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A LOOK-OUT TO THE BRAZILIAN CERRADO: analysis of the deforestation, land use, and environmental implications

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ABSTRACT: The cerrado is one of the 25 hotspots in the world and is considered the savanna with the most biodiversity of species. However, while it has high environmental relevance, the biome is the focus of intense agricultural use due to its favorable natural conditions. For the study of the cerrado, the Mapbiomas Platform has stood out in providing useful information on the cover and use of soil, water surface, and fire scars. Thus, the objective of this study was to analyze the Mapbiomas Platform concerning the use and coverage of soils in the cerrado in Brazil, and detail, at Triângulo Mineiro, on historical series from 1985-2021, and to ascertain the environmental implications arising from this action, focusing on soil organic matter. The results indicated that the cerrado, in general, has been replaced by large-scale agriculture in the last 35 years, and its areas have shrunk by 25% in this period (considering only the cerrado) the increase in pasture and agricultural areas in the Brazilian cerrado corresponds to 23% and 621%, respectively, in the period from 1985 to 2021, and the use and coverage of soils in the cerrado in the Triângulo Mineiro follow the same flow as the rest of the country in terms of the expansion of agriculture. In the opposite direction of areas occupied by agriculture, livestock, and forest plantations, water bodies showed a reduction of 5% in the same period, and hydromorphic environments decreased by 3%, corroborating the premise that the Brazilian cerrado is drying out. In general, the municipalities of the Triângulo Mineiro came from an occupation of the cerrado and transformation of its native cover by crops or pasture before the 1980s, which was consolidated during this period, maintaining high deforestation rates. The main changes in land use related to the replacement of native cerrado vegetation for the expansion of modern agriculture in recent decades are generally followed by soil C losses (~22%). In contrast, annual crops under the crop-livestock-forest system can potentially accumulate C in the soil and partially reverse C losses after converting native vegetation.
Keywords: Agricultural soil; Farming; Brazilian Savanna; Oxisols.

UM OLHAR PARA O CERRADO BRASILEIRO: análise do desmatamento, uso da terra e implicações ambientais

RESUMO: O cerrado representa um dos 25 hotspots do mundo e é considerado a savana com a maior biodiversidade de espécies. No entanto, ao mesmo tempo em que possui grande relevância ambiental, o bioma é foco de intensa utilização agropecuária devido às condições naturais favoráveis. Para o estudo do cerrado, a Plataforma Mapbiomas tem se destacado no fornecimento de informações úteis sobre a cobertura e uso do solo, da superfície de água e cicatrizes de fogo. Dessa forma, o objetivo do trabalho foi analisar a Plataforma Mapbiomas no que se refere ao uso e cobertura dos solos do cerrado no Brasil,

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e em detalhe, no Triângulo Mineiro, na série histórica de 1985-2021, e levantar as implicações ambientais decorrentes dessa ação, com foco na matéria orgânica dos solos. Os resultados indicaram que o cerrado, de modo geral, vem sendo substituído pela agricultura em larga escala nos últimos 35 anos, e recuou 25% de suas áreas nesse período (considerando apenas o cerrado stricto sensu); o aumento das áreas de pastagem e agricultura no cerrado brasileiro correspondem a 23% e 621%, respectivamente, no período de 1985 a 2021, e o uso e cobertura dos solos do cerrado no Triângulo Mineiro segue o mesmo fluxo do restante do país no que se refere a expansão da agropecuária; no sentido inverso das áreas ocupadas com agricultura, pecuária e plantios florestais, os corpos hídricos apresentaram uma redução de 5% no mesmo período, e os ambientes hidromórficos diminuíram 3%, corroborando com a premissa de que o cerrado brasileiro está secando; os municípios do Triângulo Mineiro, de modo geral, vinham de uma ocupação do cerrado e transformação da sua cobertura nativa por culturas agrícolas e/ou pastagem anterior à década de 1980, e que se consolida nesse período, mantendo altas as taxas de desmatamento (em ha); as grandes mudanças no uso da terra relacionadas à substituição da vegetação nativa do cerrado para expansão da agricultura moderna nas últimas décadas são usualmente seguidas por perdas de C no solo (~22%). Como contrapartida, as culturas anuais sob o sistema lavoura-pecuária-floresta podem, potencialmente, acumular C no solo e, parcialmente, reverter as perdas de C após a conversão da vegetação nativa.
Palavras-chave: Solos agrícolas; Agricultura; Cerrado brasileiro; Latossolo.

UNA VISIÓN PARA EL CERRADO BRASILEÑO: análisis de la deforestación, el uso del suelo y las implicaciones ambientales

RESUMEN: El cerrado representa uno de los 25 hotspots del mundo y es considerado la sabana con mayor biodiversidad de especies. Sin embargo, al mismo tiempo que tiene una gran relevancia ambiental, el bioma es foco de uso agrícola intenso debido a sus favorables condiciones naturales. Para el estudio del cerrado, la Plataforma Mapbiomas se ha destacado por proporcionar información útil sobre la cobertura y uso del suelo, la superficie del agua y las cicatrices del fuego. Así, el objetivo del trabajo fue analizar la Plataforma Mapbiomas con respecto al uso y cobertura de suelos en el cerrado de Brasil, y en detalle, en el Triângulo Mineiro, en la serie histórica de 1985-2021, y plantear la Implicaciones ambientales derivadas de esta actuación, centrándose en la materia orgánica del suelo. Los resultados indicaron que el cerrado, en general, ha sido reemplazado por la agricultura a gran escala en los últimos 35 años, y sus áreas se han reducido en un 25% en este período (considerando sólo el cerrado estricto sensu); el aumento de las áreas de pastos y agrícolas en el cerrado brasileño corresponde al 23% y 621%, respectivamente, en el período de 1985 a 2021, y el uso y cobertura de suelos del cerrado en el Triângulo Mineiro sigue el mismo flujo que el resto del país en términos de se refiere a la expansión de la agricultura; en sentido contrario a las áreas ocupadas por agricultura, ganadería y plantaciones forestales, los cuerpos de agua mostraron una reducción del 5% en el mismo período, y los ambientes hidromórficos disminuyeron un 3%, corroborando la premisa de que el cerrado brasileño se está secando; los municipios del Triângulo Mineiro, en general, provienen de una ocupación del cerrado y transformación de su cobertura nativa por cultivos agrícolas y/o pastos antes de la década de 1980, y que se consolidó durante este período, manteniendo altas tasas de deforestación (en ha); los grandes cambios en el uso de la tierra relacionados con el reemplazo de la vegetación nativa en el cerrado por la expansión de la agricultura moderna en las últimas décadas generalmente van seguidos de pérdidas de C en el suelo (~22%). Por el contrario, los cultivos anuales bajo el sistema cultivo-ganado-bosque pueden potencialmente acumular C en el suelo y, parcialmente, revertir las pérdidas de C después de la conversión de la vegetación nativa.
Palabras clave: Suelo agrícola; Cultura agrícola; Sabana; Oxisols.

Introduction

The cerrado covers a region of approximately 2.0 million km² and encompasses several states in Brazil. It is probably the region that has witnessed the large change in land use in the world since the "Green Revolution," associated with rural credit policies subsidized by government programs that began in the 1970s, especially the Cerrado Development Program (POLOCENTRO) (PEREIRA et al., 2018).

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As a result, the cerrado has become one of the principal agricultural frontiers in the tropics (GOEDERT, 1989; COSTA et al., 2002; BEUCHLE et al., 2015), with rapid replacement of native vegetation by pastures and large-scale monocultures. This showed that the region, considering 50 years (1960-2010), had the second highest deforestation rate in the entire history of humanity, being only lower than amazon deforestation (PEREIRA et al., 2018). This human pressure, associated with land degradation, has resulted in severe problems such as soil erosion and compaction, increasing production costs (CANILLAS; SALOKHE, 2002) and promoting new phenomena such as "savannization" in the amazon and "aridization" in the cerrado, resulting in deleterious effects on biodiversity and availability of water and soil for agriculture (PEREIRA et al., 2018).

In this deforestation scenario, the Mapbiomas Platform, a collaborative network formed by non-governmental organizations (NGOs), universities, and technology startups, proves to be a useful tool for environmental analysis, and purposing to produce an annual mapping of land cover and use, water surface and scars of fire monitoring with data from 1985. According to Mapbiomas, Brazil has a native vegetation coverage of 66%, resulting in a net loss of -85 Mha of vegetation between 1985-2021 (MAPBIOMAS, 2022). During this period, the growth of the pasture area was 39%, and the area occupied by agriculture increased by 228%. Mapbiomas, specifically for the cerrado, points out that its native vegetation coverage is ~53%, with a net loss of vegetation of -28 Mha for the period 1985-2021, a time in which the agricultural area increased 6.2 times (MAPBIOMAS, 2022).

Conditions such as flat relief, facilitated and large-scale mechanization, suitable climatic aspects, modern soil management techniques, and genetic improvement contributed to the increase in agricultural productivity in the cerrado. Associated with these factors, the dominant coverage of Oxisols (Ferralsols) on extensive plains and good drainage conditions make the cerrado the most suitable tropical area for intensive cultivation (RESENDE, 2002). Furthermore, it has a strategic position as the source of rivers in the country's main river basins, which allows us to understand the current model of agricultural occupation, and it is essential to question whether this model will be able to maintain the important hydrological role that the region promotes (PEREIRA; FIGUEIREDO, 2018).

Following the same sense of use and occupation of land in the cerrado, the Triângulo Mineiro region and all its municipalities have stood out in Minas Gerais and Brazil regarding their highly technical and productive agricultural production and animal and plant genetic improvement (CLEPS Jr., 2009). What has been observed is a vast territorial transformation of the region, with widespread replacement of native vegetation by the most diverse activities in the primary sector. Therefore, there is an increasing need to understand this transformed environment, future perspectives on vegetation patterns, and the state of soil conservation, especially concerning carbon stocks and impacts on the climate, as well as knowing the general environmental panorama in these areas. Thus, the Mapbiomas Platform has become a useful, reliable, and easily accessible tool, capable of scientifically assisting in purposes and investigations involving research into the use and occupation of cerrado lands (MAPBIOMAS, 2022).

Thus, the objective of this study was to analyze the use and coverage of cerrado lands in Brazil, and in detail, in the Triângulo Mineiro in the historical series of 1985-2021, and ascertain the environmental implications resulting from this action, focusing on soil organic matter, based on version 7 of the Mapbiomas Platform, as preconized by Mapbiomas (2022).

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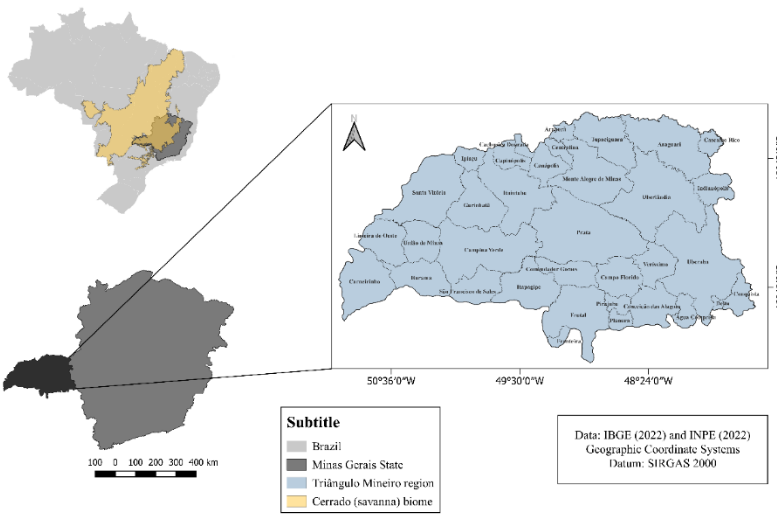
Methodology

Study area

The area of this research originally covers the vegetation of the cerrado, the second-largest biome in Brazil and the most diverse tropical savanna in the world in terms of species, genetic variation, and ecosystems (KLINK; MACHADO, 2005), as shown in Figure 1.

Among Brazilian physiographic spaces, the cerrado represents one of the large irregular polygons that form the country's landscape and ecological mosaic (AB'SABER, 2003). It predominantly occupies massive plateaus with a complex structure, with flattened summit surfaces and a significant set of compartmentalized sedimentary plateaus located at levels varying between 300 and 1700m in altitude (AB'SABER, 2003). This segmentation across the landscape is responsible for climate, soil, and vegetation pattern variability (PEREIRA; FIGUEIREDO, 2018; PEREIRA et al., 2018). According to the authors, depending on the concentration and local conditions, they may present phytophysiognomies (dominant vegetation type) called cerradão, cerrado (stricto sensu), campo limpo, campo sujo, interspersed with floodplain forest formations, and rupestrian fields. Notably, there are two well-defined seasons: a dry season, which coincides with the coldest months (April to September), and a rainy season (October to March). The average annual precipitation is 1500 mm, and the average temperature is 25 ºC, rising significantly in summer, commonly exceeding 35 ºC to 40 ºC (INMET, 2022).

Figure 1 - Geographical localization of the cerrado, Triângulo Mineiro region, and its respective municipalities



Source: the authors.

In the Triângulo Mineiro, the relief makes up the Paraná Sedimentary Basin Plateau. It is the extension in Minas Gerais of a compartment that occupies large areas in the States of São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul and corresponds to the sedimentary layers over the flows of basaltic volcanic rocks (CPRM, 2003). The predominant soils are Oxisols, Quartzipsamments, and Ultisols, which cover approximately 75% of the biome (REATTO et al., 1998). In general, soils are characterized by being acidic, leached, and made up of low-activity clay and high aluminum concentration. They are more susceptible to laminar erosion and, in places with higher slopes, prone to the formation of gullies, which can represent a serious environmental problem heightened by the replacement of native vegetation cover.

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Data sampling and analysis

The classification approach for the cerrado biome in the MapBiomas network involved the application of decision trees to generate yearly maps, scale 1:250.000, of the dominant native vegetation (NV) types, categorized into four groups: forest formation, savanna formation, wetland, and grassland formation (ALENCAR et al., 2020; SOUZA Jr. et al., 2020; MAPBIOMAS, 2022). Over time, the method for generating these maps underwent refinements, which resulted in significant improvements to version 7. According to Mapbiomas (2022), the overall classification process for cerrado native vegetation encompassed several steps (made by Mapbiomas Platform): firstly, the optimal time of year for constructing annual Landsat mosaics was selected; then, remote sensing metrics were defined as potential predictors (feature space); reference training samples were created to calibrate the classification algorithm; post-classification treatments were applied to eliminate noise and generate a consistent time series; finally, the resulting maps were integrated with other cross-cutting themes; classification results were evaluated through visual inspection and sample-based validation analysis (MAPBIOMAS, 2022). Therefore, all maps, infographics, and reports created in the Mapbiomas network were used for acquiring the data used in this study.

In this study, we selected the data from the Mapbiomas Platform, version 7, in the following layers: coverage (forest formation, savanna formation, grassland, rocky outcrop, wetland, agriculture, forest plantation, pasture, mining, water), deforestation (primary vegetation, secondary vegetation), irrigation (citrus, coffee, other perennial crops, cotton, soybeans, sugar cane, other temporary crops), fire scars and soil (soil organic carbon - SOC) for the cerrado at the national level, as well as detailed data for the cerrado in the Triângulo Mineiro, manually selected municipality by municipality, in the historical series from 1985 to 2021, according to Mapbiomas (2022). Specifically for the deforestation layer, Mapbiomas provides data from 1987 to 2020.

Using the resources available on the platform layout, the following components were manually marked in each layer: territorial section (biome, state, and municipality) and corresponding territory. In this case, a focus was the Brazilian cerrado biome, cerrado in the state of Minas Gerais and municipalities of the Triângulo Mineiro. After searching for the information, the selected data was downloaded and tabulated, tables were created in Excel software and subsequent analysis and interpretation were carried out.

Regarding the data available on the Annual Mapping of Soil Organic Carbon Stock in Brazil, within the Soil tab (beta version), Mapbiomas (2023) makes this data available through a triangulation between the platform, the SoilData repository (https://soildata.mapbiomas.org/) and the end user. The data were obtained from the analysis of the dynamics of SOC stocks from 1985 to 2021 in different land covers and uses, with a spatial resolution of 30m and showing SOC stocks from 0 to 30cm in tons per hectare.

To complement the data from Mapbiomas, a literature review on the use and coverage of cerrado soils in the period 1985-2021 was conducted, mainly focusing on rural areas, to ascertain the main environmental implications caused by this action, especially on organic matter and soils. The search terms used were land use in the cerrado, native cover in the cerrado, deforestation in the cerrado, the organic carbon in the cerrado, and organic matter in the cerrado.

Results and discussion

Land use and land cover in soils at Brazilian cerrado

An important and well-established feature of the cerrado and, specifically, the Triângulo Mineiro region in the state of Minas Gerais, is the prominent position of agricultural production on rural properties, in many cases associated with land concentration. As a

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reference, in 2020, according to data from the National Supply Company (CONAB), more than 23% of the state's grain production was produced in this region, with the municipality of Uberaba leading the state's production ranking, with more than 700,000 tons of grain produced, with soybeans and corn standing out as the main crops, as well as sugarcane, which supplies the region's sugar and alcohol mills (CONAB, 2022). The dairy and beef cattle production chain are also a major activity.

In studies on the transformation at Triângulo Mineiro into a major agricultural center in the country, some authors pointed out that this is one of the Brazilian regions where the extent and intensity of rural transformations occurred in greater harmony with the guidelines of modern agriculture (BRANDÃO, 1989; PESSÔA, 1998; CLEPS Jr., 2009; SOUZA, 2013). Thus, participating in a privileged position of geographical production reorientation, it was able to assimilate industrial forms of production quickly and fully in agriculture, expanding its production capacity. In this way, agriculture, supported by public policies, transformed the cerrado lands into a business to meet the demands of production based on the increasing use of natural resources, especially forestry and soil resources.

Table 1 points out the principal forms of use and coverage of cerrado soils at national level, as well as the advancement of agricultural areas, the suppression of forest and water bodies, and, probably, higher soil exposure to the weathering agents. It was found that the biome, in general, has been replaced by large-scale agriculture in the last 35 years and has retreated 25% of its native areas in this period (considering only the cerrado stricto sensu). Even though there is an increase in planted forests, it is worth highlighting that they are associated with planting exotic species for commercial use, such as eucalyptus and pine, to supply charcoal factories and construction and, therefore, not considered areas connected to permanent forest restoration. However, even if momentary, they are carbon-accumulating cultures.

Also noteworthy are the pasture areas, which occupy around 24% of the biome, or 47 Mha, and are intended for extensive livestock farming. The increase in these areas between 1985 and 2021 corresponds to 23%. During this period, agriculture had a 621% increase in areas converted to planting. Considering the areas occupied by soybeans, the increase was ~1400%. These increases are justified by the colonization programs in the interior of Brazil, a constant incentive to expand the agricultural frontier, and urban growth seen after the 1980s. In the opposite direction of areas occupied by agriculture, livestock, and forest plantations, water bodies notably showed a reduction of 5% in the same period, and hydromorphic environments decreased by 3%, corroborating what the scientific community has demonstrated: the Brazilian cerrado is drying up (HOFFMANN; MOREIRA, 2002; COSTA et al., 2003; MÜLLER, 2003; OLIVEIRA et al., 2005).

In Minas Gerais, according to Table 2, changes in the cerrado follow, to a certain extent, the transformation trends of the cerrado at a national level, with some particularities. The areas of cerrado stricto sensu fell by 17%, pastures fell by 18%, and agriculture advanced by 815%, demonstrating that the conversion of areas for plantations is due not only to the replacement of native vegetation but also to the advance of areas that were previously anthropized and occupied by pastures, which despite decreasing, still cover an area 2.7 times larger than that of agriculture in Minas Gerais. Water bodies reduced their areas by 22%, which may be related to climate stress and excessive use of water by irrigated agriculture. Meanwhile, hydromorphic environments increased by 3%, probably related to areas flooded by anthropogenic activities, such as transposition of rivers and flooding of agricultural lands, and even small dams in some specific places.

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Table 1 - The annual land use and land cover at Brazilian cerrado for the period 1985-2021

Land Cover	1985	1990	1995	2000	2005	2010	2015	2020	2021
	-------	-------	-------	-------	ha	-------	-------	-------	-------
Forest formation	33.121.303	31.334.708	30.290.904	29.710.994	28.901.723	28.147.849	27.801.052	28.026.327	28.025.079
Savanna formation	80.538.991	77.330.931	73.259.314	69.851.629	66.186.734	64.809.644	62.030.042	61.074.570	60.452.391
Grassland	13.056.373	12.457.832	12.022.913	11.824.829	11.416.361	11.097.140	10.734.735	10.474.366	10.469.421
Rocky outcrop	439.940	440.040	440.089	439.983	439.967	439.834	439.508	439.440	439.407
Wetland	6.176.578	5.928.312	5.888.217	5.942.819	5.958.671	6.001.750	6.021.209	6.004.099	5.994.651
Agriculture	4.107.446	7.095.258	9.954.317	12.397.151	16.486.867	19.386.621	23.015.960	25.415.187	25.487.121
Forest plantation	542.984	916.267	1.256.843	1.321.138	1.384.098	1.932.114	2.801.582	3.181.907	3.224.138
Pasture	38.223.129	44.663.127	49.268.307	52.252.437	52.981.742	51.972.281	50.627.839	47.825.957	47.097.449
Mining	7.567	14.162	18.333	22.037	26.599	33.105	40.299	46.130	46.075
Water	1.399.288	1.432.003	1.433.789	1.335.942	1.460.337	1.514.959	1.380.578	1.404.028	1.334.001

Source: adapted from Mapbiomas (2022).

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Table 2 - The annual land use and land cover at Brazilian cerrado in the Minas Gerais State for the period 1985-2021

Land Cover	1985	1990	1995	2000	2005	2010	2015	2020	2021
	ha								
Forest formation	3.502.799	3.201.736	2.986.986	2.949.744	2.892.410	2.863.459	2.881.990	2.912.371	2.879.977
Savanna formation	9.863.464	9.620.750	9.285.992	9.018.130	8.781.308	8.599.356	8.356.914	8.367.700	8.278.160
Grassland	2.108.039	1.995.555	1.942.361	1.994.224	1.990.260	1.974.614	1.879.095	1.853.880	1.852.382
Rocky outcrop	397.395	397.445	397.448	397.335	397.308	397.154	396.837	396.727	396.687
Wetland	385.480	343.336	346.856	355.006	369.118	384.994	388.884	388.230	399.640
Agriculture	398.373	705.467	1.007.790	1.367.832	1.971.483	2.385.357	2.903.061	3.223.280	3.243.044
Forest plantation	334.460	512.851	746.653	737.100	775.421	1.026.406	1.246.042	1.339.287	1.338.683
Pasture	10.358.465	11.057.718	11.232.463	11.214.887	10.675.807	9.997.447	9.454.373	8.670.152	8.501.459
Mining	2.768	4.895	6.304	8.133	10.083	11.965	14.497	16.482	16.429
Water	401.067	394.054	424.935	360.463	396.871	396.220	311.553	340.953	311.664

Source: adapted from Mapbiomas (2022).

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Thus, when observing the data concerning the use and coverage of soil in the cerrado at Triângulo Mineiro, it appears that the region follows the same model as the rest of the country regarding agricultural expansion. This model installed in the cerrado was advocated by the Green Revolution, in which genetic improvement developed in universities and research centers, soil management (correction and fertilization), and the relief (flat to gently wavy) favorable to mechanization were decisive and served as the basis for the economic success of this occupation, but at a high environmental cost (CUNHA et al., 2008; BALESTRO; SAUER, 2009).

The expansion of cities and activities such as mining and plant extraction are additional impacts that also affect the cerrado in the Triângulo Mineiro and other areas where it occurs. According to Tables 1 and 2, mining activities at cerrado increased by 600% and 585% in Brazil and Minas Gerais, respectively. This fact reveals a growing demand for mining products to supply not only rural areas but also related to the growth of cities.

The expansion of the urban area over natural ecosystems advanced towards the interior of Brazil following the construction of Brasília and the opening of roads connecting the southeast to the interior. According to Pereira (2015), the expansion of cities over native vegetation, even if punctually, was no less impactful than agriculture and a sign that it should also be part of the discussion when the subject is the radical transformation of the biome. According to Mapbiomas (2022), urbanized areas increased by 210% between 1985 and 2021, stimulated by urban expansion after the 1980s. The removal of vegetation cover to make way for cities and industries led to the degradation of the soil, contamination of groundwater, and loss of ecosystems and natural habitats of wild species in the cerrado (MAPBIOMAS, 2022).

Table 3 presents the 35 municipalities that compose the Triângulo Mineiro region and considers the combined data of forest (forest formation and cerrado) and agriculture (agriculture, forestry, and pasture). In general, there is a suppression of native vegetation to the detriment of an increase in areas occupied by agriculture in the municipalities. The municipalities that lost the most areas of native vegetation (> 30% loss) were Limeira do Oeste (45%), União de Minas (43%), Uberlândia (39%), Carneirinho (39%), São Francisco Sales (38%), Indianápolis (37%), Iturama (37%), Itapagipe (34%), Monte Alegre de Minas (33%), Santa Vitória (33%), Frutal (32%), Conceição das Alagoas (32%), and Uberaba (31%). The increase in agricultural areas ranged from 0% (Conquista) to 22% (Cascalho Rico).

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Table 3 - The annual land use and land cover at Brazilian cerrado municipalities in the Triângulo Mineiro region for the period 1985-2021

Municipality	Cover	1985	1990	1995	2000	2005	2010	2015	2020	2021	1985	2021
			-----ha-----								------%***------	
Araguari	Forest*	48.193	44.850	43.235	39.932	39.191	39.462	38.693	39.400	38.472	24.5	20.7
	Farming**	145.818	152.843	156.753	160.669	160.524	159.803	160.584	159.960	161.166	67.0	73.0
Campina Verde	Forest*	65.946	54.787	52.951	54.313	52.416	51.471	52.285	51.824	50.625	18.1	14.0
	Farming**	285.148	300.698	301.776	300.220	301.369	300.411	300.126	301.793	303.665	78.2	83.3
Campo Florido	Forest*	17.381	17.745	16.232	15.694	15.399	15.307	15.280	15.549	14.771	14.5	13.0
	Farming**	90.993	91.961	93.709	94.940	94.583	94.518	94.184	93.715	94.348	81.0	83.1
Carneirinho	Forest*	18.986	12.922	12.668	12.042	11.834	11.834	11.928	11.825	11.676	11.1	6.9
	Farming**	133.378	140.332	140.204	140.084	139.352	139.082	139.040	140.198	140.783	76.3	80.8
Cascalho Rico	Forest	6.670	6.591	6.107	5.389	5.338	5.193	5.141	5.223	5.093	18.2	14.0
	Farming	22.017	21.952	22.675	24.912	23.893	24.694	25.666	26.047	26.779	60.0	73.0
Centralina	Forest*	1.204	923	851	854	871	885	882	884	893	10.4	13.0
	Farming**	9.384	10.267	10.349	10.363	10.355	10.317	10.300	10.289	10.311	85.5	84.5
Com. Gomes	Forest*	17.677	16.489	15.432	15.766	15.616	16.194	17.049	18.167	17.562	17.0	17.0
	Farming**	82.373	84.362	85.272	85.733	85.625	84.853	83.771	82.874	83.331	79.1	80.1
Conc. das Alagoas	Forest*	6.304	5.316	4.921	4.790	4.634	4.598	4.571	4.565	4.305	9.0	8.3
	Farming**	42.674	44.663	45.065	45.365	45.427	45.363	45.260	45.235	45.526	82.1	84.0
Conquista	Forest*	838	755	721	702	740	742	760	756	756	16.4	15.0
	Farming**	3.488	3.582	3.615	3.596	3.556	3.557	3.541	3.556	3.573	82.0	82.0
Fronteira	Forest*	1.091	1.009	977	955	909	946	963	999	947	5.5	5.0
	Farming**	14.287	14.799	14.913	14.944	14.812	14.504	14.483	14.519	14.660	72.0	74.0
Frutal	Forest*	15.495	12.776	11.359	11.501	11.060	10.934	11.123	11.164	10.496	8.4	6.5
	Farming**	143.359	149.919	151.690	152.136	151.988	151.383	151.302	151.596	152.364	81.2	86.0
Gurinhatã	Forest*	31.831	27.717	26.382	26.109	25.475	25.393	25.546	25.377	25.025	19.0	16.0
	Farming**	127.920	133.716	134.996	135.185	135.425	134.092	134.822	135.222	136.251	77.0	81.4

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Indianópolis	Forest	13.729	12.262	11.252	9.441	8.769	8.914	8.904	8.890	8.691	16.5	10.5
	Farming	63.892	66.405	67.712	67.899	68.685	68.456	68.162	67.882	68.220	77.0	82.2
Itapagipe	Forest*	12.076	9.216	8.683	8.383	8.076	8.029	8.081	8.168	8.009	8.3	5.8
	Farming**	118.322	122.106	122.417	122.935	123.060	122.603	122.507	122.654	122.915	86.0	89.0
Ituiutaba	Forest*	45.074	38.727	37.587	35.365	34.187	34.226	33.757	34.235	33.498	19.4	15.0
	Farming**	173.191	184.211	185.119	187.710	189.057	187.860	188.159	187.544	188.590	75.9	81.4
Iturama	Forest*	8.231	5.204	5.005	5.041	5.114	5.060	5.370	5.263	5.189	7.4	5.2
	Farming**	85.843	90.406	90.333	89.909	89.236	88.821	88.393	88.907	89.199	80.1	83.0
Limeira do Oeste	Forest*	17.371	11.144	10.597	10.313	10.227	10.107	10.124	9.835	9.623	14.4	8.6
	Farming**	97.439	104.557	104.726	104.875	104.080	103.766	104.081	104.772	105.269	80.5	86.4
Monte A. de Minas	Forest*	40.214	33.421	28.529	27.635	27.365	27.393	27.575	27.891	26.914	16.3	11.3
	Farming**	187.412	200.646	206.104	207.697	207.820	207.447	206.859	206.350	207.432	75.8	83.4
Pirajuba	Forest*	345	396	356	364	395	411	420	408	336	5.7	7.6
	Farming**	9.336	9.412	9.410	9.470	9.412	9.373	9.349	9.377	9.434	90.0	88.2
Planura	Forest*	998	1.044	1.022	1.060	1.118	1.160	1.226	1.242	1.070	4.4	5.6
	Farming**	17.904	18.168	18.244	18.438	18.268	18.099	18.131	18.150	18.338	80.1	81.6
Prata	Forest*	77.561	71.329	64.176	62.770	62.890	64.603	67.201	68.780	65.741	16.0	13.6
	Farming**	374.410	385.222	395.376	399.123	398.451	395.869	393.920	391.648	394.388	77.2	81.4
Santa Vitória	Forest*	34.650	26.473	24.733	23.172	22.871	23.143	23.575	23.366	23.188	13.5	9.4
	Farming**	174.778	183.456	184.149	185.572	184.934	183.674	183.692	183.977	184.985	77.0	81.0
São Franc. Sales	Forest*	9.123	5.602	5.670	5.799	5.866	5.663	5.710	5.694	5.684	9.2	5.8
	Farming**	76.597	82.115	81.630	81.587	81.223	81.108	80.926	81.278	81.472	77.0	82.3
Tupaciguara	Forest*	17.918	14.814	13.514	13.269	13.170	13.368	13.346	13.316	13.026	15.5	13.1
	Farming**	82.413	87.031	88.352	88.722	88.497	88.043	87.874	87.983	88.409	70.0	75.5
Uberaba	Forest*	66.383	58.486	49.009	47.411	47.368	47.366	48.269	47.706	45.678	16.8	12.2
	Farming**	259.208	273.879	288.177	290.278	289.423	287.783	285.033	284.229	286.598	73.1	79.0

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Uberlândia	Forest*	79.571	67.312	56.357	52.929	52.505	51.958	50.950	50.850	48.749	20.2	13.0
	Farming**	272.365	290.588	304.032	308.059	308.047	305.607	304.733	302.921	304.226	68.0	75.3
União de Minas	Forest*	14.133	9.883	8.802	7.908	8.188	8.135	8.307	8.185	8.088	12.3	7.1
	Farming**	96.109	100.587	101.330	102.577	101.635	100.917	101.464	102.090	102.570	83.8	89.4
Veríssimo	Forest*	23.960	22.479	21.885	21.906	21.832	21.861	21.954	22.012	21.193	23.8	21.2
	Farming**	68.106	71.131	72.010	72.316	72.372	72.213	71.905	71.770	72.388	70.6	75.0

The municipalities of Água Comprida, Araporã, Cachoeira Dourada, Canápolis, Capinópolis, Delta, and Ipiaçu do not have data. *Consider the sum of forest formation and savanna formation. **Consider the sum of agriculture, a forest plantation, land use mosaic, and pasture. ***Percentage of areas at municipality covered by agriculture and forest, in 1985 and 2021. Source: adapted from Mapbiomas (2022).

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Comparatively, concerning the cerrado at a national level, the cerrado in Minas Gerais, and, specifically, in the Triângulo Mineiro, between 1985 and 2021, it is observed that the advance of the agricultural frontier, accompanied by the suppression of native vegetation, was more significant within the country or Minas Gerais than in the municipalities of the Triângulo Mineiro. This shows that this region already had an agricultural occupation model installed and consolidated before the period considered (1985-2021).

Figure 2 shows that the municipalities, in general, came from an occupation of the cerrado and transformation of its native cover by crops or pasture before the 1980s, which was consolidated during this period, keeping deforestation rates (in ha) high.

In the following decade (1990 onwards), the rates fell sharply and remained over the years, concomitantly leaving primary and secondary vegetation at negligible levels for several municipalities (< 10% of the original coverage), contradicting the minimum percentages required by the New Forest Code for the cerrado (35%), reasoning that if the percentage of native coverage in the municipality is low, invariably, the percentage of coverage on rural properties is also low. The analysis of Table 3 on the percentage of coverage in 1985 and 2021, the beginning and end of the historical series, respectively, shows that forest, savanna, and agricultural formations had low variation.

Among the various activities linked to agribusiness, sugar and alcohol production stands out in a relevant position concerning the occupation of the cerrado in the Triângulo Mineiro. Martins (2012) and Castillo (2015) discuss how important the sugar and alcohol sector has become in the world, as with the cultivation of sugar cane, it is possible to produce sugar and alcohol in addition to generating electricity. Martins (2012) also states that due to environmental issues, the need to use biodegradable fuels to produce energy came to the fore in the global discussion, and ethanol became a globally sought-after product. There was a high fiscal incentive from the Brazilian government for the expansion of sugar cane, which promoted the expansion of sugar and alcohol production plants throughout the region (PEREIRA, 2012).

According to data from Conab (2022), ethanol production in Brazil is currently concentrated in the Southeast and Central-West regions, located in the cerrado, which accounts for 90% of production. In the 2019-2020 harvest, the Southeast region produced more than 415 million tons of harvested sugar cane, indicating an increase of 3.7% compared to 2018-2019, while the Central-West region saw growth of 1.5% in the harvested area, occupying 1.8 million hectares.

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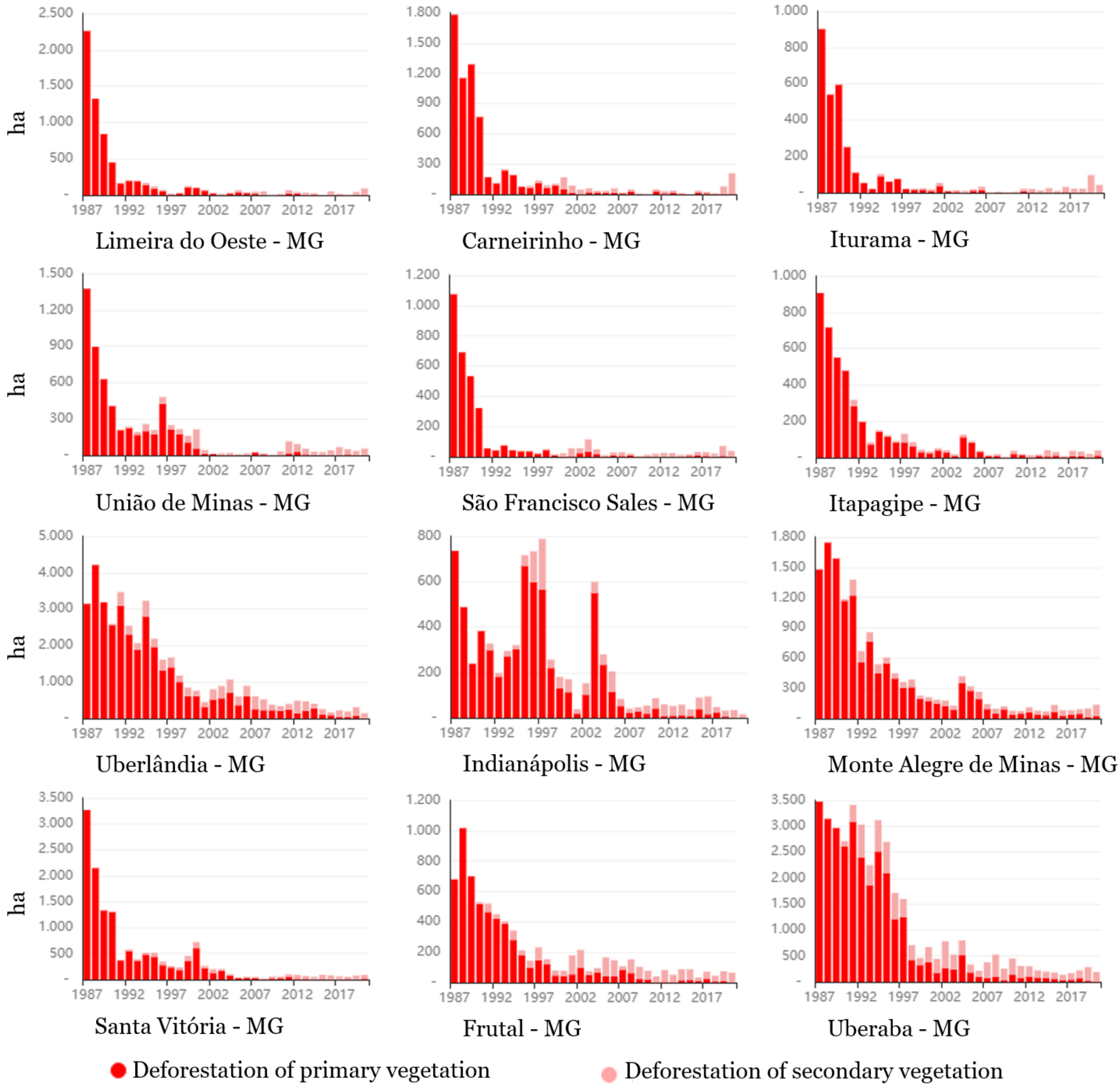
Figure 2 - The annual cerrado deforestation at some municipalities in the Triângulo Mineiro region



Source: adapted from Mapbiomas (2022).

Due to government incentives for the massive expansion of sugarcane cultivation, Góes et al. (2008) highlight that the Brazilian sugar and alcohol sector is considered the most technological in the world, being an expressive exporter of ethanol, which is a highly valued source due to environmental issues of minimizing the impacts generated by fossil fuels. However, the impacts of sugarcane production are still harmful to the environment and small producers.

With the expansion of this activity, in addition to the impacts generated on the natural environment, there is the deterritorialization of small producers forced to sell or lease their land to agribusiness companies, as well as seeing their production decrease due to environmental impacts in the vicinity of their properties, as in aerial spraying, for example. As

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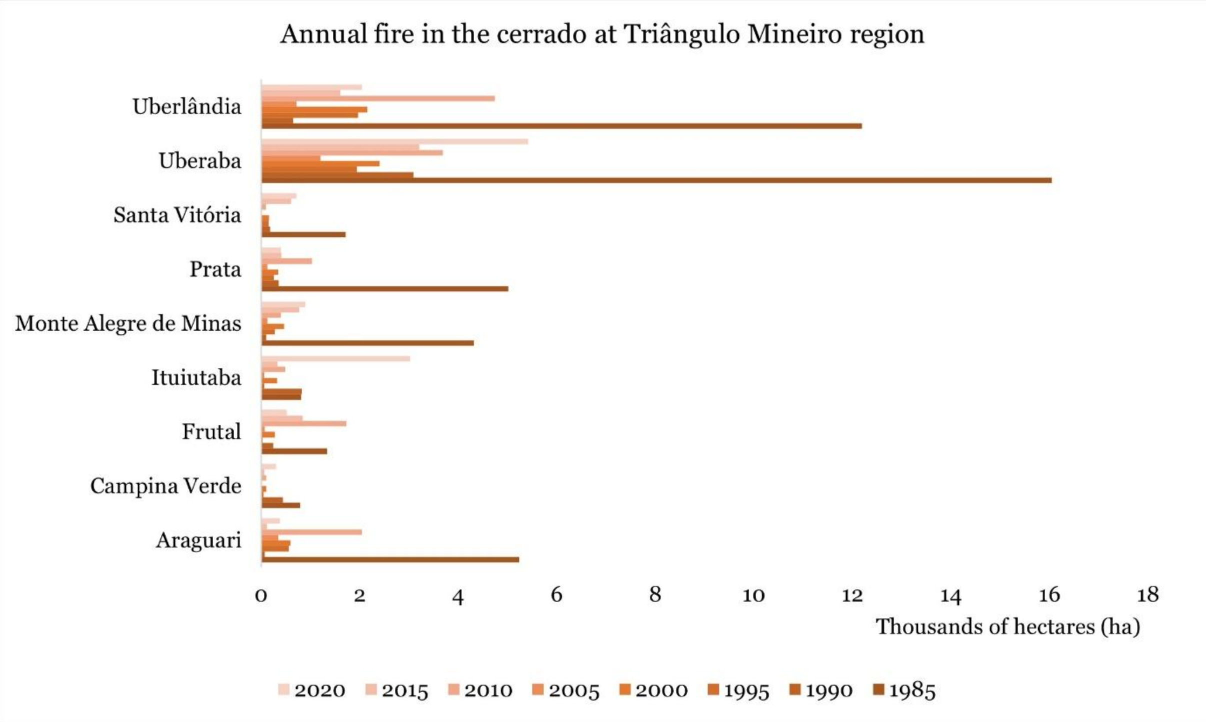
Cunha and Previtali (2014) and Ferreira (2015) highlight, the expansion of sugarcane cultivation and its presence as an export product is supported by the intensive use of chemical products, such as mineral fertilizers and pesticides, which are one of the main factors of eutrophication of rivers and lakes, acidification of soils, contamination of aquifers, and mass deaths of pollinators, such as bees, due to the pesticide spraying methods adopted, especially aerial spraying.

In addition to deforestation caused by clearing the vegetation using machinery and equipment, some fires are, on numerous occasions, caused intentionally by landowners, agribusiness companies, and rural workers (MOREIRA, 2000; ANDRADE, 2002; HOFFMANN; MOREIRA, 2002). According to the Mapbiomas Platform (2020), in 2019, the cerrado lost more than 7 million hectares to the fires that occurred throughout the biome. Considering the sum of the last 35 years, more than 241 million hectares of the cerrado have already been burned (MAPBIOMAS, 2020).

Due to its vegetational and climatic characteristics, the cerrado has a natural propensity to fire, which occurs most from June to October, a period in which the vegetation, for the most part, is dry due to drought in the region (Figure 3). However, the natural fire in the cerrado is sporadic, within a natural process of landscape evolution. Unlike the use of controlled fire to open areas, clear pastures, combat pests, and diseases, or belief that it is good for the land to set fire, doing so year after year, often in an untimely and uncontrolled manner.

Figure 3 - The annual fire in the cerrado at Triângulo Mineiro region for the period 1985-2020



Source: adapted from Mapbiomas (2022).

Figure 3 records the evolution of areas burned in the cerrado to give way to agricultural practices in some municipalities in the Triângulo Mineiro. The municipalities of Uberlândia and Uberaba are the ones that burned their areas the most, which is explained by their leading position in the region's agricultural production.

In 1985, both municipalities burned more than 28 thousand hectares of cerrado, following protocols and developmental policies from the public authorities for the occupation of interior lands in Brazil in the 1970s and 1980s. In a change of direction and return to the past, Brazil, in the last four years (2019 to 2022), completely changed its environmental policy,

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even celebrating the "fire day" in 2019, where farmers, encouraged by the high authorities of the country at the time, set fire to the rural areas of the cerrado and amazon, which will surely go down in the annals of history. As a reflection of this environmental policy, the year 2020, compared to 2015, saw an increase in fires, especially in Uberlândia, Uberaba, and Ituiutaba.

Even though it is a resilient biome with physiognomic characteristics adapted to fire, much is lost to the fires that affect the cerrado. There is a loss of native species that cannot regenerate, as well as local fauna, in addition to the exposure of the soil to the elements, which volatilizes its organic matter, contributing to the increase in CO^2 emissions into the atmosphere and, consequently, reduces microorganisms that use organic matter as an energy source.

Concerning the sustainability of water resources, it stands out not only due to the large amount of water used by sugarcane plants and crops, as well as other irrigated crops in the cerrado, such as soybeans (Table 4), but also due to the ever-present risk of releases (or leaks) of untreated effluents into rivers.

Table 4 - The annual irrigated area at Brazilian cerrado in the Minas Gerais State for the period 1985-2021

Cover	1985	1990	1995	2000	2005	2010	2015	2020	2021
	ha								
Citrus	-	9	0	74	892	1.188	1.783	2.070	2.178
Coffee	56	43	134	1.698	6.043	9.548	18.443	18.554	19.481
Other perennial crops	2.560	1.216	1.859	4.117	4.373	6.813	11.346	11.391	12.286
Soybeans	43	24.285	55.031	99.603	153.511	172.677	259.721	355.201	386.399
Sugar cane	317	238	179	48	216	9.195	17.773	22.311	24.058
Other temporary crops	18.044	36.799	44.723	44.848	57.083	73.860	73.960	66.271	80.455

Source: adapted from Mapbiomas (2022).

According to data from Mapbiomas, the coverage of water resources in the cerrado has decreased by 5% since 1985, as already discussed, due to severe droughts caused by climate change and the advance of irrigated crops. Even though the water surface gained around 11% in 2022, the biome continued to dry over the last 30 years. Thus, part of the loss of water surface in the cerrado is due to the increasing expansion of modern agriculture, which uses irrigation techniques that lead to intense waste of water in agriculture, which is mainly responsible for water consumption in recent years (ANA, 2005; LIMA; LIMA, 2007; MELO; SILVA, 2007).

Soil organic carbon at Brazilian cerrado

Globally, soil contains almost twice as much C as the atmosphere, plants, and animals combined, thus representing approximately 2500 Gt (soil), 800 Gt (atmosphere), and 560 Gt (plants and animals) (IPCC, 2019). From this amount of C in the soil, 1550 Gt is organic, and 950 Gt is inorganic (containing materials such as calcite, dolomite, and gypsum) (ONTL; SCHULTE, 2012). Organic carbon is much more dynamic and subject to changes in its quantity in a short time. Specifically for tropical savanna areas, the IPCC (2019) estimates a stock of 117t ha^{-1} of carbon in C in soils at the expense of 29t ha^{-1} of C in biomass, while for the cerrado in Brazil, Mapbiomas (2023) projects a reserve of 41t ha^{-1} of organic C in soils for a layer 0-30 cm deep.

Organic carbon is a vital soil component for the functionality of terrestrial ecosystems, with human activities in the last 150 years being a crucial factor in losses of organic C in the soil, especially in activities involving the replacement of native covers with pastures and crops

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(ONTL; SCHULTE, 2012; SANDERMAN et al., 2017), with notable effects on food security and climate change (LAL, 2020).

In Brazil, the largest changes in the C cycle in the soil and its consequent losses were identified in the cerrado (OLIVEIRA et al., 2023), also considered one of the 25 hotspots on the planet (MYERS et al., 2000). According to Guo and Gifford (2002), Ramankutty et al. (2002), Don et al. (2011), and Bonanomi et al. (2019), most changes in land use related to the replacement of natural vegetation for the expansion of modern agriculture in recent decades are usually followed by losses of C in the soil, principally when crop management substantially reduces the increase in biomass in the soil or increases the decomposition of organic carbon.

According to Karp et al. (2015) and Hunke et al. (2015), the principal factor in deforestation in tropical regions is the conversion of native vegetation to agricultural environments, and in a relatively short time, with significant changes in the physical and biogeochemical properties of cerrado soils. Such changes occur through a reduction in the input of organic matter that reaches the soil and, consequently, its incorporation (ASHAGRIE et al., 2007; MATIAS et al., 2009; SIQUEIRA-NETO et al., 2010; DON et al., 2011; CORBEELS et al., 2016).

In the cerrado, Oliveira et al. (2023) calculated soil C stocks for a depth of 0-10 cm, with average results obtained from 37.5 ± 23.0 Mg ha^{-1} in areas with native vegetation to 18.5 ± 10.0 Mg ha^{-1} in areas under deforestation. According to the authors, pastures, and crops (in the crop-livestock-forest system) showed a similar soil C stock at this depth, with values approximately 22% lower than those observed for native vegetation. For soil layers of 0-30 cm and 0-50 cm, C stocks in areas under native vegetation were estimated on average at 60.7 ± 26.6 and 86.9 ± 45.1 Mg ha^{-1}, respectively. At a depth of 0-1 m, areas of native vegetation maintain the largest reserves of C in cerrado soils, with an average of 128.8 ± 55.0 Mg ha^{-1}, equivalent to 24 Gt of C. As pointed out, annual crops under the crop-livestock-forest system can potentially accumulate C in the soil and partially reverse C losses after the conversion of native vegetation (OLIVEIRA et al., 2023).

Table 5 demonstrates that studies in different areas of the cerrado indicate that it is among the biomes that lost the most C, from 2002 to 2023, the focus of modern agriculture in Brazil. In this sense, the results indicate that the highest carbon losses occurred in the 0 - 20cm depth layer of soil and were caused by different land uses, including conventional agriculture and extensive livestock farming.

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Table 5 - Studies regarding organic carbon losses in soils at cerrado from the turning of native vegetation by grazing and cropping lands

Authors	Study area	Estimative of organic carbon losses in the soil after replacement of native cerrado	Note
*Guo e Gifford (2002)	Tropical, subtropical, and temperate areas in the world	42%	Based on analyses of revised metadata from 74 papers, the authors indicated that soil carbon stock declines whenever there is a change in land use, with maximum losses when pastures and native forests are replaced by crops.
*Murty et al. (2002)	Tropical, subtropical, and temperate areas in the world	30%	The authors showed that the replacement of native forests by crops leads to a loss of soil carbon.
Araújo et al. (2007)	Fazenda Água Limpa-DF	10%	They studied the losses of soil organic matter, in g kg^{-1}, at 0-30cm depth in a Red-Yellow Oxisol after conversion of native C cerrado vegetation by conventional planting.
Siqueira-Neto et al. (2010)	Rio Verde-GO Montividiu-GO Santa Helena de Goiás-GO	1.5 kg m^{-2}	The authors analyzed carbon losses at cerrado Oxisols ten years after the replacement by agricultural systems. They also evaluated the effectiveness of the no-tillage system in improving carbon stock in soils.
Rosolen et al. (2012)	Triângulo Mineiro	0.9%	The authors analyzed carbon losses in Oxisols with clayey to sandy texture at 0-30cm depth after replacing native vegetation with conventional planting and pasture.
Mendes (2015)	Maranhão State	1.57 Mt	The carbon losses were analyzed in soils in the State of Maranhão, Brazil, until 2010, at 0-30cm depth, due to the replacement of native cover by agriculture. The biome areas studied were amazon (35%), caatinga (1%), and cerrado/savanna (64%).
Gmach et al. (2018)	Uruçuí-PI	Up to 45%	The authors studied the losses and differences in soil carbon stocks at 0-40cm depth in crops with the no-tillage system, pasture, and forest plantation, (eucalyptus).
Horák-Terra et al. (2022)	Bonfinópolis-MG	22%	They studied soil carbon losses at 0-20cm depth in an anthropized/drained vereda (hydromorphic savanna). The soils sampled were Organosol and Gleisol.
Oliveira et al. (2023)	Some areas of cerrado	22%	The research reviewed 87 papers and 1156 data about C stock, which analyzed C losses/recovery at soils of cerrado for the four main soil management systems used in the biome.
Ribeiro et al. (2023)	Francisco Sá-MG Curvelo-MG	33 Mg ha^{-1} 54 Mg ha^{-1}	Utilizing the Century model, they studied the soil carbon stock losses at 0-20cm depth due to the replacement of the native vegetation, with a projection for the next 100 years. The soil analyzed from Francisco Sá was an Inceptisol and from Curvelo, a Red Oxisol.

*Study in different areas of native vegetation around the world.

Unoptimistic projections reveal a disturbing future for the biome if there is no change in its occupation in the coming years. It is estimated that a large part of the soils in the cerrado will be degraded and with low quantity and quality of organic matter due to the almost complete replacement of native cover, especially in the states of Minas Gerais, Goiás, Mato Grosso, and Mato Grosso do Sul. In addition to the damage to the soil, there is also climate change caused by the intense release of carbon into the atmosphere, which occurs with the

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conversion of native vegetation areas into agriculture - factors identified as the principal causes of greenhouse gas emissions by the agricultural sector (CARVALHO et al., 2014; FUJISAKI et al., 2015; DURIGAN et al., 2017; CERRI et al., 2018).

According to Table 6, compiled from data from Mapbiomas (2023), carbon stocks in Brazil and some municipalities in the Triângulo Mineiro analyzed, considering the 0-30 cm deep layer, had a slight increase in these stocks over the years. This fact, in a first analysis, contradicts what has been found in the literature regarding the organic carbon reserve of cerrado soils since the replacement of the biome's native cover by crops and pastures has caused a drop in the organic matter, especially in the 0-20 cm deep layer.

Table 6 - The annual soil organic carbon pool at some Brazilian cerrado municipalities in the Triângulo Mineiro region, considering 0 - 30 cm depth, for the period 1985-2021

Country and municipality	1985	1990	1995	2000	2005	2010	2015	2020	2021
	Gt*								
Brazil (all cerrado)	7.94	7.96	7.95	7.96	7.98	8.08	8.17	8.15	8.13
	Mt**								
Araguari	14.37	14.64	14.65	14.71	14.74	14.84	15.03	14.97	14.94
Campina Verde	11.25	11.41	11.45	11.26	11.51	11.69	12.02	11.83	11.73
Frutal	8.14	8.37	8.34	8.23	8.34	8.47	8.65	8.56	8.52
Ituiutaba	8.36	8.42	8.44	8.36	8.47	8.63	8.77	8.74	8.66
Monte Alegre de Minas	11.16	11.31	11.26	11.20	11.32	11.54	11.60	11.59	11.53
Prata	16.70	17.11	17.00	16.79	17.07	17.37	17.70	17.61	17.49
Santa Vitória	8.23	8.31	8.29	8.21	8.37	8.58	8.80	8.65	8.59
Uberaba	27.42	27.69	27.66	27.69	27.96	28.19	28.30	28.12	28.08
Uberlândia	21.37	21.61	21.41	21.37	21.50	21.78	21.73	21.64	21.56

*Gt (gigaton); **Mt (megaton). Source: adapted from Mapbiomas (2022).

However, the analysis of the Mapbiomas (2023) database (the beta version) found that it was created with the inclusion of profile data collected by external users, who supplied it from the SoilData repository, creating a need to apply models to spatialize the results and define estimates of carbon stocks for other areas of the cerrado not covered by soil collections, some of which represent ample gaps in data.

Another point to consider is the collected areas. Several were already anthropically modified when monitoring began (1985) until 2021— or even the expansion of these anthropic areas in the biome. In other words, the same agricultural area that had soil collected in 2021 was probably also an agricultural area in 1985, therefore not characterizing an area that had the replacement of native vegetation cover (in 1985) by crops and pastures (in 2021), generating data more similar over the years, with a slight increase in 2021, perhaps due to some improvement in the soil management system (use of direct planting, for example). However, regardless of these reflections, it is an important material, easily accessible, and useful for complementary studies regarding organic matter stocks in cerrado soils.

Various studies point to strategies to mitigate organic carbon losses due to land use changes (MINASNY et al., 2017; LAL, 2019; LORENZ et al., 2019; YANG et al., 2019). New technologies and intelligent cultivation methods are currently widespread, such as the direct planting system, crop-livestock-forest integration, the recovery of degraded pastures, and the use of nanotechnologies such as metal-organic frameworks (MOFs), remineralizers, and bio-inputs. These strategies can be used to improve soil quality and the storage of CO in cerrado soils. Oliveira et al. (2023) point out that such practices are essential and have been widely adopted in areas of the biome. Gmach et al. (2018) highlighted that the recovery of pasture areas represents an important practice, with the best results in maintaining and storing CO in the soil.

While some of these response options have immediate impacts, others take decades to produce measurable results. Examples that provide multiple ecosystem services and functions but take longer to show results include reforestation and restoration of high-carbon ecosystems, agroforestry, and restoration of degraded soils (IPCC, 2019).

According to the IPCC (2019), given the specific local nature of climate change impacts on food system components and the considerable variations in agroecosystems, adaptation and mitigation options and their barriers are related to the environmental and cultural context at regional and local levels. In this sense, increasing food productivity and dietary choices and reducing waste can also reduce the demand for the conversion of native vegetation to crops to promote the sustainability of soils, which function as major carbon sink on the planet, also acting as thermometers of climate change at a global level.

Conclusions

The cerrado, in general, has been replaced by large-scale agriculture in the last 35 years, and its areas have shrunk by 25% in this period (considering only the cerrado stricto sensu).

The increase in pasture and agricultural areas in the Brazilian cerrado corresponds to 23% and 621%, respectively, in the period from 1985 to 2021, and the use and coverage of cerrado soils in the Triângulo Mineiro follow the same way as the rest of the country regarding the expansion of agriculture.

In the opposite direction of areas occupied by agriculture, livestock, and forest plantations, water bodies showed a reduction of 5% in the same period, and hydromorphic environments decreased by 3%, corroborating the premise that the Brazilian cerrado is drying out.

Most municipalities of the Triângulo Mineiro came from an occupation of the cerrado and transformation of its native cover by crops or pasture before the 1980s, which was consolidated during this period, maintaining high deforestation rates (in ha).

The loss of soil C (~22%) usually follows the extensive changes in land use related to the replacement of native cerrado vegetation for the expansion of modern agriculture in recent decades. In contrast, annual crops under the crop-livestock-forest system can potentially accumulate C in the soil and partially reverse C losses after converting native vegetation.

Results pointed out by Annual Mapping of Soil Organic Carbon Stock in Brazil, 2023 (Mapbiomas - beta version) had a slight increase in these stocks over the years. This fact contradicts what has been found in the literature regarding the organic carbon sink of cerrado soils since the replacement of the biome's native cover by crops and pastures has caused a drop in the organic matter, especially into the 0-20 cm deep layer.

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References

AB'SABER, A. N. **Domínios de natureza no Brasil**: potencialidades paisagísticas. São Paulo: Ateliê Editorial, 2003.

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INSTITUTO DE CIÊNCIAS HUMANAS DO PONTAL
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ALENCAR, A.; SHIMBO, J. Z.; LENTI, F.; BALZANI MARQUES, C.; ZIMBRES, B.; ROSA, M.; ARRUDA, V.; CASTRO, I.; FERNANDES MÁRCICO RIBEIRO, J. P.; VARELA, V.; ALENCAR, I.; PIONTEKOWSKI, V.; RIBEIRO, V.; M. C. BUSTAMANTE, M.; EYJI SANO, E.; BARROSO, M. Mapping three decades of changes in the Brazilian savanna native vegetation using Landsat data processed in the Google Earth Engine platform. **Remote Sensing**, v. 12, n. 6, 2020. DOI: 10.3390/rs12060924

ANA-Agência Nacional das Águas. Disponibilidade e demandas de recursos hídricos no Brasil. Estudo Técnico. **Caderno de Recursos Hídricos**. Brasília: ANA, 2005. 123 p.

ANDRADE, L. A. Z. **Impacto do fogo no banco de sementes de cerrado sensu stricto**. Dissertação de Doutorado. Universidade de Brasília, Brasília, 2002.

ARAÚJO, R.; GOEDERT, W. J.; LACERDA, M. P. C. Qualidade de um solo sob diferentes usos e sob cerrado nativo. **Revista Brasileira de Ciência do Solo**, v.31, p.1099-1108, 2007.

ASHAGRIE, Y.; ZECH, W.; GUGGENBERGER, G.; MAMO, T. Soil aggregation, and total and particulate organic matter following conversion of native forests to continuous cultivation in Ethiopia. **Soil Tillage Research Journal**, v.94, p.101-108, 2007.

BALESTRO, M. V.; SAUER, S. A diversidade no rural, transição agroecológica e caminhos para a superação da Revolução Verde: introduzindo o debate. In: SAUER, S.; BALESTRO, M. V. **Agroecologia**: os desafios da transição agroecológica. Expressão Popular. p. 7-16, 2009.

BEUCHLE, R.; GRECCHI, R. C.; SHIMABUKURO, Y. E.; SELLINGER, R.; EVA, H. D.; SANO, E.; ACHARD, F. Land cover changes in the Brazilian Cerrado and Caatinga biomes from 1990 to 2010 based on a systematic remote sensing sampling approach. **Applied Geophysics**, v. 58, p. 116-127, mar. 2015.

BONANOMI, J.; TORTATO, F. R; GOMES, R. S. R.; PENHA, J. M.; BUENO, A. S.; PERES, C. A. Protegendo florestas em detrimento de campos nativos: política de uso da terra incentiva perda de habitat aberto no Bioma Cerrado brasileiro. **Revista Perspectivas em Ecologia e Conservação**, v.17, p.26-31, 2019.

BRANDÃO, C. A. **Triângulo Capital Comercial, Geopolítica e Agroindústria**. 1989. Dissertação – Centro de Desenvolvimento e Planejamento Regional, Universidade Federal de Minas Gerais, Belo Horizonte, 1989.

CANILLAS, E. C.; SALOKHE, V. M. A decision support system for compaction assessment in agricultural soils. **Soil Tillage Research**, v. 65, p. 221-230, 2002. DOI: 10.1016/S0167-1987(02)00002-8

CARVALHO, J. L. N.; RAUCCI, G. S.; FRAZÃO, L. A.; CERRI, C. E. P.; BERNOUX, M.; CERRI, C. C. Crop-pasture rotation: A strategy to reduce soil greenhouse gas emissions in the Brazilian Cerrado. **Agriculture Ecosystems and Environment**, v. 183, p. 167-75, 2014.

CASTILLO, R. Dinâmicas recentes do setor sucroenergético no Brasil: competitividade regional e expansão para o bioma cerrado. **Revista Geographia**, n. 35, p. 95-119, 2015.

CERRI, C. E. P.; CERRI, C. C.; MAIA, S. M. F.; CHERUBIN, M. R.; FEIGL, B. J.; LAL, R.

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BRAZILIAN GEOGRAPHICAL JOURNAL
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DOI: https://doi.org/10.14393/BGJ-v14n2-a2023-72532

Reducing Amazon Deforestation through Agricultural Intensification in the Cerrado for Advancing Food Security and Mitigating Climate Change. **Sustainability J**., v. 10, p.989, 2018. DOI: 10.3390/su10040989

CLEPS Jr, J. Concentração de poder no agronegócio e (des)territorialização: os impactos da expansão recente do capital sucroalcooleiro no Triângulo Mineiro. **Caminhos de Geografia**, v. 10, n. 31, p. 249-264, 2009.

CONAB-Companhia Nacional de Abastecimento. Acompanhamento da Safra Brasileira de Grãos, Brasília, DF, v. 10, safra 2022/23, n. 1º primeiro levantamento, 2022.

CORBEELS, M.; MARCHÃO, R.L.; SIQUEIRA-NETO, M.; FERREIRA, E.G., MADARI, B.E.; SCOPEL, E.; BRITO, O.R. Evidence of limited carbon sequestration in soils under no-tillage systems in the cerrado of Brazil. **Scientific Reports**, v.6, p.1-8, 2016.

COSTA, L. M.; NACIF, P. G. S.; COSTA, O. V.; OLSZEVSKI, N. Manejo dos solos na região dos cerrados. In: ARAÚJO, Q. R., editor. **500 anos de uso do solo no Brasil**. Ilhéus: Editus, 2002. p. 201-218.

COSTA, M. H.; BOTTA, A.; CARDILLE, J. Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. **Journal of Hydrology**, v. 283, p. 206- 217, 2003.

CPRM - Serviço Geológico do Brasil. Mapa Geológico do Estado de Minas Gerais. Escala 1:1.000.000, 2003.

CUNHA, N. R. S.; LIMA, J. E.; GOMES, M. F. M.; BRAGA, M. J. A intensidade da exploração agropecuária como indicador da degradação ambiental na região dos Cerrados, Brasil. **Rev. Econ. Sociol. Rural**, v. 46, n. 2, p. 291-323, 2008.

CUNHA, T. R; PREVITALI, F. S. Expansão do etanol e impactos socioambientais no Brasil do século XXI. **Horizonte Científico**, v. 8, n. 1, p. 1-20, 2014.

DON, A., SCHUMACHER, J., FREIBAUER, A. Impact of Tropical Land-use Change on Soil Organic Carbon Stocks - A meta-analysis. **Global Change Biology**, v.17, p.1658-1670, 2011.

DURIGAN, M. R.; CHERUBIN, M. R.; CAMARGO, P. B.; FERREIRA, J. N.; BERENGUER, E.; GARDNER, T. A.; BARLOW, J.; DIAS, C. T. S.; SIGNOR, D.; OLIVEIRA, R. C.; CERRI, C. E. P. Soil organic matter responses to anthropogenic forest disturbance and land use change in the eastern Brazilian Amazon. **Sustainability J**., v. 9, p. 379, 2017.

FERREIRA, M. L. P. C. A pulverização aérea de agrotóxicos no Brasil: cenário atual e desafios. **Revista de Direito Sanitário**, v. 15, p. 18-45, 2015.

FUJISAKI, K.; PERRIN, A. S.; DESJARDINS, T.; BERNOUX, M.; BALBINO, L. C.; BROSSARD, M. From forest to cropland and pasture systems: A critical review of soil organic carbon stocks changes in Amazonia. **Global Change Biology J**., v.21, p. 2773-2786, 2015.

GMACH, M. R.; DIAS, B.; SILVA, C.; NÓBREGA, J.; LUSTOSA FILHO, J. F.; NETO, M. Soil organic matter dynamics and land-use change on Oxisols in the Cerrado, Brazil. **Geoderma**, v. 14, p.1-8, 2018.

ISSN 2179-2321
UNIVERSIDADE FEDERAL DE UBERLÂNDIA
INSTITUTO DE CIÊNCIAS HUMANAS DO PONTAL
Articles | Artigos | Artículos | Articles
DOI: https://doi.org/10.14393/BGJ-v14n2-a2023-72532

GOEDERT, W. J. Região dos Cerrados: potencial agrícola e política para seu desenvolvimento. **Pesquisa Agropecuária Brasileira**, v. 24, n. 1, p. 1-17, 1989.

GÓES, T.; MARRA, R.; SILVA, G. S. E. Setor sucroalcooleiro no Brasil: Situação atual e perspectivas. **Revista de Política Agrícola**, n. 2, p. 39-51, 2008.

GUO, L. B.; GIFFORD, R. M. Soil carbon stocks, and land use change: a meta-analysis. **Global Change Biology**, v. 8, p. 345-360, 2002. DOI: 10.1046/j.1354-1013.2002. 00486.x

HOFFMANN, W. A.; MOREIRA, A. G. The role of fire in population dynamics of woody plants. The cerrados of Brazil: ecology and natural history of a neotropical savanna, Columbia University Press, p.159-177, 2002.

HORÁK-TERRA, I.; TERRA, F. S.; LOPES, A. K. A.; DOBBSS, L. B.; FONTANA, A.; SILVA, A. C.; VIDAL-TORRADO, P. Soil characterization and drainage effects in a savanna palm swamp (vereda) of an agricultural area from Central Brazil. **Revista Brasileira de Ciência do Solo**, v. 46, e0210065, 2022.

HUNKE, P.; ROLLER, R.; ZEILHOFER, P.; SCHRÖDER, B.; MUELLER, E. N. Soil Changes Under Different Land-uses in the Cerrado of Mato Grosso. Brazil. **Geoderma Regional J**., v. 4 p. 31-43, 2015.

INMET - Instituto Nacional de Meteorologia. Gráficos Climatológicos, 2022. Disponível em: portal.inmet.gov.br/servicos/graficos-climatologicos.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Malha Municipal Digital e Áreas Territoriais 2022. Rio de Janeiro: IBGE, 2022. Disponível em: https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. COORDENAÇÃO GERAL DE OBSERVAÇÃO DA TERRA. PROGRAMA DE MONITORAMENTO DA AMAZÔNIA E DEMAIS BIOMAS. **Limite do Bioma Cerrado**. Disponível em: https://terrabrasilis.dpi.inpe.br/downloads/.

IPCC - Intergovernmental Panel on Climate Change. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. UK: Cambridge University Press, 2019. 896 p. DOI: 10.1017/9781009157988

KARP, D. S; TALLIS, H.; SACHSE, R.; HALPERN, B.; THONICKE, K.; CRAMER, W.; MOONEY, H.; POLASKY, S.; TIETJEN, B.; WAHA, K.; WALZ, A.; WOLNY, S. National Indicators for Observing Ecosystem Service Change. **Global Environmental Change J**., v. 35, p. 12-21, 2015.

KLINK, C. A.; MACHADO, R. B. A conservação do Cerrado brasileiro. In: Megadiversidade, desafios e oportunidades para a conservação da biodiversidade no Brasil. **Revista Conservação Internacional**, v.1, p.147-155, 2005.

LAL, R. Promoting “4 Per Thousand” and “Adapting African Agriculture” by south-south cooperation: Conservation agriculture and sustainable intensification. **Soil and Tillage Research J**., v. 188, p. 27-34, 2019.

ISSN 2179-2321
UNIVERSIDADE FEDERAL DE UBERLÂNDIA
INSTITUTO DE CIÊNCIAS HUMANAS DO PONTAL
Articles | Artigos | Artículos | Articles
DOI: https://doi.org/10.14393/BGJ-v14n2-a2023-72532

LAL, R. Food security impacts of the "4 per Thousand" initiative. **Geoderma**, v. 374, e114427, 2020. DOI: 10.1016/j.geoderma.2020.114427

LIMA, V. C.; LIMA, M. R. Formação do solo. In: LIMA, V. C.; LIMA, M. R.; MELO, V. F. **O solo no meio ambiente**: abordagem para professores do ensino fundamental e médio e alunos do ensino médio. Curitiba: Universidade Federal do Paraná, Departamento de Solos e Engenharia Agrícola, p. 1-10, 2007.

LORENZ, K.; LAL, R.; EHLERS, K. Soil organic carbon stock as an indicator for monitoring land and soil degradation in relation to United Nations' Sustainable Development Goals. **Land Degradation and Development J**., v. 30, p. 824-38, 2019.

MAPBIOMAS. Coleção 7.1 da Série Anual de Mapas da Cobertura e Uso do Solo do Brasil, 2022. Acessado em 23/11/2022 por meio do link: https//plataforma.brasil.mapbiomas.org

MAPBIOMAS. Mapeamento Anual do Estoque de Carbono Orgânico do Solo no Brasil 1985-2021 (coleção beta), 2023. DOI: 10.58053/MapBiomas/DHAYLZ, MapBiomas Data, V1"

MAPBIOMAS. Relatório Anual do Desmatamento no Brasil 2019. São Paulo: MapBiomas, 2020, 49 páginas.

MARTINS, R. R. **Panorama do Cultivo da Cana-de-Açúcar e suas Consequências na Região do Triângulo Mineiro**. 2012. 54 f. Monografia de Final de Curso - Curso de Ciências Sociais, Universidade Federal de Uberlândia, Uberlândia, 2012.

MATIAS, M. D. C. B.; SALVIANO, A. A. C.; CARVALHO LEITE, L. F.; ARAÚJO, A. S. F. Biomassa microbiana e estoques de C e N do solo em diferentes sistemas de manejo, no cerrado do estado do Piauí. **Acta Scientiarum Agronomy**, v. 31, p. 517-521, 2009.

MENDES, T. J. **Estimativa da variação do estoque de carbono do solo em diferentes cenários de uso e manejo agropecuário no estado do Maranhão**. 2015. 52 p. Tese (doutorado) - Universidade Estadual Paulista Júlio de Mesquita Filho, Faculdade de Ciências Agrárias e Veterinárias de Jaboticabal, 2015.

MINASNY, B.; MALONE, B. P.; McBRATNEY, A. B.; ANGERS, D. A.; ARROUAYS, D.; CHAMBERS, A.; CHAPLOT, V.; CHEN, Z.S.; CHENG, K.; DAS, B.S.; FIELD, D. J.; GIMONA, A.; HEDLEY, C. B.; HONG, S. Y.; MANDAL, B.; MARCHANT, B. P.; MARTIN, M.; McCONKEY, B. G.; MULDER, V. L.; O'ROURKE, S.; RICHER-DE-FORGES, A. C.; ODEH, I.; PADARIAN, J.; PAUSTIAN, K.; PAN, G.; POGGIO, L.; SAVIN, I.; STOLBOVOY, V.; STOCKMANN, U.; SULAEMAN, Y.; TSUI, C. C.; VÅGEN, T. G.; van WESEMAEL, B.; WINOWIECKI, L. Soil carbon 4 per mille. **Geoderma**. v. 292, p. 59-86, 2017.

MOREIRA, A. G. Effects of Fire Protection on Savanna Structure in Central Brazil. **Journal of Biogeography**, v. 27, p. 1021-1029, 2000.

MÜLLER, C. **Expansion and modernization of agriculture in the cerrado – the case of soybeans in Brazil's Center-West**. Department of Economics Working Paper 306, Universidade de Brasília, Brasília, 2003.

MURTY, D.; KIRSCHBAUM, M. U. F.; MCMURTRIE, R. E.; MCGILVRAY, H. Does conversion of forest to agricultural land change soil carbon and nitrogen? a review of the literature. **Global Change Biology**, v. 8, n. 2, p. 105-123, 2002. DOI: 10.1046/j.1354-1013.2001. 00459.x

ISSN 2179-2321
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INSTITUTO DE CIÊNCIAS HUMANAS DO PONTAL
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DOI: https://doi.org/10.14393/BGJ-v14n2-a2023-72532

MYERS, N.; MITTERMEIER, R. A.; MITTERMEIER, C. G.; FONSECA, G. A.; KENT, J. Biodiversity Hotspots for Conservation Priorities. **Nature,** v. 403, p. 853-858, 2000.

OLIVEIRA, D. M. S.; TAVARES, R. L. M.; LOSS, A.; MADARI, B. E.; CERRI, C. E. P.; ALVES, B. J. R.; PEREIRA, M. G.; CHERUBIN, M. R. Climate-smart agriculture and soil C sequestration in Brazilian Cerrado: a systematic review. **Revista Brasileira de Ciência do Solo**, v. esp. 47, e0220055, 2023. DOI: 10.36783/18069657rbcs20220055

OLIVEIRA, R. S.; BEZERRA, L.; PINTO, F.; KLINK, C. A.; NEPSTAD, D. C.; DAVIDSON, E. A.; MOREIRA, A. G. Deep Root Function in Soil Water dynamics in Cerrado Savannas of central Brazil. **Functional Ecology J.**, v. 19, p. 574-581, 2005.

ONTL, T. A.; SCHULTE, L. A. Soil carbon storage. **Nature Educ. Knowledge**. v. 3, n. 10, p. 35, 2012.

PEREIRA, M. F. V. As cidades da cana no Triângulo Mineiro: Para uma discussão das implicações territoriais do agronegócio e de seus nexos urbanos. In: Encuentro de Geógrafos de América Latina - EGAL. Havana, 2015.

PEREIRA, M. F. V. Os agentes do agronegócio e o uso do território no Triângulo Mineiro/Alto Paranaíba: Da moderna agricultura de grãos à expansão recente da cana-de-açúcar. **Revista do Departamento de Geografia**, v. 23, p. 83-104, 2012.

PEREIRA, T. T. C.; ALMEIDA. I. C. C; OLIVEIRA. F. S.; SCHAEFER. C. E. G. R.; PINHEIRO. L. S.; MATUK. F. A. Hydropedology of a High Tableland with Cerrado, Brazilian Central Plateau: the Frutal Catchment Case Study. **Revista Brasileira de Ciência Solo**, Viçosa-MG, v. 42, p. 1-16, 2018.

PEREIRA, T. T. C.; FIGUEIREDO, L. P. S. Veredas do Triângulo Mineiro: estudos de solos e significância socioambiental. **Rev. Geo. Acadêmica**, v. 12, n. 2, 2018.

PESSÔA, V. L. S. **Ação do Estado e as Transformações Agrárias no Cerrado das Zonas de Paracatu e Alto Paranaíba, MG**. 1988. Tese (Doutorado em Geografia) - Instituto de Geociências e Ciências Exatas, Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro, p.143, 1988.

RAMANKUTTY, N.; FOLEY, J. A.; OLEJNICZACK, N. J. Peoples on the land: Changes in global population and croplants during the 20th century. **AMBIO**: A Journal of the Human Environment, v. 31, p. 251-257, 2002.

REATTO, A.; CORREIA, J. R.; SPERA, S. T. Solos do bioma cerrado: aspectos pedológicos. In: SANO, S. M.; ALMEIDA, S. P. (Ed.). **Cerrado**: ambiente e flora. Planaltina: EMBRAPA-CPAC, p. 47-86, 1998.

RESENDE, M. 500 anos de uso do solo no Brasil. In: ARAÚJO, Q. R. (ed). **500 anos de uso do solo no Brasil**. Ilhéus: Editus, 2002. p. 1-49.

RIBEIRO, J. M.; FREITAS, I. G.; BRITO, B. G. S.; FERNANDES, L. A.; LEITE, L. F. C.; BARBOSA, D. L. A.; SANTOS, M. V.; CERRI, C. E. P.; FRAZÃO, L. A. Agrosilvopastoral system as a potential model for increasing soil carbon stocks: a century model approach. **Revista Brasileira de Ciência do Solo**, v. 47, e0220136, 2023. DOI: 10.36783/18069657rbcs20220136

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ROSOLEN, V.; RESENDE, T. M.; BORGES, E. N.; FRARE, C. T.; MACHADO, H. A. Impactos da substituição da vegetação original do Cerrado brasileiro em sistemas agrícolas: alteração do carbono orgânico do solo e δ13C. **Investigaciones geográficas**, v. 79, p. 39-47, 2012.

SANDERMAN, J.; HENGL, T.; FISKE, G. J. Soil carbon debt of 12000 years of human land use. **Proc Natl Acad Sci**. v. 114, p. 9575-80, 2017. DOI: 10.1073/pnas.1706103114

SIQUEIRA-NETO, M.; SCOPEL, E.; CORBEELS, M.; CARDOSO, A. N.; DOUZET, J. M.; FELLER, C.; PICCOLO, M. C.; CERRI, C. C.; BERNOUX, M. Soil carbon stocks under no-tillage mulch-based cropping systems in the Brazilian Cerrado: An on-farm synchronic assessment. **Soil and Tillage Research**, v. 110, n. 1, p. 187-195, 2010.

SOUZA Jr., C. M.; SHIMBO, J. Z.; ROSA, M. R.; PARENTE, L. L.; ALENCAR, A.; RUDOR, B. F. T.; HASENACK, H.; MATSUMOTO, M.; FERREIRA, L. G.; SOUZA-FILHO, P. W. M.; OLIVEIRA, S. W.; ROCHA, W. F.; FONSECA, A. V.; MARQUES, C. B.; DINIZ, C. G.; COSTA, D.; MONTEIRO, D.; ROSA, E. R.; VÉLEZ-MARTIN, E.; WEBER, E. J.; LENTI, F. E. B.; PATERNOST, F. F.; PAREYN, F. G. C.; SIQUEIRA, J. V.; VIERA, J. L.; FERREIRA NETO, L. C.; SARAIVA, M. M.; SALES, M. H.; SALGADO, M. P. G.; VASCONCELOS, R.; GALANO, S.; MESQUITA, V. V.; AZEVEDO, T. Reconstructing three decades of land use and land cover changes in Brazilian biomes with Landsat archive and Earth Engine. **Remote Sens.**, v. 12, 2735, 2020. DOI: 10.3390/rs12172735

SOUZA, L. C. E. **O agronegócio da pecuária no Triângulo Mineiro/Alto Paranaíba**: relações de poder e políticas públicas de 1990 a 2010. 2013. 104 f. Dissertação Mestrado em Ciências Sociais em Desenvolvimento, Agricultura e Sociedade - Instituto de Ciências Sociais Aplicadas, Universidade Federal Rural do Rio de Janeiro, Rio de Janeiro-RJ, 2013.

YANG, Y.; TILMAN, D.; FUREY, G.; LEHMAN, C. Soil carbon sequestration accelerated by restoration of grassland biodiversity. **Nature Communications J.**, v.10, p.718, 2019.

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