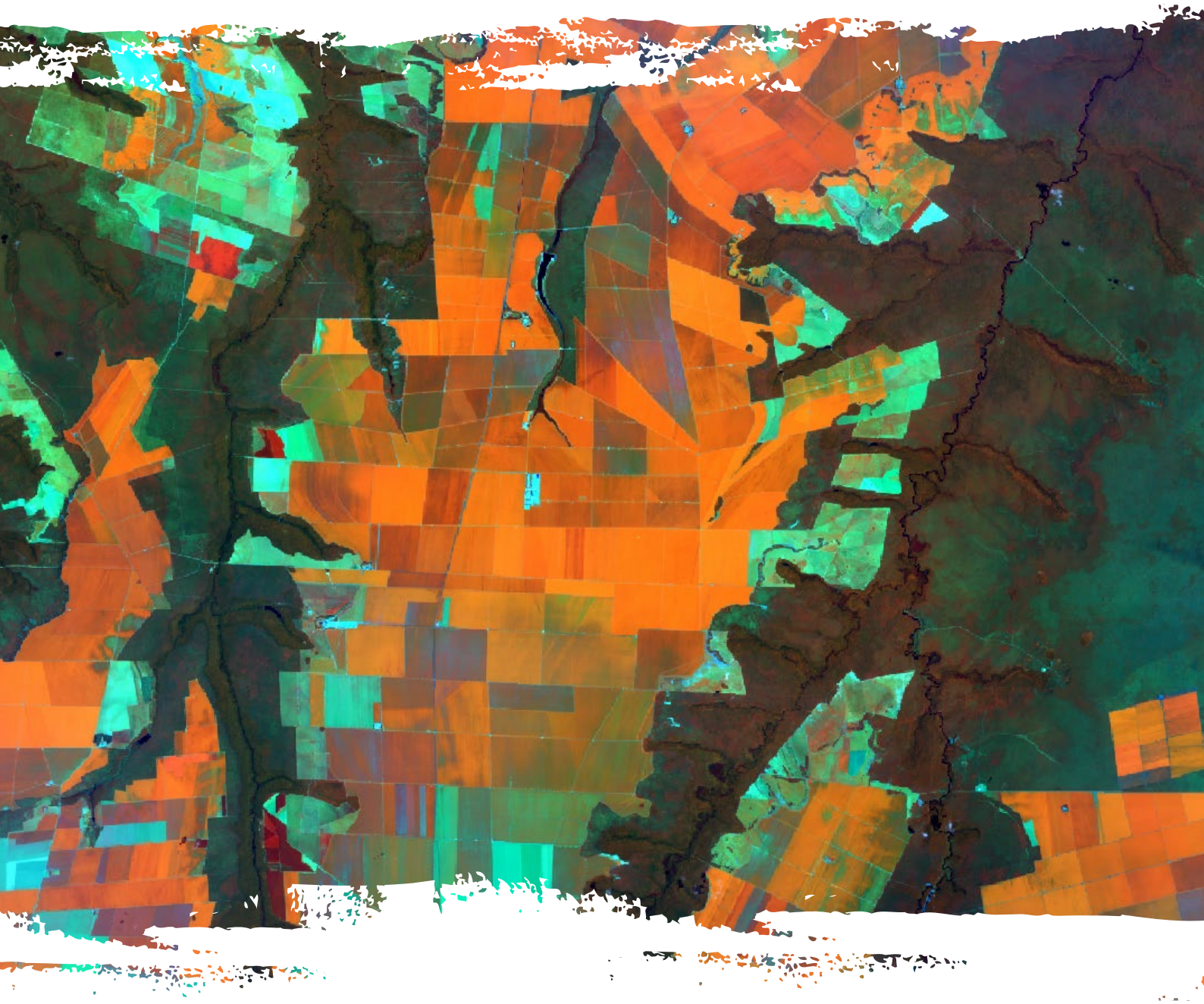
GEOSPATIAL ANALYSIS OF **SOY EXPANSION** IN THE **CERRADO BIOME**

2000/01 TO 2021/22

Updated and Revised Analysis Using the Biome's New Boundaries



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Technical Report..

1. Soy mapping – Crop year 2021/22. 2. Cerrado Biome. 3. Satellite images. 4. Native vegetation.
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Summary

Executive Summary

This report presents an updated version of the geospatial analysis of soy expansion, taking into consideration the new boundaries of the Cerrado Biome, on a scale of 1:250,000, published by the Brazilian Institute of Geography and Statistics (IBGE) in 2019. The objective is to use satellite images to portray the dynamics of change in land use associated with soy crops. In addition, it extends the analysis to include the 2021/22 crop year.

The new version of the Brazilian Biome Map, made it necessary to align the analyses in this study with the new boundaries for the Cerrado Biome. Of the six Brazilian biomes, the Cerrado suffered the greatest change in area, going from 204.01 million hectares to 198.46 million hectares. Although this reduction corresponds to just 2.7%, the Biome's boundaries underwent a more significant change, losing 20.06 million hectares and gaining 14.51 million hectares, a net loss of 5.55 million hectares, thereby justifying this new assessment of soy expansion dynamics based on the new and more refined sizing of the Cerrado Biome. All the results from the analyses in this study refer to the new boundaries of the Cerrado Biome.

The soy area has practically tripled over the last 21 years, going from 7.43 million hectares in 2000/01 to 21.43 million hectares in 2021/22. This area represents almost 11% of the Biome and 51.7% of Brazil's current soy area, according to the CONAB (National Supply Company) survey (41.45 million hectares), and 50.0% according to Agrosatélite's survey based on satellite images (42.85 million hectares). The average growth rate in the period 2001-2022 was 0.667 million hectares per year; however, this average annual rate has increased over the last two years to 1.321 million hectares (1.172 million hectares in 2020/21 and 1.470 million hectares in 2021/22). In terms of the dynamics of the change in land use, the Cerrado Biome includes the MATOPIBA

region – Brazil's largest agricultural frontier – where soy expansion with conversion of native vegetation is increasing, compared with the more consolidated regions of the Cerrado Biome, herein called Other States. In MATOPIBA, the soy area went from 0.965 million hectares in 2000/01 to 5.086 million hectares in 2021/22, more than a fivefold increase, taking this region's share in the Cerrado's soy area from 13% to 24%. In Other States, the soy area went from 6.47 million hectares in 2000/01 to 16.35 million hectares in 2021/22, a 2.5-fold increase representing 76% of the Cerrado's current soy area.

The deforestation rates in the Cerrado Biome, which in the early 2000s were around 2.8 million hectares per year, have been relatively stable over the last six years with an annual average rate of 0.74 million hectares, almost four times lower. In addition to the lower deforestation rates seen in recent years, there is a marked difference between the MATOPIBA and Other States regions. If in the early 2000s the Other States region contributed 70% of the deforestation, it now contributes only 35%, despite covering over two-thirds of the Cerrado's territory.

Considering the Cerrado Biome's soy area in the 2021/22 crop year, 4.54 million hectares were planted on land deforested after 2001. This means that 78.8% of the Cerrado's 2021/22 soy area – equivalent to 16.89 million hectares – is free of post-2000 deforestation. If we consider only the deforestation occurring after 22 July 2008, which is the date that defines consolidated areas in accordance with the 2012 Forest Code, we see that 1.801 million hectares (15.3% of the total post-2008 deforestation) have been converted to soy, of which 1.443 million hectares are in MATOPIBA (28.4% of the soy area in this region) and 358,000 hectares are in Other States (2.2% of this region's soy area). In other words, the dynamics of soy expansion onto land deforested after 2008 differ greatly between the two regions.

A detailed analysis of the dynamics of the change in land use and cover associated with the soy expansion of 5.89 million hectares in the period 2013/14 to 2021/22 shows that change occurs both through incorporation of new areas from the conversion of native vegetation or intensification of land use from the conversion of pastures, and through agricultural management practices from crop rotation or fallow land. In Other States, expansion due to intensification (expanding onto pastures) amounted to 2.81 million hectares and expansion with deforestation amounted to 0.19 million hectares. In MATOPIBA, the expansion of only 0.40 million hectares was onto pastures, while 0.70 million hectares was expansion with deforestation. In both regions, a significant part of the soy expansion was onto land that was fallow in the 2013/14 crop year (2.25 million hectares).

Based on the analyses carried out in this study, the Cerrado Biome's soy expansion trend has continued in an accelerated manner over the last two crop years. In the most recent period, soy expansion onto land converted from native vegetation is relatively low in the Other States region, but still persists in MATOPIBA.

1. Dynamics of Soy Expansion in the Cerrado Biome

Brazil is divided into six biomes, each with typical phytophysiognomies, as in the case of the Cerrado Biome. Historically, soy production started in southern Brazil, in the Atlantic Forest Biome, and began gaining prominence in the Cerrado Biome in the 1980s, when the development of new technologies enabled its production in areas previously considered unsuitable. According to the new Cerrado Biome boundaries, published by IBGE (Brazilian Institute of Geography and Statistics) in 2019, this Biome covers an area of 198,455,393 hectares, corresponding to 23.3% of Brazil's territory, with just over 50% of its native vegetation preserved. Currently, about 50% of Brazil's soy area[1] is located in the Cerrado Biome, with emphasis on the MATOPIBA[2] region (Figure 1), the biggest and newest agricultural frontier in Brazil, where soy expansion onto native vegetation is still relevant. In the Cerrado's more consolidated region, herein called Other States[3] (Figure 1), there is a large stock of cleared land suitable for soy production, with ample opportunity for soy expansion through intensification of land use, as has been observed.

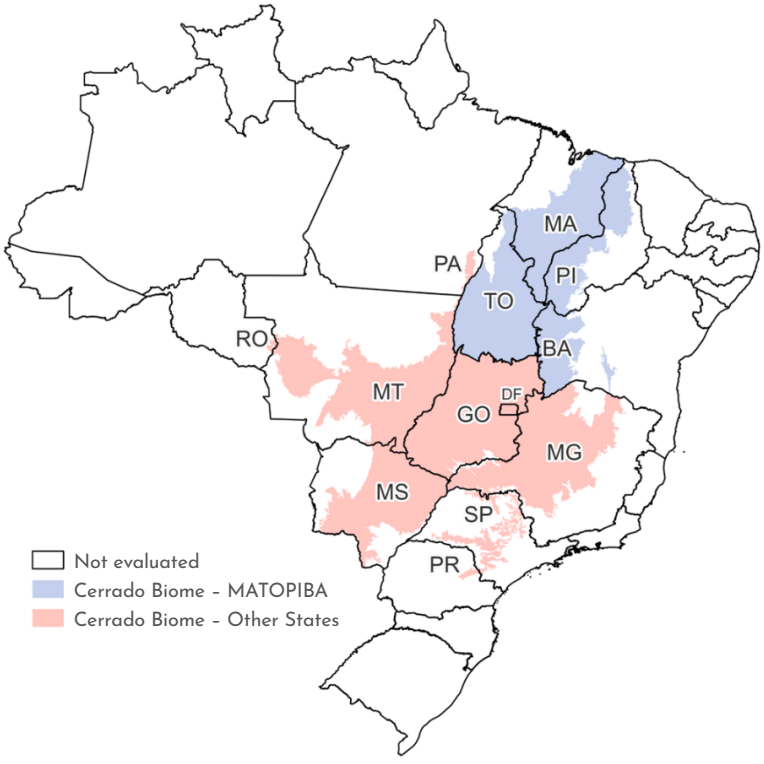

Figure 1. Highlight of the regions "Other States" and "MATOPIBA" in the Cerrado Biome.

1. CONAB – Companhia Nacional de Abastecimento (National Supply Company). Acompanhamento da Safra Brasileira de Grãos, Brasília, v.9 – Safra 2021/22, n.12 – Décimo segundo levantamento, pg. 1-88, September 2022. ISSN 2318 6852.
2. MATOPIBA is the region formed by the states of Maranhão – MA, Tocantins – TO, Piauí – PI and Bahia – BA, in those areas located in the Cerrado Biome and in the transitions with the Amazon Biome, where an intense transformation of the landscape has been occurring through the expansion of high technology seasonal agriculture.
3. Other States is the region formed by parts of the states of Mato Grosso – MT, Goiás – GO, Minas Gerais – MG, Mato Grosso do Sul – MS, São Paulo – SP, Paraná – PR; Rondônia – RO, Pará – PA and the Federal District – DF.

1.1 Evolution of the soy area

The detailed analysis of the dynamics of soy expansion in the Cerrado Biome completed 21 years in the 2021/22 crop year, and it has now gone through a complete revision to take into account the Biome's new boundaries. A thorough analysis of the images acquired by satellites[4], enabled both an assessment of the soy area's gradual growth and the detailing of the transitions that occurred in terms of the change in land use and land cover over these 21 years. This period coincides with a greater environmental awareness in the sense of preserving natural resources by seeking alternatives to the clearing of new areas through better use of the areas already cleared and through new technologies that increase productivity. Nevertheless, preservationist appeals are faced with a growing opportunity to increase food production for export, a trend which has strongly boosted Brazilian agribusiness.

Objective information regarding the spatial distribution of soy crops and their association with recent conversions of native vegetation, and awareness that there is a stock of land suitable for soy production, supply key elements to reach a balance between environmental preservation and increased soy production. In this sense, satellite images not only reveal what has happened in the region as a result of soy expansion, but also allow territorial planning for the sustainable development of agribusiness.

In this report, we make an integrated presentation of the results of Agrosatélite's prior studies that mapped soy crops in the Cerrado Biome in the 2000/01, 2006/07, 2013/14 and 2016/17 crop years, supported by the Gordon and Betty Moore Foundation and by the GTC/TNC (Cerrado Working Group/The Nature Conservancy), as well as ABIOVE[5] (Brazilian Association of Vegetable Oil Industries) for the 2018/19, 2019/20 and 2020/21 crop years, including an update of the mapping for the 2021/22 crop year and a reassessment of all prior-year mappings using the new Cerrado Biome boundaries. These mappings show the spatial distribution of crops and estimate the planted area at all levels, from rural properties, through municipalities and states, to the Biome as a whole[6].

The objective of analysing this historic mapping sequence is to broaden understanding of recent soy expansion throughout the Cerrado Biome, highlighting the MATOPIBA region, Brazil's new agricultural frontier where recent expansion with conversion of native vegetation is far more evident than in the Other States region, where most expansion has been onto land that has been cleared for a longer time.

Figures 2 to 9 illustrate soy mapping for the Cerrado Biome in eight crop years (2000/01, 2006/07, 2013/14, 2016/17, 2018/19, 2019/20, 2020/21 and 2021/22). Each figure highlights four cutouts of less consolidated regions where soy crops acquired greater relevance after the year

4. This study used images acquired by Landsat and Sentinel-2 satellites in the visible, near- and mid-infrared wavelengths of the electromagnetic spectrum, with spatial resolution between 10 and 30 metres (~100 to 10 pixels per hectare). The joint operation of these satellites allows the same location to be revisited every 2-5 days, which enables the acquisition of cloud-free images during the best period for identifying soy fields. About 3,000 images were available to accurately identify soy crops in the Cerrado Biome in the 2021/22 crop year through visual interpretation techniques of the images. The starting point was the map of the 2020/21 soy crop. The following RGB colour compositions of the images were used: 4-5-3 bands for the ETM+/Landsat-7 sensor; 5-6-4 bands for the OLI/Landsat-8 sensor; and 8a-11-4 bands for the MSI/Sentinel-2 sensor. The visual interpretation procedure also considered the analysis of the temporal series of images obtained by the MODIS sensor, transformed into the EVI Enhanced Vegetation Index in the form of 16-day temporal compositions through consulting the web application of EMBRAPA's SatVeg project (www.satveg.cnptia.embrapa.br). It is worth noting that the mapping of the 2016/17 soy crop, prepared by Agrosatélite, was validated by a third party (University of Maryland) based on data obtained in the field, with an overall mapping accuracy of 98.4%.
5. Reports available for public consultation can be found on https://agrosatelite.com.br/cases/#expansao-agricola.
6. The Cerrado Biome boundaries used in this study are those established by the IBGE in 2019, on a scale of 1:250,000 (https://www.ibge.gov.br/geociencias/cartas-e-mapas/informacoes-ambientais/15842-biomas.html?edicao=25799&t=acesso-ao-produto).

2000. That is the case of the Paranatinga/MT municipality, shown in Cutout I, where the soy area in the Cerrado Biome went from 32,419 hectares in 2006/07 to 138,697 hectares in 2013/14, an approximate fourfold growth in eight years. Between 2013/14 and 2019/20, the average annual growth fell to 4,261 hectares, but over the last two years soy area in Paranatinga has increased by 16,200 hectares in 2020/21 and 32,607 hectares in 2021/22, taking the current soy area in this municipality to 213,071 hectares. The regions surrounding Balsas in Maranhão state and Baixa Grande do Ribeiro in Piauí state (both in Cutout II), as well as the regions surrounding Barreira in Bahia state (Cutout III) and Porto Nacional in Tocantins state (Cutout IV) also stand out for the intense expansion of their soy areas, which has grown four to five times over the last 21 years. All these regions are located in MATOPIBA.

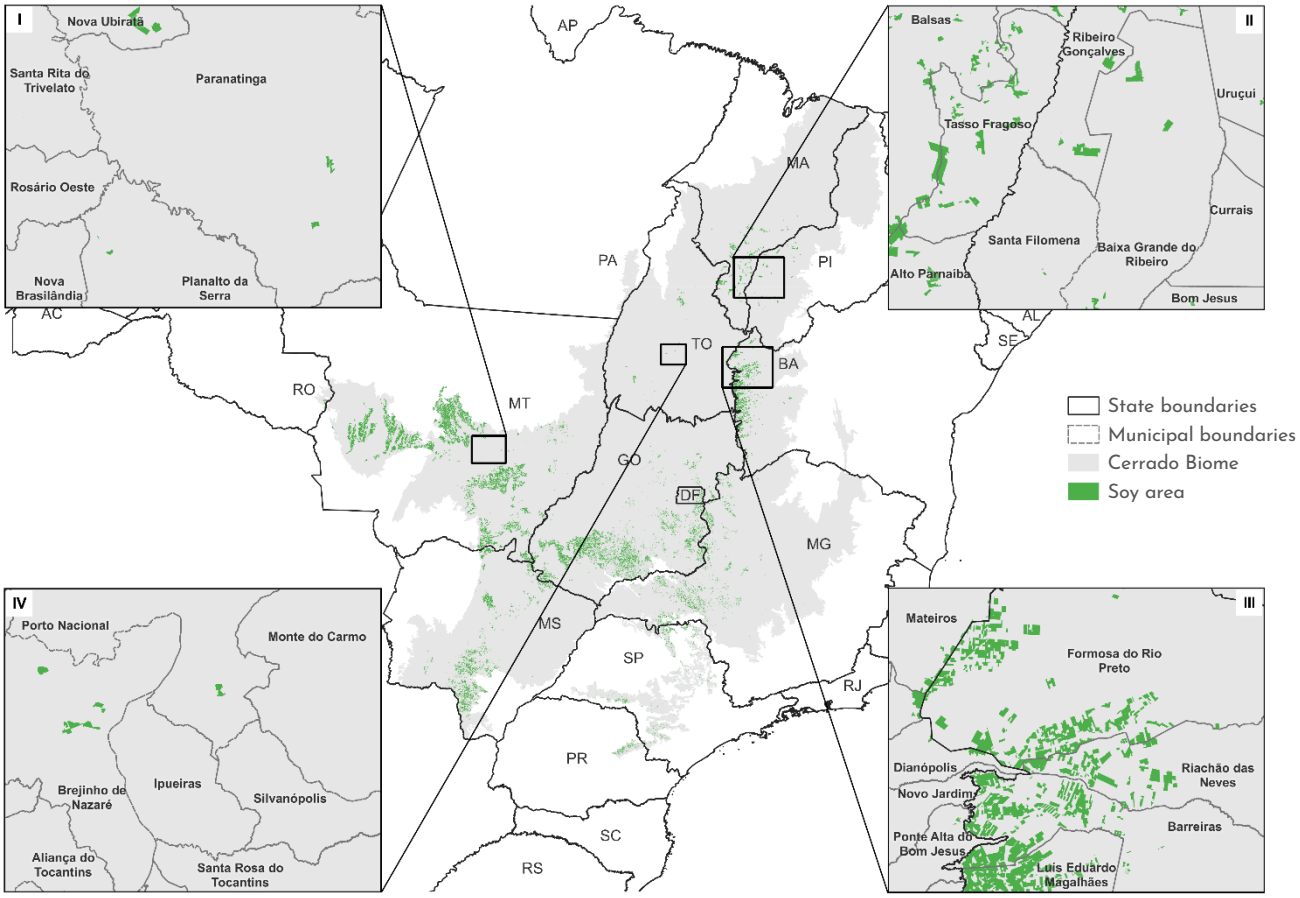

Figure 2. Map of soy areas in the Cerrado Biome for the crop year 2000/01, highlighting regions with significant soy expansion.

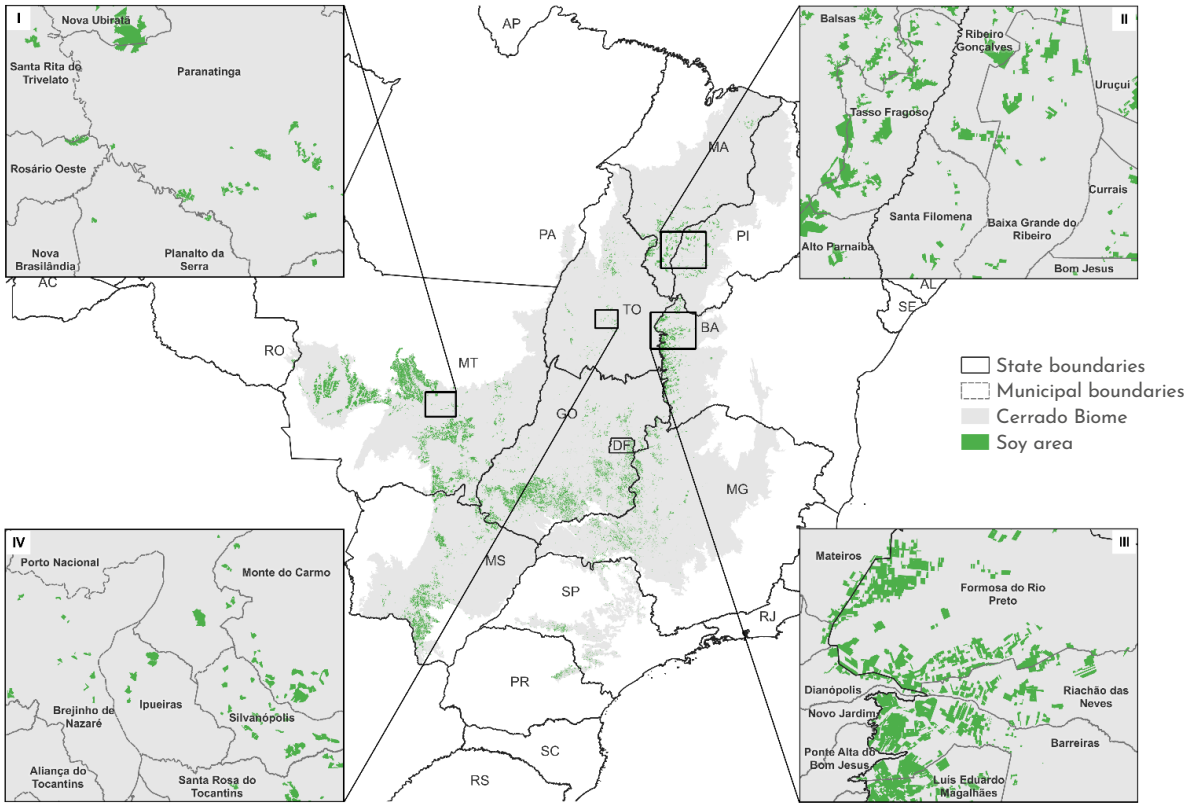

Figure 3. Map of soy areas in the Cerrado Biome for the crop year 2006/07, highlighting regions with significant soy expansion.

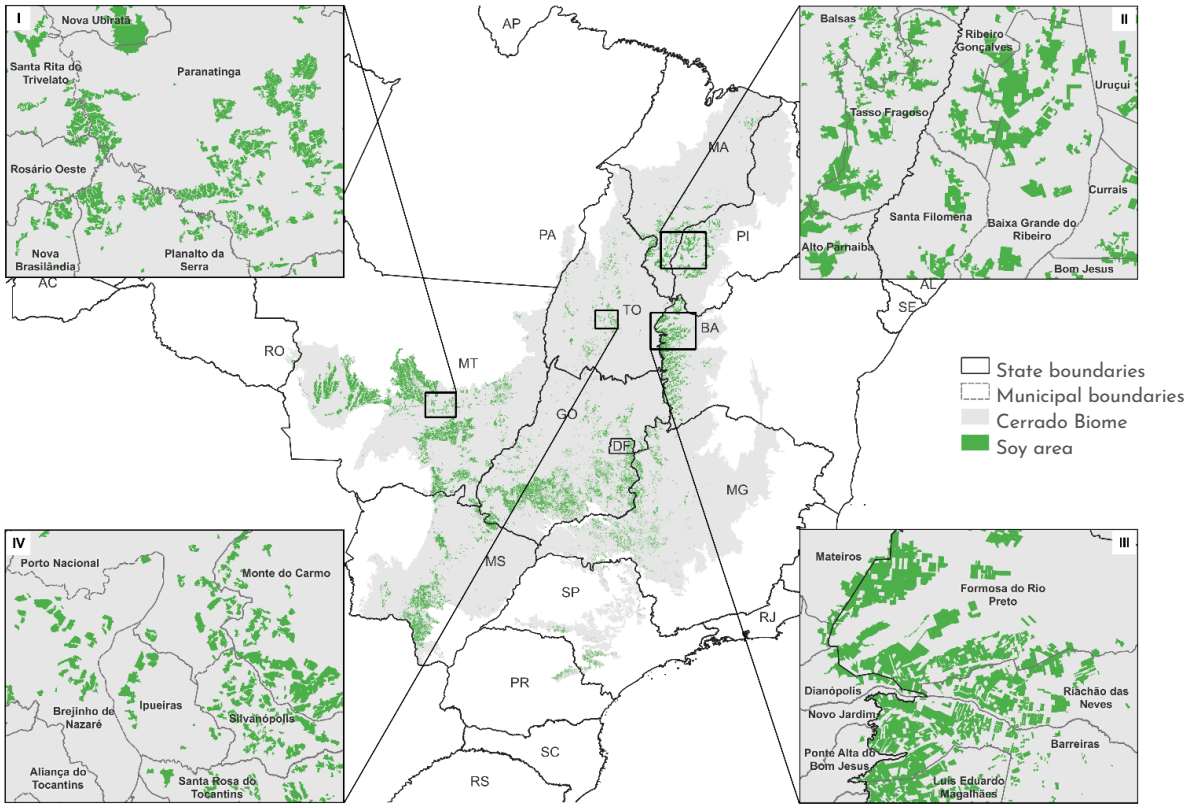

Figure 4. Map of soy areas in the Cerrado Biome for the crop year 2013/14, highlighting regions with significant soy expansion.

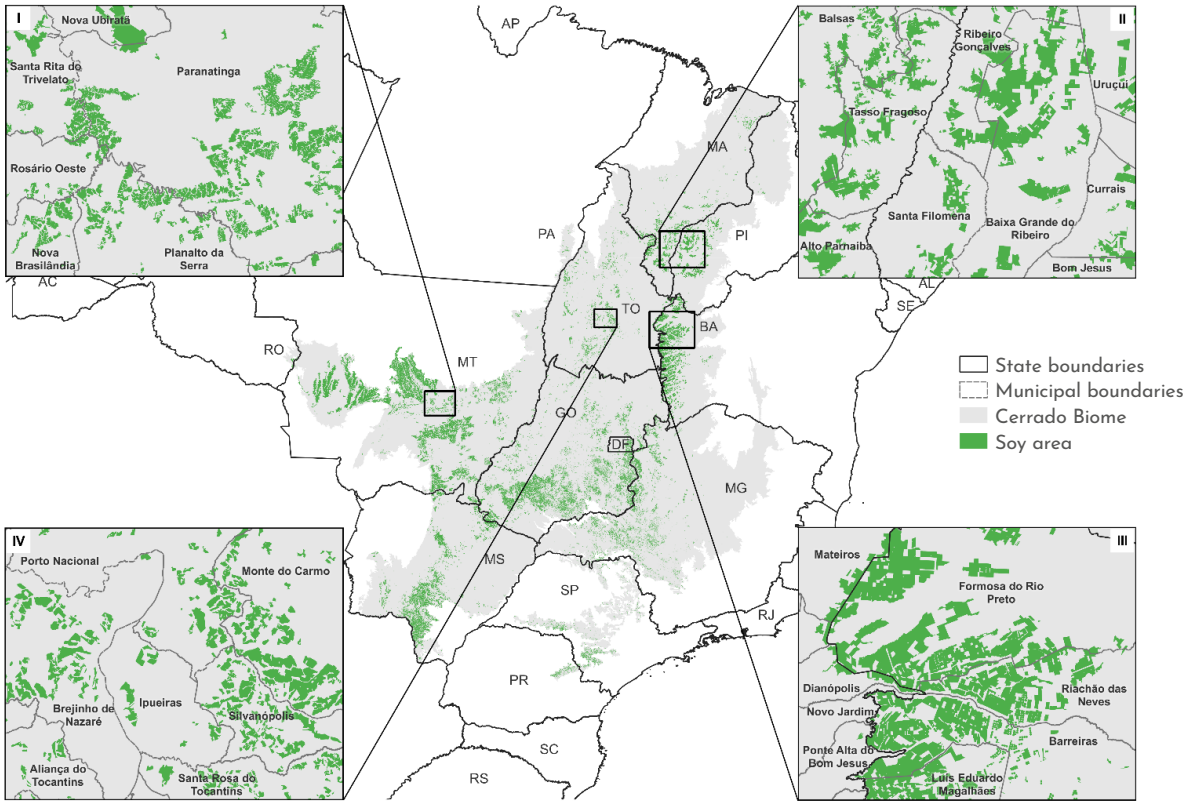

Figure 5. Map of soy areas in the Cerrado Biome for the crop year 2016/17, highlighting regions with significant soy expansion.

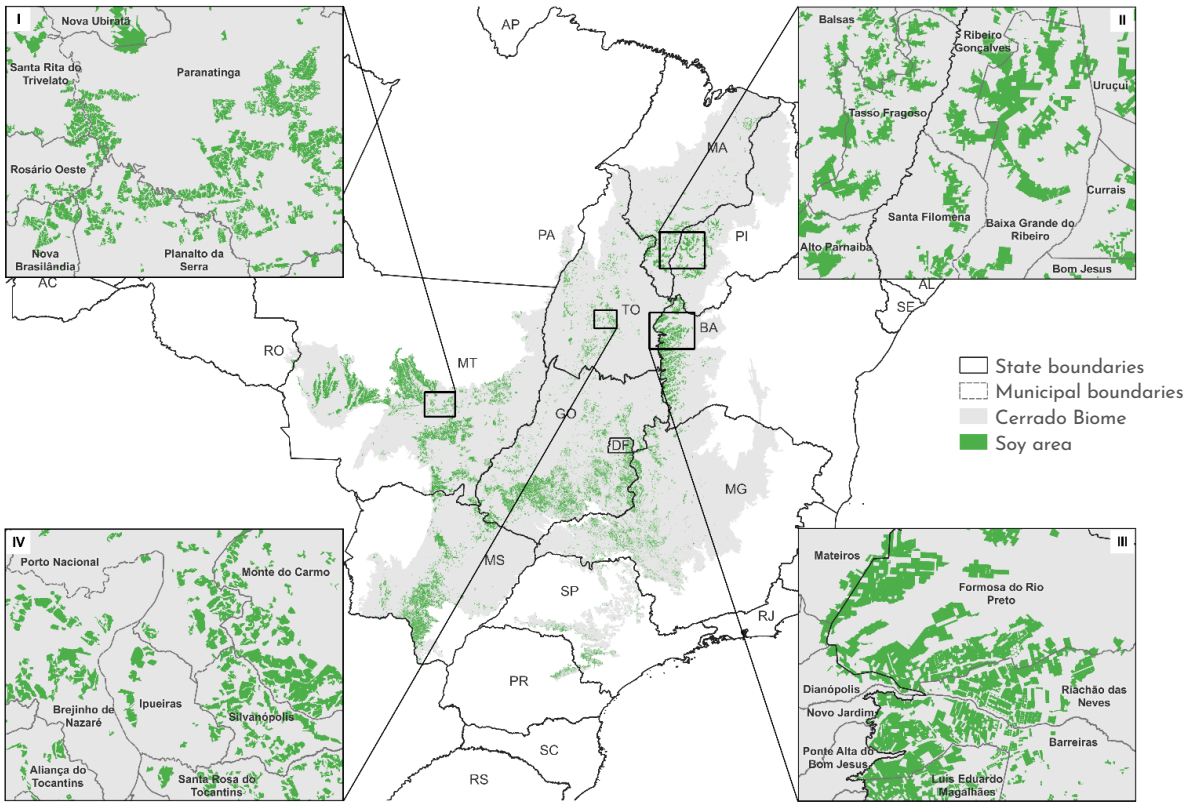

Figure 6. Map of soy areas in the Cerrado Biome for the crop year 2018/19, highlighting regions with significant soy expansion.

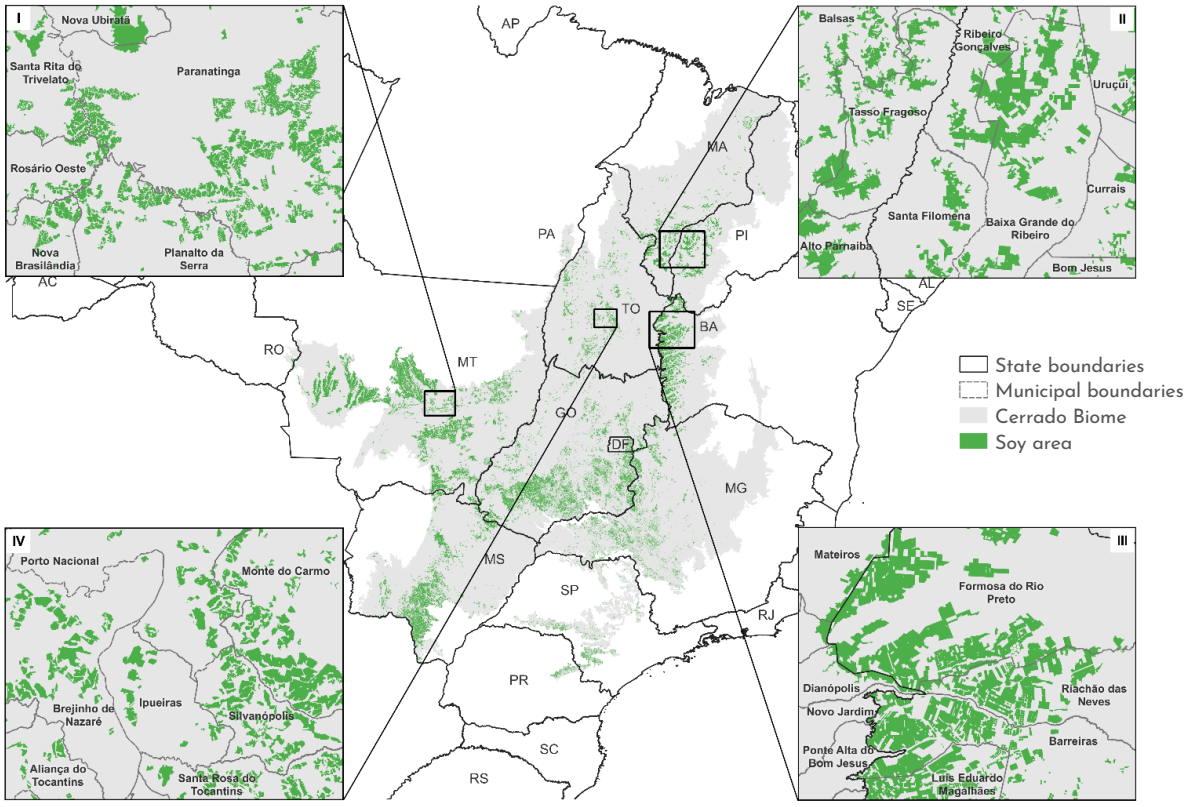

Figure 7. Map of soy areas in the Cerrado Biome for the crop year 2019/20, highlighting regions with significant soy expansion.

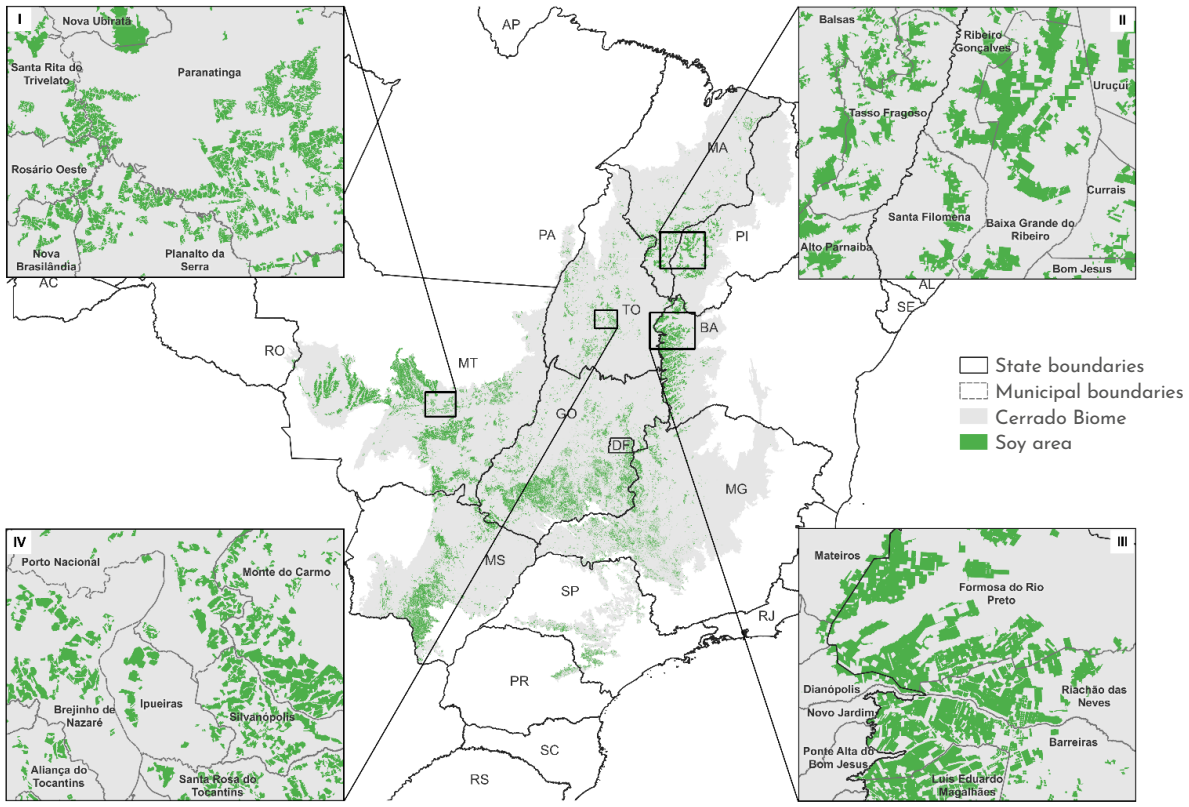

Figure 8. Map of soy areas in the Cerrado Biome for the crop year 2020/21, highlighting regions with significant soy expansion.

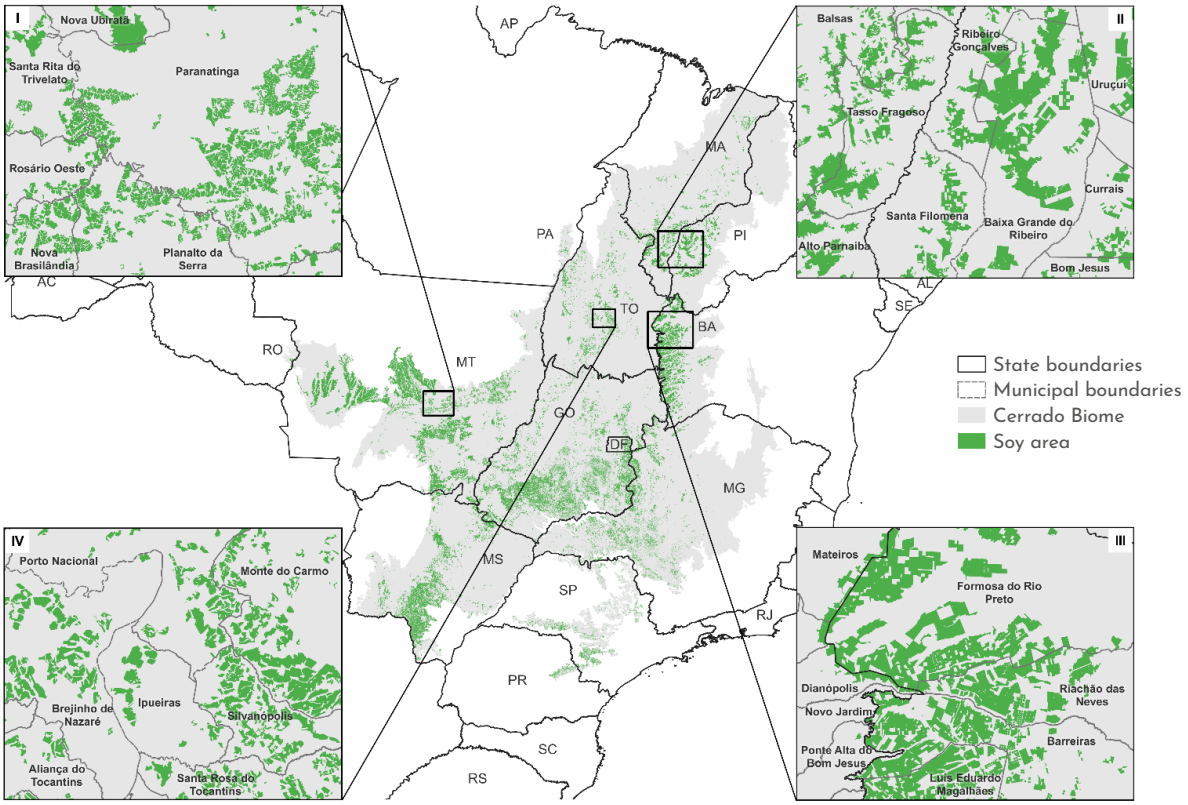

Figure 9. Map of soy areas in the Cerrado Biome for the crop year 2021/22, highlighting regions with significant soy expansion.

Table 1 presents the soy area in the Cerrado Biome, by state and for the Other States and MATOPIBA regions, obtained from satellite images for the same eight crop years shown in Figures 2 to 9.

States	2000/01	2006/07	2013/14	2016/17	2018/19	2019/20	2020/21	2021/22
	hectares	hectares	hectares	hectares	hectares	hectares	hectares	hectares
DF	39,727	54,956	80,002	88,351	93,245	85,447	84,867	101,636
GO	1,737,618	2,369,355	3,522,707	3,690,694	4,012,149	4,162,932	4,445,196	4,958,919
MG	593,000	779,797	1,198,138	1,460,482	1,703,974	1,718,523	1,867,793	2,014,220
MS	836,773	1,221,143	1,675,896	1,995,603	2,218,406	2,409,115	2,582,202	2,678,239
MT	3,000,481	3,837,277	5,272,195	5,385,347	5,377,462	5,505,054	5,599,613	5,898,078
PR	52,544	62,731	68,841	76,218	89,581	89,892	91,147	87,777
SP	196,207	158,679	283,971	338,175	418,894	447,693	502,472	539,119
RO	13,121	21,124	24,748	22,926	23,432	23,472	23,301	23,435
PA	481	2,302	5,518	18,192	21,203	28,143	33,493	46,574
Other States	**6,469,953**	**8,507,365**	**12,132,015**	**13,075,988**	**13,958,346**	**14,470,270**	**15,230,085**	**16,347,996**
MA	220,838	437,129	682,536	750,764	818,397	833,834	904,794	1,006,071
TO	77,279	258,419	675,573	916,883	1,020,581	1,089,378	1,171,838	1,284,372
PI	59,385	226,330	629,328	671,529	741,964	732,856	819,459	867,573
BA	607,305	765,005	1,419,428	1,606,627	1,609,218	1,665,150	1,837,307	1,927,707
MATOPIBA	**964,806**	**1,686,883**	**3,406,864**	**3,945,804**	**4,190,160**	**4,321,218**	**4,733,398**	**5,085,723**
TOTAL	**7,434,759**	**10,194,248**	**15,538,879**	**17,021,791**	**18,148,506**	**18,791,487**	**19,963,483**	**21,433,719**

Key: DF-Federal District; GO-Goiás; MG-Minas Gerais; MS-Mato Grosso do Sul; MT-Mato Grosso; PR-Paraná; SP-São Paulo; RO-Rondônia; PA-Pará; MA-Maranhão; TO-Tocantins; PI-Piauí; BA-Bahia

Table 1. Soy area in hectares in the Cerrado Biome, by state and for the Other States and MATOPIBA regions, for the crop years 2000/01, 2006/07, 2013/14, 2016/17 and 2018/19 to 2021/22.

Over the last 21 years, the soy area in the Cerrado Biome has practically tripled, going from 7.43 million hectares in 2000/01 to 21.43 million hectares in 2021/22, an increase of 14.00 million hectares, or an average annual rate of 0.667 million hectares (0.470 million hectares in Other States and 0.196 million hectares in MATOPIBA). Favourable soy prices in recent years have led to accelerated production and provoked an increase in planted area of 1.172 million hectares in 2020/21 (0.760 million hectares in Other States and 0.412 million hectares in MATOPIBA) and of 1.470 million hectares in 2021/22 (1.118 million hectares in Other States and 0.352 million hectares in MATOPIBA), well above the average annual growth of 0.667 million hectares seen in the 21-year historical series (Table 1, Figure 10). The MATOPIBA soy area went from 0.965 million hectares in 2000/01 to 5.086 million hectares in 2021/22, a more than five-fold increase, taking this region's share in the Cerrado Biome's soy area from 13% to 24%. In the Other States region, the soy area went from 6.470 million hectares in 2000/01 to 16.348 million hectares in 2021/22, an increase of 2.5 times, representing 76% of soy's current area in the Cerrado (Table 1, Figure 10).

Figure 10 graphically illustrates the values for the soy area in Other States and in MATOPIBA (Table 1), including the annual expansion rates in each period.

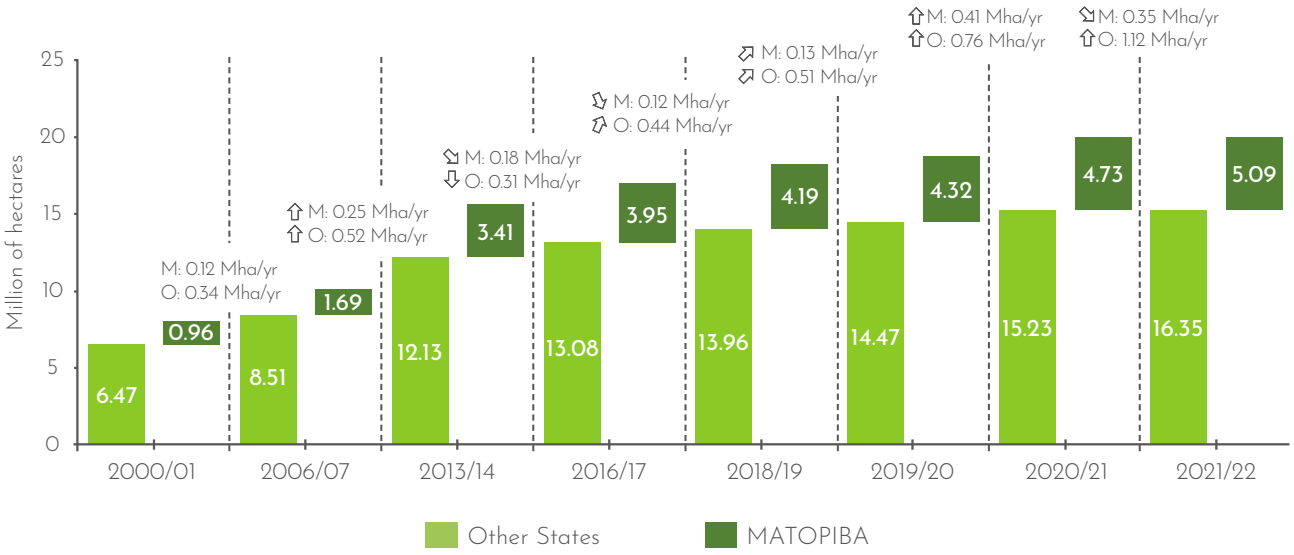

Figure 10. Evolution of soy area from the 2000/01 crop to the 2021/22 crop in Other States and in MATOPIBA, and annual growth rates in areas cultivated with soy in the seven periods analysed: 2000/01 to 2006/07; 2006/07 to 2013/14; 2013/14 to 2016/17; 2016/17 to 2018/19; 2018/19 to 2019/20; 2019/20 to 2020/21; and 2020/21 to 2021/22.

Table 2 shows the percentage variation in soy area for the 2021/22 crop year, compared to that of the prior year.

States	2020/21	2021/22	Variation %
	(a)	(b)	(b*100/a)-100
DF	84,867	101,636	19.8
GO	4,445,196	4,958,919	11.6
MG	1,867,793	2,014,220	7.8
MS	2,582,202	2,678,239	3.7
MT	5,599,613	5,898,078	5.3
PR	91,147	87,777	-3.7
SP	502,472	539,119	7.3
RO	23,301	23,435	0.6
PA	33,493	46,574	39.1
Other States	**15,230,085**	**16,347,996**	**7.3**
MA	904,794	1,006,071	11.2
TO	1,171,838	1,284,372	9.6
PI	819,459	867,573	5.9
BA	1,837,307	1,927,707	4.9
MATOPIBA	**4,733,398**	**5,085,723**	**7.4**
TOTAL	**19,963,483**	**21,433,719**	**7.4**

Key: DF-Federal District; GO-Goiás; MG-Minas Gerais; MS-Mato Grosso do Sul; MT-Mato Grosso; PR-Paraná; SP-São Paulo; RO-Rondônia; PA-Pará; MA-Maranhão; TO-Tocantins; PI-Piauí; BA-Bahia

Table 2. Change in soy area in the Cerrado Biome, in hectares and as a percentage, by state and for the Other States and MATOPIBA regions, for the 2020/21 versus the 2021/22 crop years.

It should be noted that Agrosatélite's team of image analysts has access to an enormous collection of satellite images, a fact that fosters a meticulous analysis to identify correctly and map precisely the soy fields in the 2021/22 crop year, as well as the revision of the historical series of mappings based on the Cerrado Biome's new boundaries, published by IBGE in 2019. The estimates of the soy area based on these mappings are higher than those released by CONAB (National Supply Company) for those states whose soy area is practically all within the Cerrado Biome. For example, for the states of Goiás and Bahia, Agrosatélite estimated 565,000 hectares and 34,000 hectares, respectively, above CONAB's estimates. In the 2020/21 crop year, Agrosatélite carried out field work in Goiás state to assess the quality of the mapping, finding no inconsistencies that would justify a revision of the mapping. With about 700 samples of land use collected in the field in Goiás, the mapping had a 98.3% overall accuracy for this state. Therefore, Agrosatélite is confident that the estimates of the soy area in the Cerrado Biome shown in this report very reliably represent the territorial extension occupied by soy crops. It is worth noting that the mapping of the 2016/17 crop year underwent validation by a third party (University of Maryland) that indicated an overall mapping accuracy for the entire Cerrado Biome of 98.4%.

2. Deforestation in the Cerrado Biome

Figure 11 presents the Cerrado Biome deforestation rates estimated by PRODES-Cerrado from 2001 to 2021. The annual deforestation rates, which were approximately 2.8 million hectares/year at the beginning of this millennium, have fallen over the last six years to about 0.74 million hectares/year. The reduction was more marked in Other States, which registered two-thirds of the Biome's deforestation at the beginning of the millennium. This regional situation though has been inverted and, in recent years, MATOPIBA has registered two-thirds of the deforestation, even though this region represents only one-third of the Cerrado Biome. The lowest deforestation rate of the 21 years in this study was registered in 2019 (0.632 million hectares), but it has been increasing annually both in MATOPIBA and in Other States, reaching 0.853 million hectares in 2021.

2.1 Deforested land converted to soy

Figure 12 shows the same information shown in Figure 11, highlighting the deforestation converted to soy from 2001 to 2021, considering the 2020/21 crop year. Figure 11 shows that deforestation in the Cerrado Biome from 2001 to 2021 was 28.97 million hectares, of which 4.54 million hectares (Figure 12) was converted into soy. That means that 15.7% of the area deforested over the last 21 years was used to grow soy in the 2021/22 crop year; in other words, 84.3% (24.43 million hectares) of the deforested area was used for purposes other than soy. Furthermore, 79.0% of the Cerrado Biome's soy area in the 2021/22 crop year – equivalent to 16.89 million hectares – was free of post-2008 deforestation.

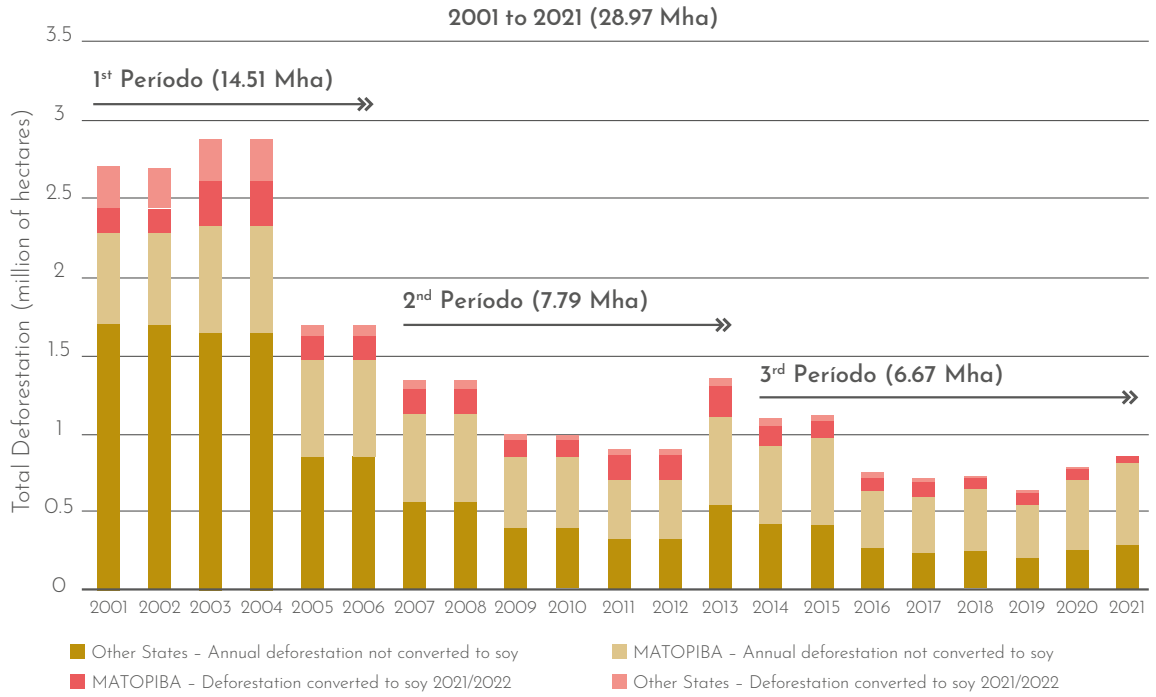

Figure 11. Annual deforestation rates in the Cerrado Biome from 2001 to 2021, highlighting the annual portion deforested and the portion converted to soy, based on crop year 2021/22.

If we consider just the deforestation that occurred after 22 July 2008, when the 2012 Forest Code defined consolidated areas, then the deforested area in the Cerrado Biome was 11.79 million hectares, of which 1.801 million hectares, or 15.3% (84.7% free of deforestation after 2008), were converted directly or indirectly into soy, of which 1.443 million hectares are located in MATOPIBA, corresponding to 28.4% of this region's soy area (71.6% are free of post-2008 deforestation), and 0.358 million hectares are in Other States, corresponding to 2.2% of this region's soy area (97.8% are free of post-2008 deforestation). This shows that the dynamics of soy expansion onto deforested land after 2008 differ greatly between the two regions.

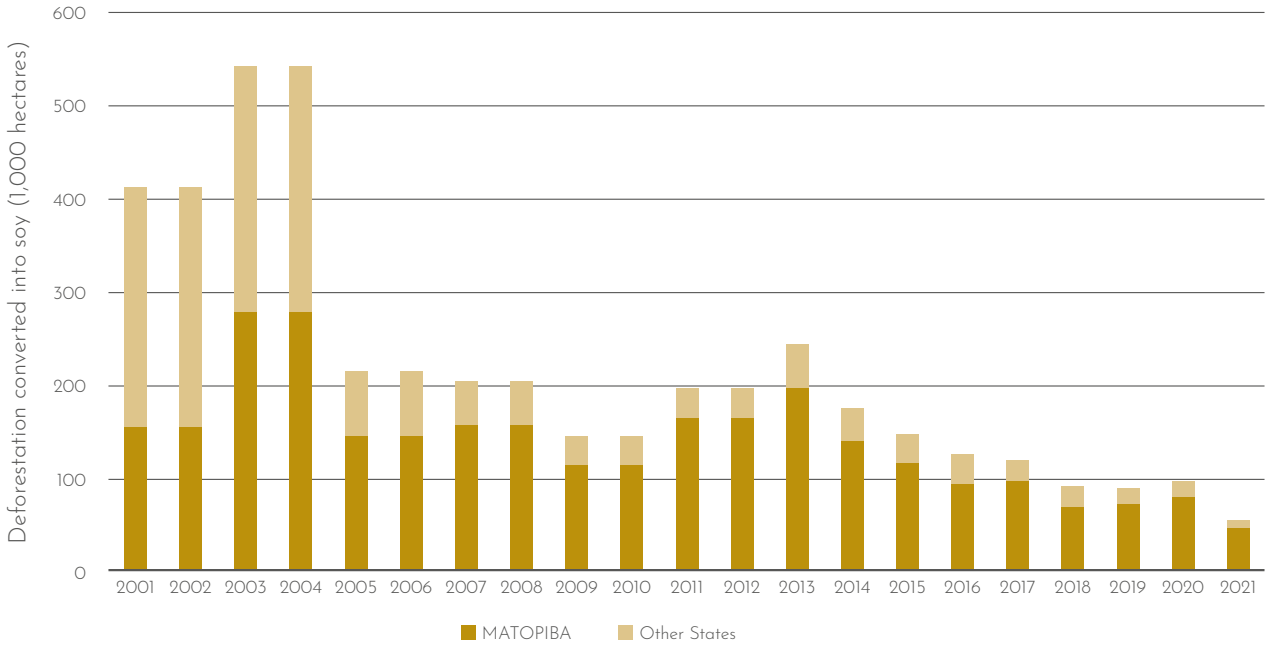

Figure 12. Soy expansion onto deforested areas that occurred from 2001 to 2021 in the Cerrado Biome, highlighting the regions MATOPIBA and Other States, based on crop year 2021/22.

3. Change in Land Use and Land Cover Attributed to Soy

The change in land use caused by the dynamics of soy expansion in the Cerrado Biome was analysed in three periods (Figure 11), taking into consideration the following classification: 1) change in land cover from native vegetation to soy, herein called expansion with deforestation[7]; 2) change in land use to soy, herein called expansion without deforestation[8] and 3) areas of retraction[9], consisting of land that was used for soy production but had been allocated to other uses, either permanently or temporarily (e.g., fallow ground or crop rotation).

This analysis considers both the availability of soy mappings in specific crop years, according to prior Agrosatélite studies (Footnote 5) and the number of years in each period analysed. The main focus of this analysis is to assess the trends of soy expansion with deforestation over time. The scope of each period analysed should therefore be long enough to effectively capture the change in land use and land cover caused by soy expansion, as well as short enough to show the variations and trends in the pattern of changes in land use and land cover over the 21 crop years analysed.

Analysis of the expansion with deforestation of the soy areas mapped in 2021/22 was made by intersecting with the annual PRODES-Cerrado deforestation maps[10], using the procedure described in Agrosatélite (2018)[5].

3.1 Soy expansion with and without deforestation

To better capture soy's contribution to the deforestation that has occurred since 2001, the analysis of soy expansion with deforestation was carried out in three periods: first period with six crop years (2000/01 to 2006/07); second period with seven crop years (2006/07 to 2013/14); and third period with eight crop years (2013/14 to 2021/22), as shown in Figure 11. The definition of these periods also considered the availability of soy maps for these specific years, following the methodology used in prior Agrosatélite studies (Footnote 5). The objective of this fractional analysis is to show the downward trend of native vegetation conversion into soy in the most recent period. It should be noted that each period was analysed independently; in other words, deforestation outside the period under analysis does not impact soy expansion with deforestation in that period. For example, an area deforested in 2012 (second period) and converted to soy in 2016 (third period) is not considered as a conversion of native vege-

7. Expansion with deforestation corresponds to the land cover change caused by the deforestation of areas with native vegetation in the Cerrado Biome (regardless of phytophysiognomy) at the beginning of each period, which were converted to soy by the end of the same period.
8. Expansion without deforestation corresponds to land use change caused by soy expansion into areas with other uses at the beginning of each period, which were converted to soy by the end of the same period. For example, pastures converted to soy consist of intensification of land use; this often occurs in Other States where many pastures have an agricultural suitability for soy. Examples of other uses at the beginning of each period include: a) areas with annual crop rotation (e.g., cotton and first-crop corn); b) fallow areas; and c) sugarcane areas being renewed or converted to soy.
9. Retraction are areas with soy at the beginning of each period that ended the same period with other uses. For example: a) areas with annual crop rotation (such as cotton and first-crop corn); b) fallow areas; c) areas that reverted to sugarcane as part of sugarcane renewal; and d) areas that effectively ceased to be used for soy because they were abandoned or underwent a land use change, as occurred in the first decade of this millennium due to the large sugarcane expansion in the Centre-South region (https://www.mdpi.com/2072-4292/2/1/290).
10. PRODES annually maps the deforestation that occurs from August of the previous year to July of the current year. PRODES-14, for example, maps the deforestation that occurred from August 2013 to July 2014.

tation into soy in the fractional analysis. Therefore, of the 4.58 million hectares deforested and converted to soy from 2001 to 2021, 2.95 million hectares (64.3%, the sum of the deforestation converted into soy in each of the three periods) were considered in the fractioned analysis. This suggests that the number of years in each period adequately represents the time involved in the process of converting deforestation into soy crops. Deforestation that takes longer to be converted into soy, having first gone through transitional land uses (e.g., pastures), is considered to be expansion without deforestation.

When analysing the three periods shown in Figure 13, we see that the percentage of soy expansion with deforestation, in relation to the total soy produced in the Cerrado Biome, is falling, though in absolute terms this fall is modest. In the Other States region, there was a significant fall in the soy area with deforestation from the first to the second period, though it increased somewhat from the second to the third period. In MATOPIBA, where soy expansion with deforestation is very significant, only in relative terms were there reductions in expansion with deforestation, since the absolute numbers continue high in each period analysed (Figure 13).

Figure 14 presents the numbers for soy expansion with and without deforestation considering only the soy expansion in each period, whereas Figure 13 considers soy expansion in relation to the total soy produced. In MATOPIBA, expansion was a little over one million hectares in the first period, with about 50% converted from native vegetation; in the second and third periods, expansion more than doubled with about 30% converted from native vegetation. It should be noted that, from the first to the second period, there was a marked reduction in soy expansion with deforestation in Other States, but the recent acceleration in soy expansion in this region shows an increasing trend in the percentage expansion with deforestation, but the fact that the third period covers eight years versus seven years in the second period should also be borne in mind.

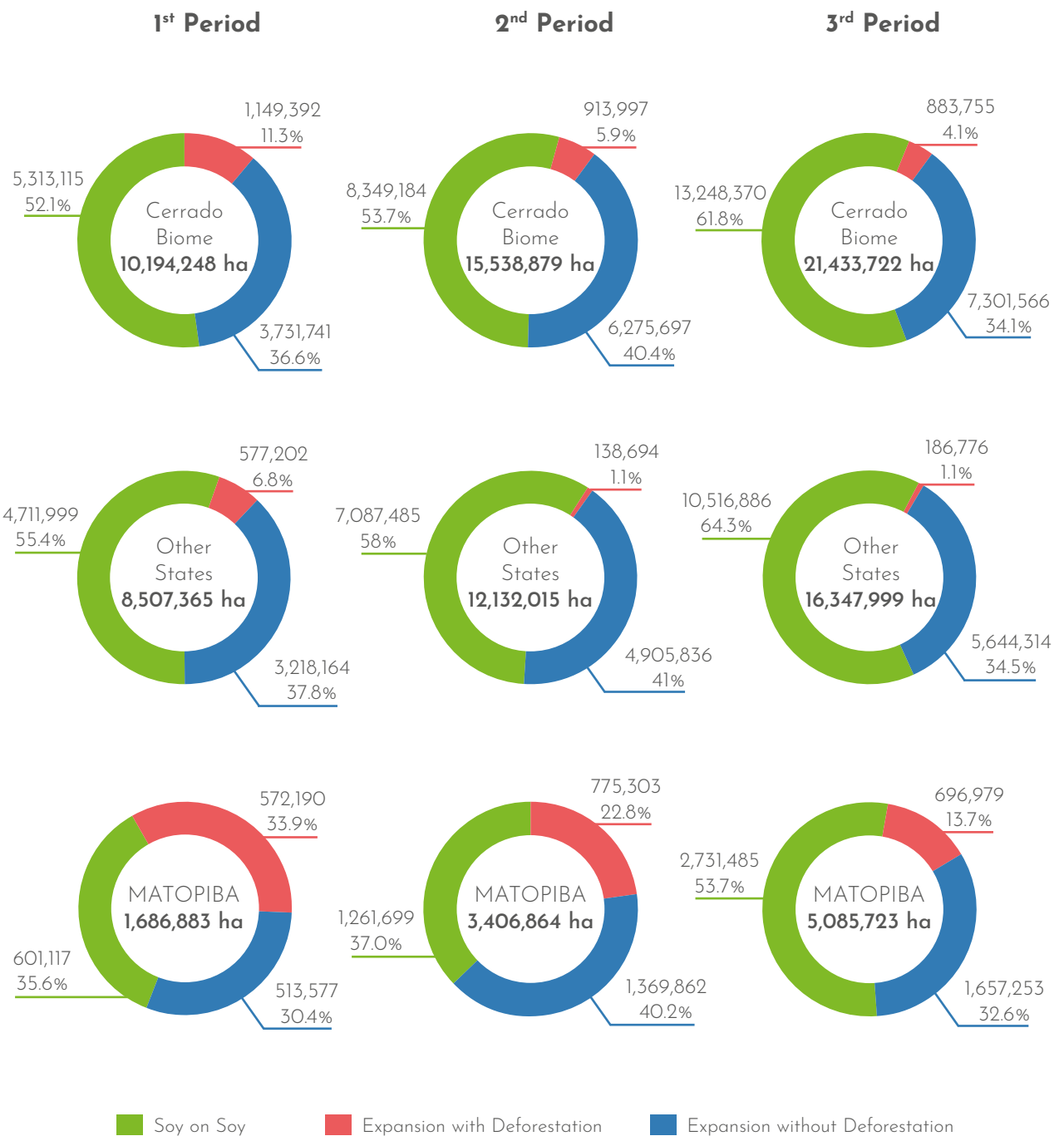

Figure 13. Areas of soy on soy, soy expansion with and without deforestation in the Cerrado Biome, in Other States and MATOPIBA in three periods: 2000/01 to 2006/07; 2006/07 to 2013/14 and 2013/14 to 2021/22.

Note: *Soy on soy* are the areas that began and ended the period with soy. For example, in MATOPIBA, at the beginning of the third period has 3,406,864 hectares, of which 2,731,485 hectares had soy at the end of this period, while 675,379 hectares ceased to grow soy in 2021/22 (retraction, see grey bars in Figure 16 or Figure 19)

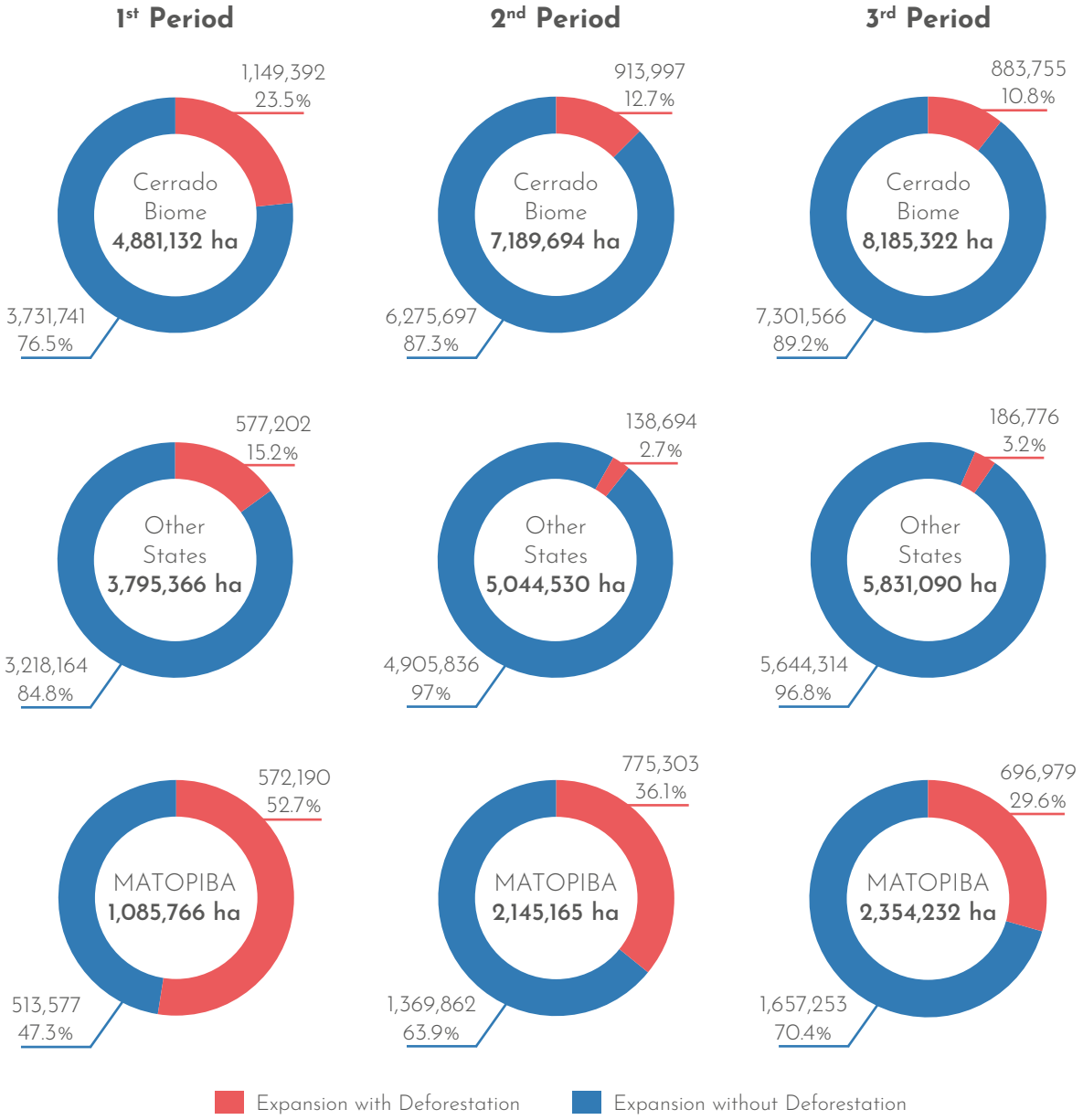

Figure 14. Areas of soy expansion with and without deforestation in the Cerrado Biome, in Other States and MATOPIBA in three periods: 2000/01 to 2006/07; 2006/07 to 2013/14 and 2013/14 to 2021/22.

While Figure 14 shows the soy area that expanded with and without deforestation in each period analysed, Figure 15 shows the total deforestation in the Cerrado Biome from 2014 to 2021 and the portion of this area that had soy in the 2021/22 crop year. In this period, compared to the two previous periods (Figure 11), the deforestation rates fell; however, the portion of deforestation converted to soy in the Biome was not significantly lower, indicating that the areas deforested in the third period (2014 to 2021) made a relevant contribution to soy expansion with deforestation (0.884 million hectares, equivalent to 13.3% of the third-period deforestation, Figure 15b). In Other States, the deforested area was 2.56 million hectares, with 0.187 million hectares (7.3% of the deforestation, Figure 15c) converted to soy. In MATOPIBA, 4.10 million hectares were deforested, with 0.697 million hectares (17.0%, Figure 15d) converted to soy. It should be noted that some of the land deforested in the period from 2014 to 2021 could still be converted to soy in future crop years, increasing the soy area with deforestation.

Among the states that make up MATOPIBA, Maranhão had the largest area of soy with deforestation in the period from 2014 to 2021 (0.190 million hectares), followed by Tocantins (0.185 million hectares), Bahia (0.184 million hectares) and Piauí (0.138 million hectares), as shown in Figure 15a. Tocantins and Maranhão also hold the record for total deforestation in this period, with 1.51 million hectares and 1.34 million hectares, respectively (Figure 14a). In the Other States region, the state with the largest area of soy with deforestation was Mato Grosso (0.076 million hectares), followed by Goiás (0.047 million hectares). These two states together represent 65.9% of the soy area with deforestation in this region (Figure 15a).

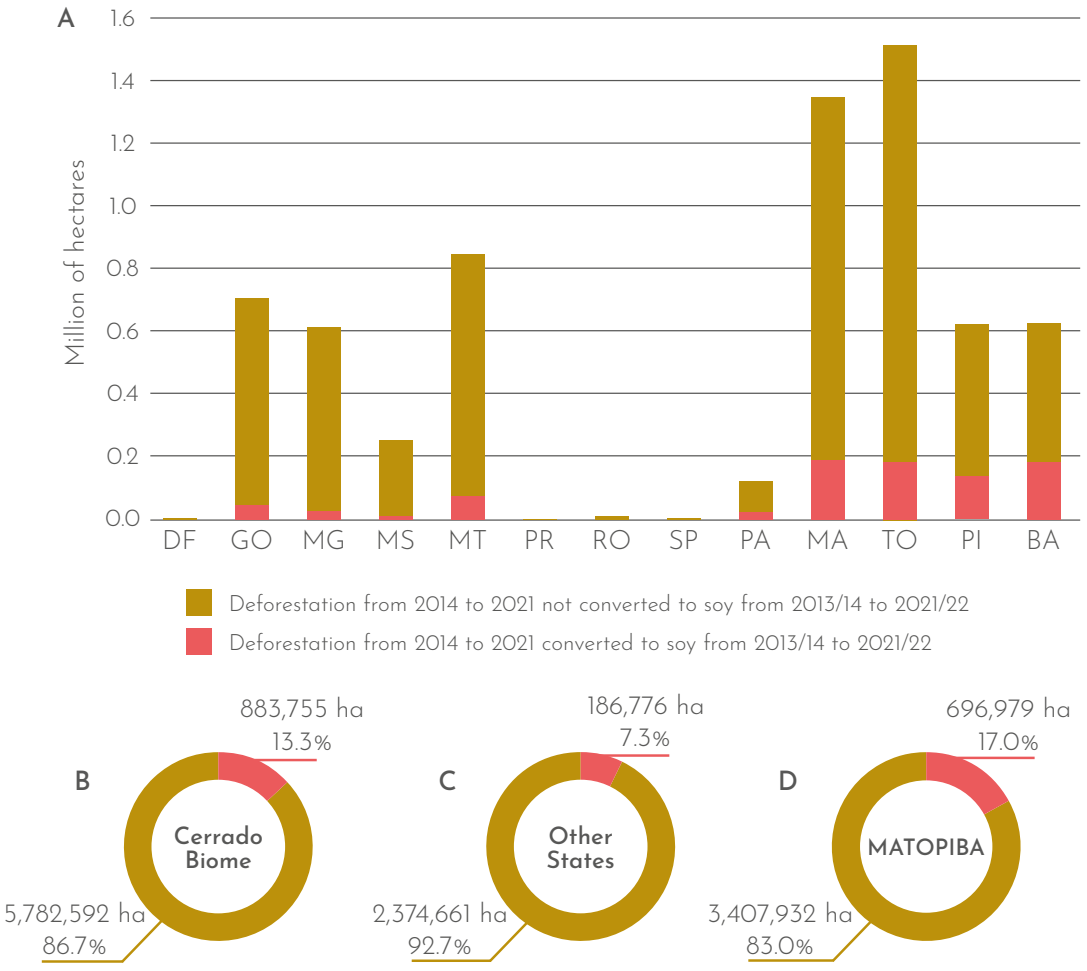

Figure 15. Deforested area in the period 2014 to 2021 (PRODES-Cerrado), with and without conversion to soy, based on the 2021/22 crop year, for a) that part of the states within the Cerrado Biome; b) Cerrado Biome; c) Other States; and d) MATOPIBA.

3.2 Change in land use and land cover from 2000/01 to 2021/22

Figure 16 presents the results of the dynamics of the change in land use and land cover in the process of soy's expansion and retraction in Other States and in MATOPIBA, for the eight--year period between the 2013/14 and 2021/22 crops (the results of this study) and for the two prior periods – the six-year period between the 2000/01 and 2006/07 crops, and the seven-year period between the 2006/07 and 2013/14 crops (Agrosatélite, 2015, 2018)[5].

The presence of soy in MATOPIBA is significantly less than that in Other States, but has been growing over time. As seen earlier (Item 1.1), this region's share of the Cerrado Biome's soy area grew from 13% in 2000/01 to 24% in 2021/22. Despite this growth, the average rate of native vegetation conversion into soy in this region, which reached 0.11 million hectares/year from 2006/07 to 2013/14, fell to 0.09 million hectares/year in the most recent period (2013/14 to 2021/22). In Other States, the average rate of native vegetation conversion into soy has remained relatively stable, with 0.02 million hectares/year from 2006/07 to 2013/14 and in the most recent period (Figure 16).

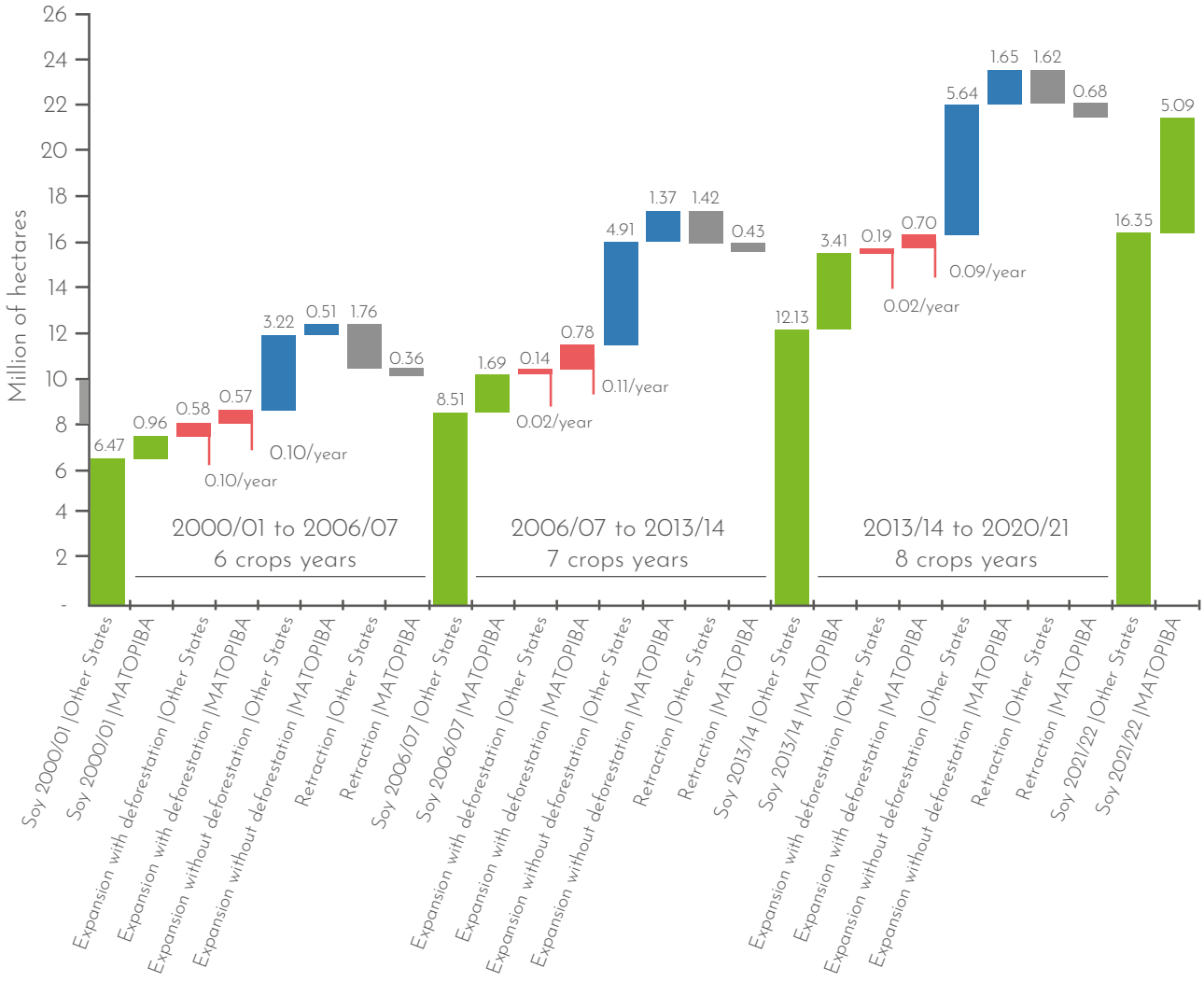

Figure 16. Change in land use and cover involved in the process of soy expansion and retraction in Other States and MATOPIBA in three periods: first period from 2000/01 to 2006/07; second period from 2006/07 to 2013/14; and third period from 2013/14 to 2021/22. Below the bars for expansion with deforestation (orange) is the annual rate of conversion of native vegetation into soy.

3.3 Details of the dynamics of expansion and retraction | 2013/14 to 2021/22

Figures 17 and 18 show cutouts of two distinct areas in terms of the dynamics of soy expansion in the Cerrado Biome to illustrate both the soy area's spatial distribution and the soy expansions with and without deforestation, in addition to retractions, in the period from 2013/14

to 2021/22[11]. In these Figures, soy expansion without deforestation onto pastures, fallow land and others is shown in blue without hatching, while soy expansion onto corn, first-crop cotton or sugarcane is shown in blue with hatching. Soy retraction is shown in grey without hatching when the area went over to fallow land or other uses, and grey with hatching when soy was rotated with corn, first-crop cotton or sugarcane.

From 2013/14 to 2021/22, soy's net expansion was 5.89 million hectares – total expansion was much larger (8.19 million hectares) due to the dynamics of soy production, where part of the soy crops rotated with other agricultural crops (corn, first-crop cotton and sugarcane renewal) or the land was left fallow (Footnote 9, Figures 17 and 18). Likewise, areas that had crops such as corn, first-crop cotton or sugarcane, or had been left fallow, could have rotated to soy. The dynamics of soy expansion therefore consist of incorporating into the production system the areas originating from conversion of native vegetation or from the intensification of land use by converting pastures, as well as the agricultural management practices of rotating crops and fallow land.

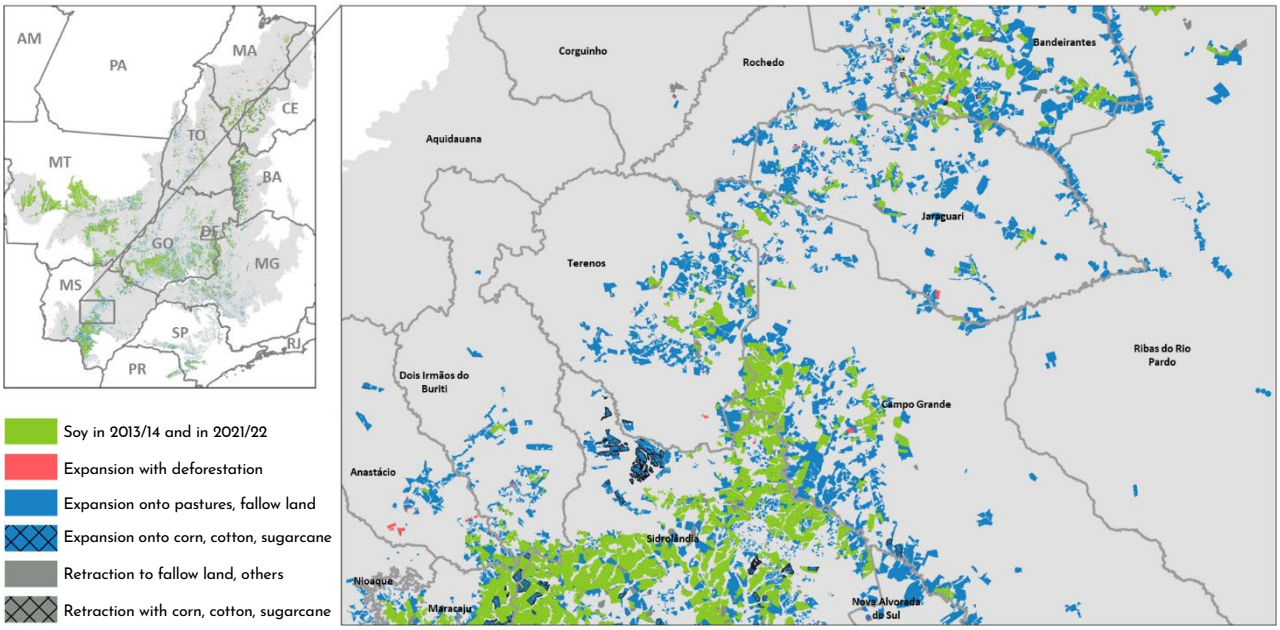

Figure 17. Territorial dynamics of soy from 2013/14 to 2021/22 in the central region of Mato Grosso do Sul, close to the state capital, Campo Grande, which concentrates large areas of pastures with high agricultural suitability for soy and which, in recent years, has shown increasing conversion into soy. This is what makes Mato Grosso do Sul the Cerrado Biome's state with the second-largest area of soy expansion in recent years, losing only to Goiás.

11. To quantify the dynamics of soy expansion-retraction, satellite images were used to evaluate the 2021/22 soy area that expanded without deforestation in 2013/14, separating them into: a) agricultural crops (first-crop corn and cotton, and sugarcane); b) fallow land or other uses; and c) pastures (Áreas de Pastagens do Brasil, 2014, basis LAPIG/MapBiomas). Furthermore, still based on the satellite images, the soy area in the 2013/14 crop year that suffered retraction due to crop rotation or else ceased to grow soy in the 2021/22 crop year (fallow land or other uses) was evaluated.

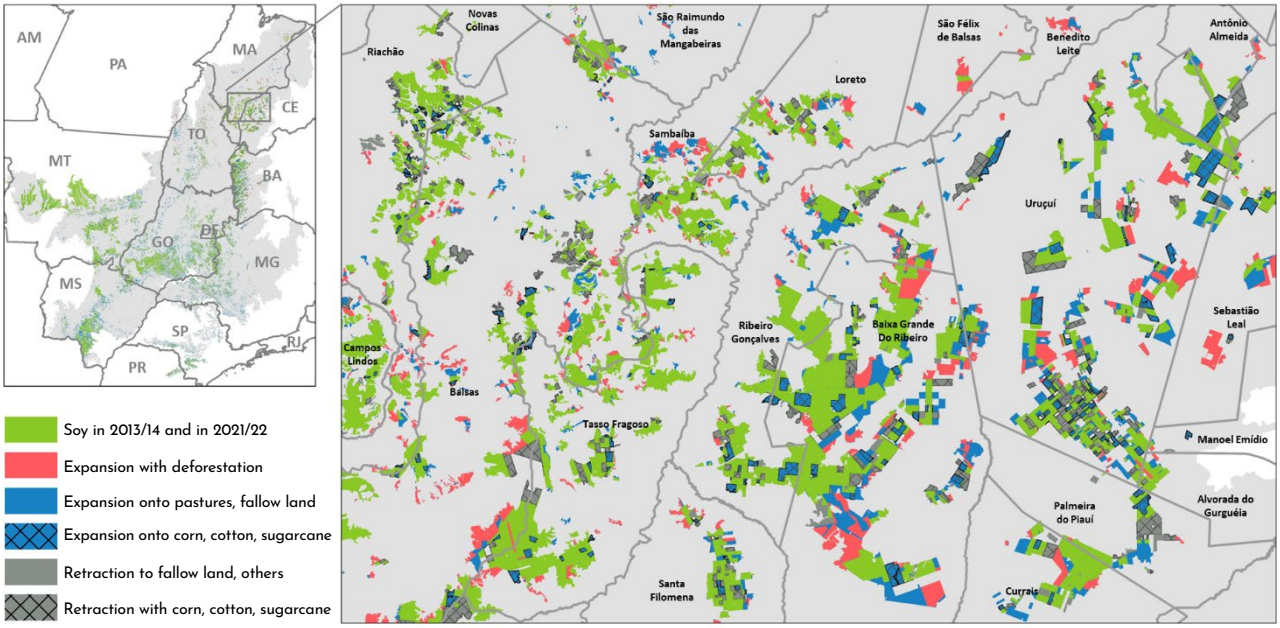

Figure 18. Territorial dynamics of soy from 2013/14 to 2021/22 in southern Maranhão and Piauí. This region is located in the most recent agricultural frontier in Brazil, where expansion with deforestation in the Cerrado Biome is more prevalent and where first-crop corn and cotton also rotate with soy.

The results of this detailed analysis are presented in Figure 19, which illustrates the transitions in land use and land cover associated with the soy dynamics in Other States and in MATOPIBA.

In Other States, the net expansion in soy area was 4.22 million hectares, of which:

- 1.50 million hectares expanded onto land that was fallow;
- 2.81 million hectares expanded onto pastures (intensification);
- 1.33 million hectares expanded onto annual crops (corn, first-crop cotton and sugarcane);
- 0.19 million hectares expanded onto deforested land.

In 2013/14, soy was grown on 1.61 million hectares that, in 2021/22, passed to fallow land (1.00 million hectares) or were used to grow corn, cotton or sugarcane (0.61 million hectares) as shown in Figure 19 (Other States).

In MATOPIBA, the net expansion in soy area was 1.68 million hectares, of which:

- 0.75 million hectares expanded onto land that was fallow;
- 0.40 million hectares expanded onto pastures (intensification);
- 0.50 million hectares expanded onto annual crops (corn, first-crop cotton and sugarcane);
- 0.70 million hectares expanded onto deforested land.

In 2013/14, soy was grown on 0.67 million hectares that, in 2021/22, passed to fallow land (0.21 million hectares) or were used to grow corn, cotton or sugarcane (0.46 million hectares) as shown in Figure 19 (MATOPIBA).

In both regions, a significant portion of the expansion in soy area was onto land that was fallow in 2013/14. Expansion onto annual crops is partly due to the rotation of soy with first-crop corn – a management practice that is still very common, especially in some regions of the states of Goiás and Minas Gerais – or when renewal of sugarcane fields rotates with soy, or even replacing sugarcane

with soy which has greater profitability (Canasat Project/Agrosatélite)[12]. Another point related to crop rotation is the replacement, in recent years, of first-crop cotton with soy in a large part of Mato Grosso state, since the production of second-crop cotton is increasing in this state. In Other States, expansion onto pastures is far more marked due to the considerable stock of degrading pastures with agricultural suitability. On the other hand, in MATOPIBA, a region located in Brazil's most recent agricultural frontier where agricultural consolidation is ongoing and where the stock of cleared land with agricultural suitability is relatively scarce, soy with conversion of native vegetation accounts for 13.7% (0.70 million hectares) of the soy area, compared to 1.1% (0.19 million hectares) in Other States, a region that is more consolidated and has an ample stock of anthropised land with agricultural suitability for soy. The contribution of pasture conversion to soy expansion was more relevant in Other States (2.81 million hectares) than in MATOPIBA (0.40 million hectares), a total of 3.22 million hectares in the Cerrado Biome in the most recent period.

An analysis of the data in CAR (Rural Environmental Registry) revealed that 95.4% (20.45 million hectares) of the soy area in crop year 2021/22 was grown on 96 thousand properties with CAR, considering a minimum area of ten hectares of soy, while the remaining 4.6% (0.99 million hectares) was grown on properties without CAR. Soy area with less than 10 hectares in properties with CAR represents only 0.11% of the total soy area.

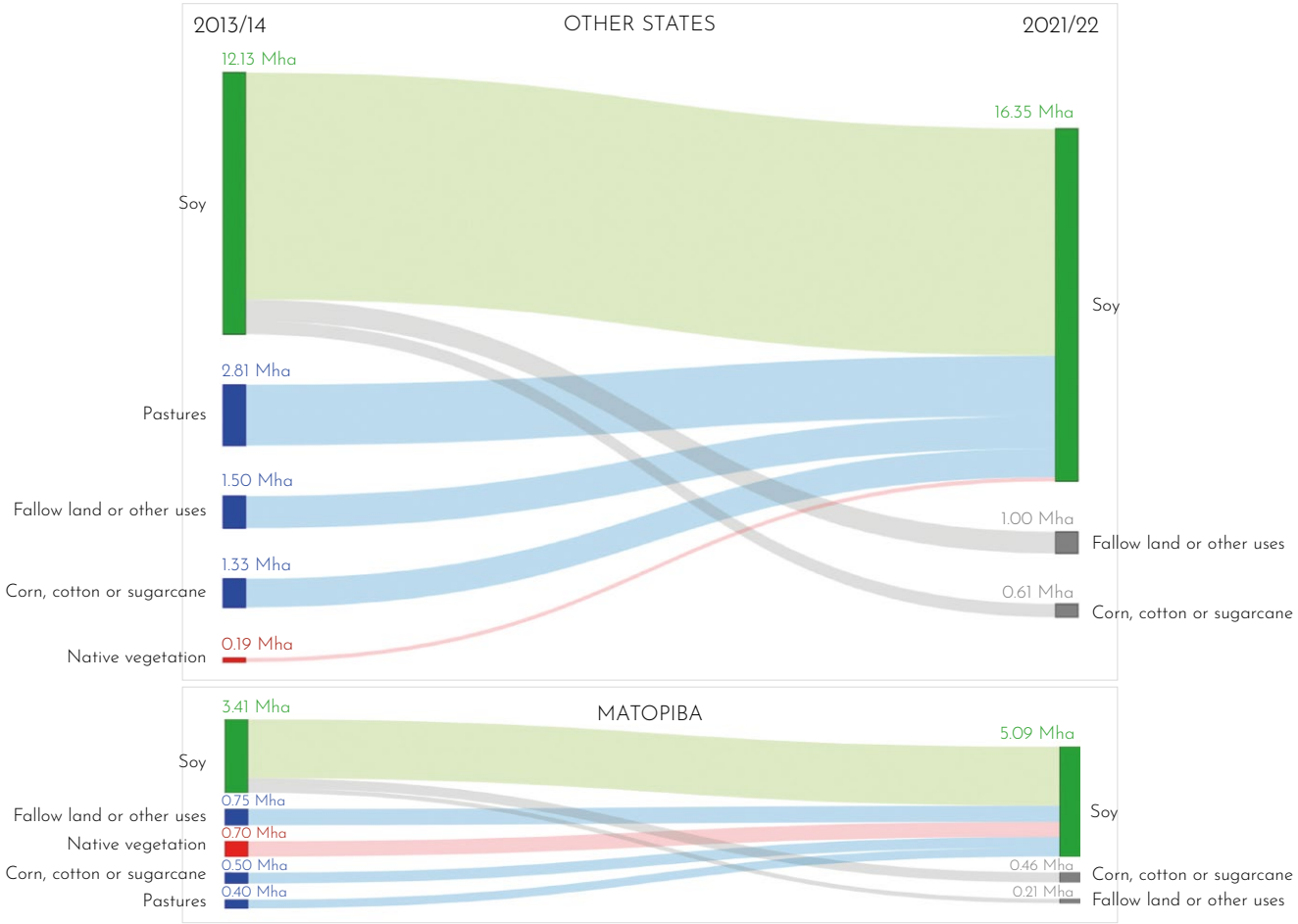

Figure 19. Sankey Diagram, illustrating the soy areas in the 2013/14 and 2021/22 crop years, together with the transitions in land use and land cover that occurred in that period in Other States and MATOPIBA.

12. This project is described and commented on https://agrosatelite.com.br/cases/#canasat.

4. Final Considerations and Recommendations

Over the last 21 years, soy has practically tripled its production area, going from 7.43 million hectares in 2000/01 to 21.43 million hectares in 2021/22. This area represents almost 11% of the Cerrado Biome and 50% of the soy produced in Brazil, according to Agrosatélite's satellite image survey (42.85 million hectares), using the more refined map boundaries for the Cerrado Biome published by IBGE in 2019.

Soy's favourable price accelerated the growth of the soy area in the Cerrado Biome. The average annual growth rate over the 21 crop years was 0.667 million hectares, but it has doubled in the last two years to 1.321 million hectares per year (1.172 million hectares in 2020/21 and 1.470 million hectares in 2021/22).

The dynamics of the land use change associated with soy production differ significantly between the MATOPIBA region and the Other States region, especially as it relates to conversion of native vegetation. In Other States, the soy associated with conversion of native vegetation in the most recent period from 2013/14 to 2021/22 represents just 1.1% (0.187 million hectares) of the soy area in the 2020/21 crop, while in MATOPIBA it represents 13.7% (0.697 million hectares) and in the Cerrado Biome as a whole it represents 4.1% (0.884 million hectares).

In the Other States region, there was a very significant reduction in soy expansion with deforestation from the first to the second period, going from 96,000 hectares per year to 20,000 hectares per year, respectively. However, in the third period, this rate increased slightly (23,000 hectares per year).

In the MATOPIBA region, the rates for converting native vegetation into soy remained relatively stable in each of the periods analysed, with 95,000 hectares, 110,000 hectares and 87,000 hectares per year in the first, second and third periods, respectively.

This shows that there is a marked difference between these two soy-producing regions in the Cerrado Biome. The Other States region, considered more consolidated, has an ample stock of cleared land with agricultural suitability, so that there is less pressure on the native vegetation in soy-producing properties. On the other hand, in MATOPIBA, the stock of land that has been cleared for a longer time is limited, when compared to the stock of suitable land with native vegetation, so that a good portion of the soy expansion with deforestation is still a reality in this region.

With the new map of Brazil's biomes, published by IBGE in 2019, the Cerrado Biome went from 204,007,393 hectares to 198,455,393 hectares, a reduction of 5,552,000 hectares (-2.7%) and now represents 23.3% of Brazil's territory. However, the alteration has repercussions on a much larger territory: 20,059,783 hectares are no longer part of the Cerrado Biome while another 14,507,783 hectares have been included in this Biome. A comparison of the soy area of previous crop year (2020/21) between the former and the current Biome boundaries shows that 983,923 hectares (4.9%) were incorporated into the Cerrado Biome, while another 1,021,424 hectares (5.1%) are no longer part of the Biome. This means that the soy area remains almost unchanged, with a reduction of only 0.2%.

Appendix 1 Differences between the Brazilian biome maps

The first map of Brazil's biomes, published by the IBGE (Brazilian Institute of Geography and Statistics) in 2004, was based on the Map of Brazilian Vegetation on a scale of 1:5,000,000. In 2019, a second version with more detailed boundaries was published, based on the Map of Brazilian Vegetation on a scale of 1:250,000.

Table A1 shows the area, in hectares, of the six Brazilian biomes, comparing the 2004 and 2019 maps, together with the areas of loss and gain that occurred in each biome due to improvements, both in the scale of the map and in better allocation of the phytophysiognomies. The comparison of these areas was made using the Brazil Albers Conic projection. The Cerrado Biome went from 204,007,393 hectares to 198,455,393 hectares, a reduction of 5,552,000 hectares (-2.7%), and now represents 23.3% of Brazil's territory. However, the territorial change impacted a much larger area as 20,059,783 hectares ceased to be part of the Cerrado Biome, while a further 14,507,783 hectares were included in this Biome.

Biome	IBGE, 2004	IBGE, 2019							
	Area (ha) (a)	Area (ha) (b)	Diff % (b-a)/a	Matching		Loss		Gain	
				Area (ha) (c)	% (c/a)	Area (ha) (d)	% (d/a)	Area (ha) (e)	% (e/a)
Amazon	419,905,838	421,543,440	0.4%	416,632,722	99.2%	3,273,116	0.8%	4,910,718	1.2%
Caatinga	82,796,057	86,263,953	4.2%	75,518,287	91.2%	7,277,771	8.8%	10,745,666	13.0%
Cerrado	204,007,393	198,455,393	-2.7%	183,947,611	90.2%	20,059.783	9.8%	14,507,783	7.1%
Atlantic Forest	111,786,485	110,684,551	-1.0%	104,179,287	93.2%	7,607,198	6.8%	6,505,264	5.8%
Pampa	16,581,294	19,394,730	17.0%	16,272,406	98.1%	308,888	1.9%	3,122,325	18.8%
Pantanal	15,118,241	15,096,104	-0.1%	14,009,759	92.7%	1,108,481	7.3%	1,086,345	7.2%
Total	**850,195,308**	**851,438,172**	**0.1%**	**810,560,072**	**95.3%**	**39,635,236**	**4.7%**	**40,878,100**	**4.8%**

Table A1. Area in hectares of the six Brazilian biomes in the 2004 and 2019 map versions, and the areas of loss and gain in each biome.

Brazil's official territory is 8,510,345.54 km², published in D.O.U. No. 38 (Brazil's official federal gazette) on 23 February 2022, in accordance with Ordinance No. PR-73 on 21 February 2022. This area concurs with the 2021 IBGE's Municipal Network, available on: **https://www.ibge.gov.br/geociencias/organizacao-do-territorio/estrutura-territorial/15761-areas-dos-municipios.html?=&t=acesso-ao-produto**.

Differences in the 2020/21 soy area between the two map versions (2004 and 2019) for the Cerrado Biome

A comparative assessment between the former and current boundaries of the Cerrado Biome, as they relate to soy crops in the 2020/21 crop year, is shown in Table A2. This table shows that, with the new Biome boundaries, 1,021,424 hectares are no longer part of this Biome, while a further 983,923 hectares have been included in the Biome. Despite the significant alteration in the Biome's territory caused by the new 2019 biome map, the gains and losses in soy area practically cancel each other out. The net reduction in soy area is 37,500 hectares (0.2%).

IBGE MAP, 2004	IBGE MAP, 2019								
Soy Area Old Boundaries (a)	Soy Area New Boundaries (b)	Difference %		Matching		Loss		Gain	
		Soy Area (b-a)	% (b-a/a)	Soy Area (c)	% (c/a)	Soy Area (d)	% (d/a)	Soy Area (e)	% (e/a)
20,000,983	19,963,483	-37,500	-0.2%	17,995,636	90.0%	1,021,424	5.1%	983,923	4.9%

Table A2. Soy area in hectares for the 2020/21 crop year, according to the 2004 and 2019 map versions, and the areas of soy loss and gain in each biome.

Figure A1 shows in red the soy areas that passed from the Cerrado Biome to other biomes and in green the soy areas that became part of the Cerrado Biome with the new 2019 IBGE boundaries. The southern part of Mato Grosso do Sul state had a significant gain in soy area. São Paulo state and the Triangle region of Minas Gerais state had a loss in their soy areas, which passed to the Atlantic Forest Biome for a better allocation of the Cerrado phytophysiognomy. All along the new boundary between the Cerrado and the Amazon Biomes there were several losses and gains in soy areas.

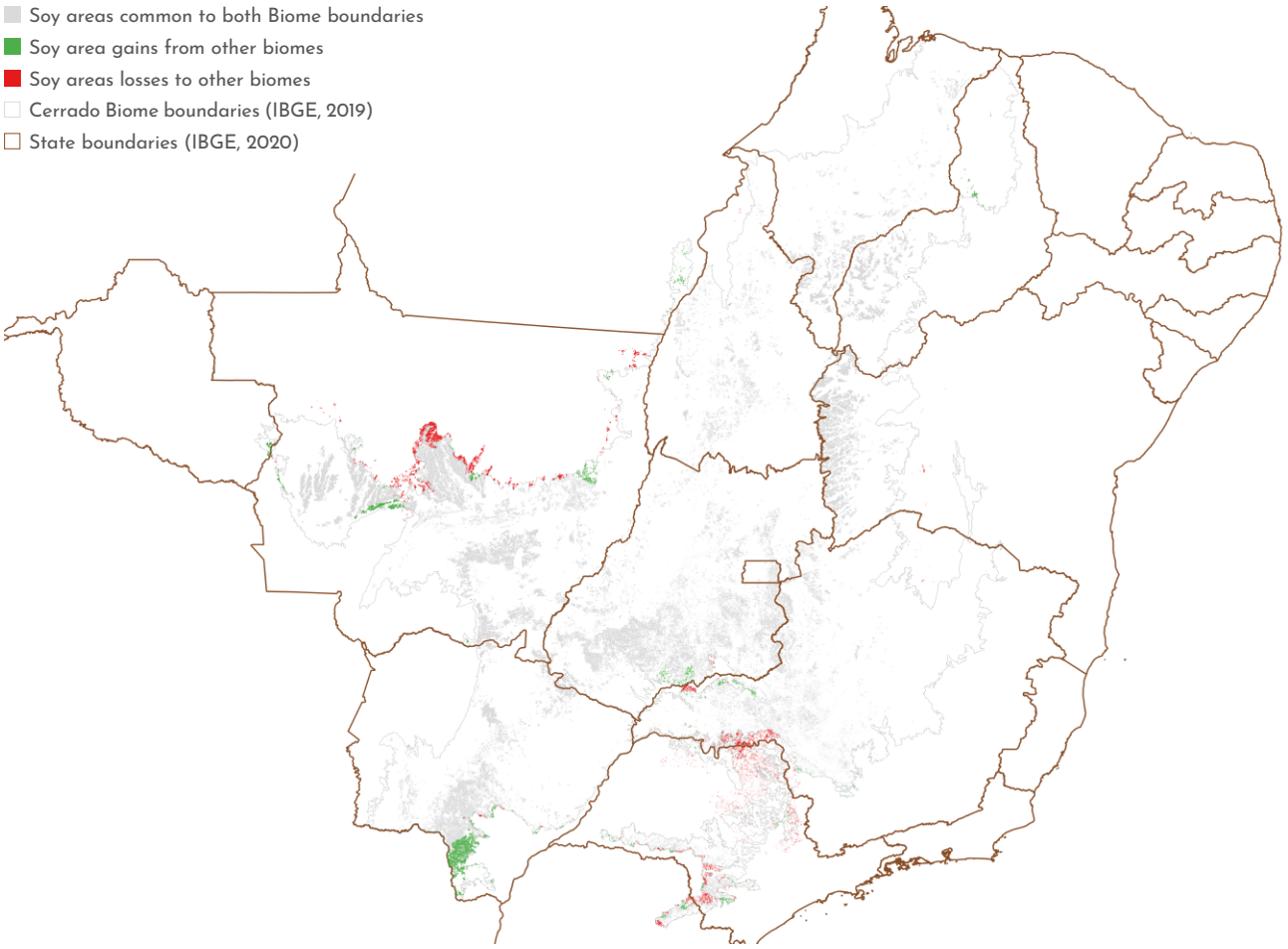

Figure A1. Map of the soy area for the 2020/21 crop year in the Cerrado Biome, showing in green the soy area that passed to the Cerrado and in red the soy area that passed to other biomes.

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