *Journal of Cleaner Production, 364*, 132549.

LIMA, D. O., CROUZEILLES, R., & VIEIRA, M. V. (2020). Integrating strict protection and sustainable use areas to preserve the Brazilian Pampa biome through conservation planning. *Land Use Policy, 99*.

MARIN, F. R., et al. (2022a). Protecting the Amazon forest and reducing global warming via agricultural intensification. *Nature Sustainability*, 1–9. https://www.nature.com/articles/s41893-022-00968-8

MMA. (2022). *Ministério do Meio Ambiente - Pampa*. https://www.gov.br/mma/pt-br/assuntos/ecossistemas-1/biomas/pampa

OVERBECK, G. E., et al. (2022). Placing Brazil's grasslands and savannas on the map of science and conservation. *Perspectives in Plant Ecology, Evolution and Systematics, 56*, 125687.

THEISEN, G., et al. (2017). The birth of a new cropping system: Towards sustainability in the sub-tropical lowland agriculture. *Field Crops Research, 212*, 82–94.

VAN DIJK, M., et al. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food, 2*(7), 494–501. https://www.nature.com/articles/s43016-021-00322-9

VASCONCELOS, K., et al. (2018a). Livestock-derived greenhouse gas emissions in a diversified grazing system in the endangered Pampa biome, Southern Brazil. *Land Use Policy, 75*, 442–448.

ZIMMER, T., et al. (2020). Influence of clearness index and soil moisture in the soil thermal dynamic in natural pasture in the Brazilian Pampa biome. *Geoderma, 378*, 114582.