Geospatial Analysis of Soy Crop

Cerrado Biome

EXPANSION DYNAMICS | AGRICULTURAL SUITABILITY

EVALUATION SYSTEM FOR FINANCIAL COMPENSATION

2001 — 2019

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EXECUTIVE SUMMARY

Agrosatélite has been dedicating its efforts to produce studies with objective information on the growing expansion of soy crops in the Cerrado Biome. Thousands of satellite images acquired since the year 2000 were processed and analyzed to follow the evolution of soy crops, both because of its economic importance and because of the socio-environmental concerns related to soy expansion in the Cerrado Biome.

This study updates the historical data series, offering greater insight into the most recent trends regarding the land use and land cover changes resulting from soy expansion. It also provides information on the spatial distribution of native vegetation and anthropic areas with agricultural suitability for soy. To complement this information, the study presents a system that assesses the agricultural suitability of native vegetation in areas that are surplus to the Legal Reserves within soy properties – and to verify if these properties are qualified to receive financial compensation for maintaining the surplus area. To better understand regional diversity trends, the Cerrado Biome was divided into two areas: Other States (which includes the states of Mato Grosso, Goiás, Minas Gerais, Mato Grosso do Sul, São Paulo, Paraná and Rondônia as well as the Federal District) and Matopiba (the states of Maranhão, Tocantins, Piauí and Bahia).

The study shows that, in the last 18 crop years, the soy area in the Cerrado has grown 2.4 times, going from 7.53 million hectares to 18.20 million hectares. Currently, 51% of the national soy area is located in the Cerrado Biome. Almost a third of the expansion was concentrated in Matopiba, where the soy area went from 1.0 million hectares to 4.3 million hectares during the same period – in 2018/19, this region had 23% of the soy area in the Cerrado. More recently, from 2013/14 – 2018/19, there was a slight fall in the Biome's annual rate of soy expansion, driven mostly by the expansion decrease in Matopiba.

Soy expansion in deforested areas of the Cerrado has been continuously decreasing, going from 215 thousand hectares per year in the period 2000/01-2006/07 to 192 thousand hectares per year in the period 2006/07 – 2013/14. From 2013/14 – 2018/19, it fell further to 73 thousand hectares per year.

Both in Matopiba and in Other States, crop rotation and fallow lands have a direct effect on the dynamic of soy expansion between crop years. Conversion of pastures is more relevant in Other States, contributing to 67.2% of the expansion seen in the period 2013/14 – 2018/19 – in this region, whereby during the same period, deforestation represented just 4.4% (0.08 million hectares) of the net expansion in soy area.

In Matopiba, conversion of pastures contributed less, just 28.6% (0.22 million hectares) from 2013/14 – 2018/19, while deforestation contributed more, representing 36.4% (0.28 million hectares) of the net soy expansion. However, the falling trend that is evident when comparing soy expansion in the period 2013/14 – 2018/19, with the two prior periods (2000/01 – 2006/07 and 2006/07 – 2013/14), needs to be noted.

The Cerrado Biome has an anthropic area of 95.73 million hectares (46.8%), whereby 26.14 million hectares are pastures in areas with agricultural suitability for soy. The soy area in the Cerrado is expected to grow as much as 5.0 million hectares by the 2028/29 crop year. Pastures should supply most of the land for the next soy expansion cycle. The area of pastures is huge in the Other States region (22.55 million hectares), but much smaller in Matopiba (3.59 million hectares, whereby 79%, or 2.83 million hectares, are concentrated in Tocantins state). The biggest potential for conversion can be found in the 6.10 million hectares of suitable pastures in rural properties of the Cerrado Biome that already produce soy. In these properties, the surplus of native vegetation suitable for soy is 4.41 million hectares, distributed almost equally between the Other States (2.25 million hectares) and Matopiba (2.16 million hectares). This area represents the total available for financial compensation under the mechanism currently being developed for the Cerrado Biome.

The evaluation of eligibility for financial compensation will be made using a system named CCM – Cerrado Conservation Mechanism, a web platform developed to aid the various players involved in this conservation mechanism, available online at https://psacerrado.com.br.

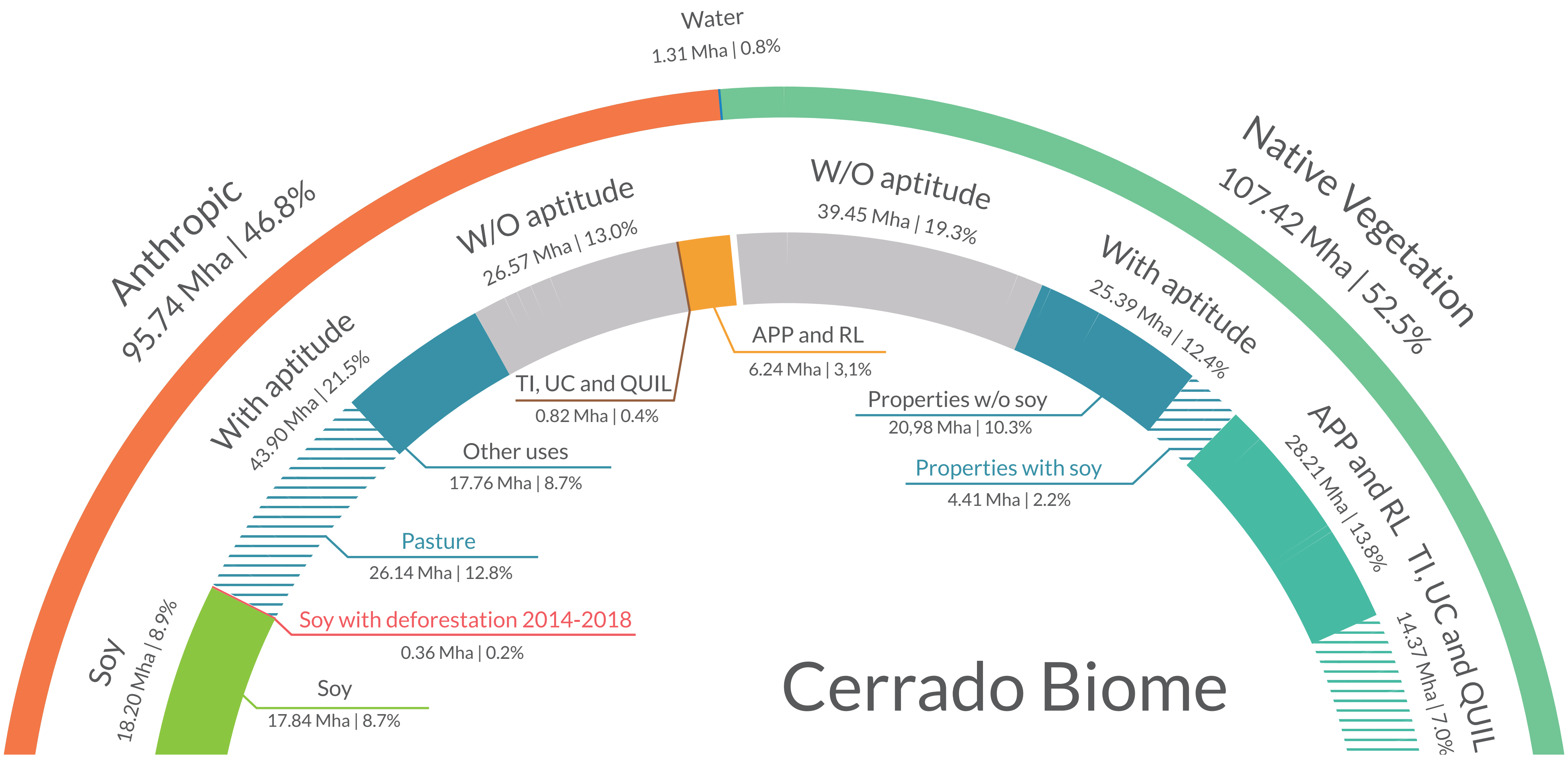
Water
1.31 Mha | 0.8%
Anthropic
95.74 Mha | 46.8%
Native Vegetation
107.42 Mha | 52.5%
W/O aptitude
26.57 Mha | 13.0%
W/O aptitude
39.45 Mha | 19.3%
With aptitude
43.90 Mha | 21.5%
With aptitude
25.39 Mha | 12.4%
TI, UC and QUIL
0.82 Mha | 0.4%
APP and RL
6.24 Mha | 3,1%
Properties w/o soy
20,98 Mha | 10.3%
Properties with soy
4.41 Mha | 2.2%
Other uses
17.76 Mha | 8.7%
Pasture
26.14 Mha | 12.8%
Soy with deforestation 2014-2018
0.36 Mha | 0.2%
Soy
17.84 Mha | 8.7%
Soy
18.20 Mha | 8.9%
APP and RL
28.21 Mha | 13.8%
TI, UC and QUIL
14.37 Mha | 7.0%
Cerrado Biome

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Image of 02/13/2019, São Desidério - BA | Landsat-8, Path/Row 220/69, 5(R)6(G)4(B).

1. INTRODUCTION

The Cerrado Biome covers a quarter of Brazil's territory. It has a rich biodiversity, is the source of Brazil's main aquifers, and brings together favourable conditions for developing large-scale agriculture. Over the last two decades, these characteristics have resulted in an intense transformation of the Biome's landscape, in which soy production plays an important role.

To better understand the dynamic of soy expansion in the Cerrado, the Biome can be divided into two large regions. One region, called Other States in this study, covers two-thirds of the Biome and includes the states of Mato Grosso, Goiás, Minas Gerais, Mato Grosso do Sul, São Paulo, Paraná, Rondônia and the Federal District. More intense agricultural activity on a large scale began in the 1960s and has now reached the point of consolidation, although it continues to have several expansion fronts as this region still has large tracts of land suitable for soy production that are currently used for pastures. The second region, called Matopiba, includes the states of Maranhão, Tocantins, Piauí and Bahia, and occupies one-third of the Biome. Exploration of this region began in the 1980s. It is currently an important agricultural production centre and features in the debates on deforestation-free soy production because this region has the highest rates of recent deforestation, as well as the highest proportion of the Biome's native vegetation that are partially suitable for soy production.

This study makes a geospatial analysis of the soy dynamic in the Cerrado Biome in order to provide detailed information regarding the expansion of this crop from 2000/01 to 2018/19 – highlighting the most recent period 2013/14-2018/19. To assess soy's footprint in the Biome's deforestation, the contribution of soy production to land use and land cover changes was also analysed. Furthermore, the study analyses at length the region's agricultural suitability for soy with the objective to assess, spatially and quantitatively, the land with high and medium edaphoclimatic conditions, without slope and altitude restrictions, in areas of native vegetation and in anthropic areas. Finally, an online system was developed to assess the eligibility of rural producers to a financial compensation mechanism for maintaining the native vegetation in the area that was authorised for clearance, based on the following requirements: be a current soy producer, meet the minimum criteria for socio-environmental compliance, and the area must have agricultural suitability for soy production.

Image of 01/10/2019, Palmas - TO | Landsat-8, Path/Row 220/67, 5(R)6(G)4(B).

2. DYNAMIC OF SOY EXPANSION

2.1 EVOLUTION OF THE SOY PLANTED AREA

The images acquired by satellites orbiting our planet[1] are an excellent source of information to observe the accelerated dynamic of agricultural activity and its contribution to the land use and land cover changes. These images were used in previous studies carried out by Agrosatélite to map soy in the Cerrado Biome in crop years 2000/01, 2006/07, 2013/14 and 2016/17, with fundings from the Gordon & Betty Moore Foundation, ABIOVE and TNC[2]. In this study, the images were used to update the historical mapping sequence for crop year 2018/19, with a view to increase the understanding of the recent soy expansion in the Cerrado Biome and its regional peculiarities. In addition to the spatial distribution of the soy fields, it was possible to obtain estimates of planted areas from the rural properties level, going through municipalities and states, up to the Biome as a whole[3].

Table 1 shows the soy area in the Cerrado Biome in crop year 2018/19, by state, mapped by Agrosatélite, including information on the planted area in crop years 2013/14 and 2016/17 from prior studies. As can be seen, 72.7% of the soy in the Cerrado is in the states of Mato Grosso, Goiás, Mato Grosso do Sul and Minas Gerais.

Table 1. Soy area in the Cerrado Biome for crop years 2013/14, 2016/17 and 2018/19, by state, in hectares and as a percentage.

State	2013/2014		2016/2017		2018/2019	
	ha	%	ha	%	ha	%
DF	80,211	0.5	88,572	0.5	93,496	0.5
GO	3,472,889	22.3	3,644,519	21.4	3,954,372	21.7
MG	1,267,109	8.1	1,531,541	9.0	1,778,323	9.8
MS	1,375,051	8.8	1,652,907	9.7	1,848,181	10.2
MT	5,524,610	35.4	5,630,600	33.0	5,636,978	31.0
PR	70,952	0.5	79,499	0.5	91,831	0.5
SP	402,992	2.6	496,431	2.9	618,544	3.4
RO	0	0.0	431	0.0	489	0.0
Other States	12,193,814	78.2	13,124,500	76.9	14,022,214	77.0
MA	680,550	4.4	748,482	4.4	816,521	4.5
TO	675,835	4.3	914,009	5.4	1,018,243	5.6
PI	617,219	4.0	653,375	3.8	718,304	3.9
BA	1,433,741	9.2	1,627,367	9.5	1,629,217	8.9
Matopiba	3,407,345	21.8	3,943,233	23.1	4,182,285	23.0
Cerrado Biome	15,601,159	100.0	17,067,733	100.0	18,204,499	100.0

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

Figures 1 to 5 illustrate the soy maps in the Cerrado Biome for five crop years (2000/01, 2006/07, 2013/14, 2016/17 and 2018/19). Each figure shows four enlarged sections of the less-consolidated regions, in which soy became relevant as from the year 2000. This is the case of section I, the Paranatinga/MT municipality, where the soy area in the Cerrado Biome went from 32 thousand hectares in 2006/07 to 156 thousand hectares in 2013/14, increasing almost fivefold in eight years. Since then, expansion has slowed, and reached an area of 174 thousand hectares in 2018/19. The regions surrounding Balsas in Maranhão state, and Baixa do Rio Grande in Piauí state (both on section II), as well as the areas surrounding Barreiras in Bahia state (section III) and those surrounding Porto Nacional in Tocantins state (section IV) have also seen an intense expansion of soy production, growing four- or five-fold in less than 20 years – all these areas lie within Matopiba, Brazil's new and important agricultural frontier.

1 For this study, images were acquired from the Landsat and Sentinel-2 satellites in the visible, the near infrared and the medium infrared wavelengths of the electromagnetic spectrum, with spatial resolution between 10 and 30 metres (~100 at 10 pixels per hectare). The joint operation of these satellites allows the same location to be revisited at intervals of two to five days, which favours the acquisition of cloud-free images during critical periods to identify soy fields. Approximately 3,150 images were available to accurately identify the soy in crop year 2018/19 in the Cerrado Biome by visual image interpretation techniques. The starting point was the soy map for crop year 2016/17. The visual interpretation procedure also took into consideration the analysis of time series of images from the MODIS sensor, transformed into the EVI (Enhanced Vegetation Index) in the form of 16-day temporal compositions by consulting EMBRAPA's SatVeg project web application (www.satveg.cnptia.embrapa.br). The following RGB coloured compositions of the images were used: 4-5-3 bands for the ETM+ sensor/Landsat-7; 5-6-4 bands for the OLI sensor/Landsat-8; and 8a-11-4 bands for the MSI sensor/Sentinel-2. The soy map for crop year 2016/17, preformed by Agrosatélite, was validated by a third party (University of Maryland), based on field data, with a global mapping accuracy of 98.4%.

2 Reports available for public consultation on https://agrosatelite.com.br/en/cases/#expansao-agricola.

3 The boundaries of the Cerrado Biome used in this study were those defined by the IBGE on a scale of 1:5,000,000 (https://www.ibge.gov.br/geociencias/informacoes-ambientais/15842-biomas.html)

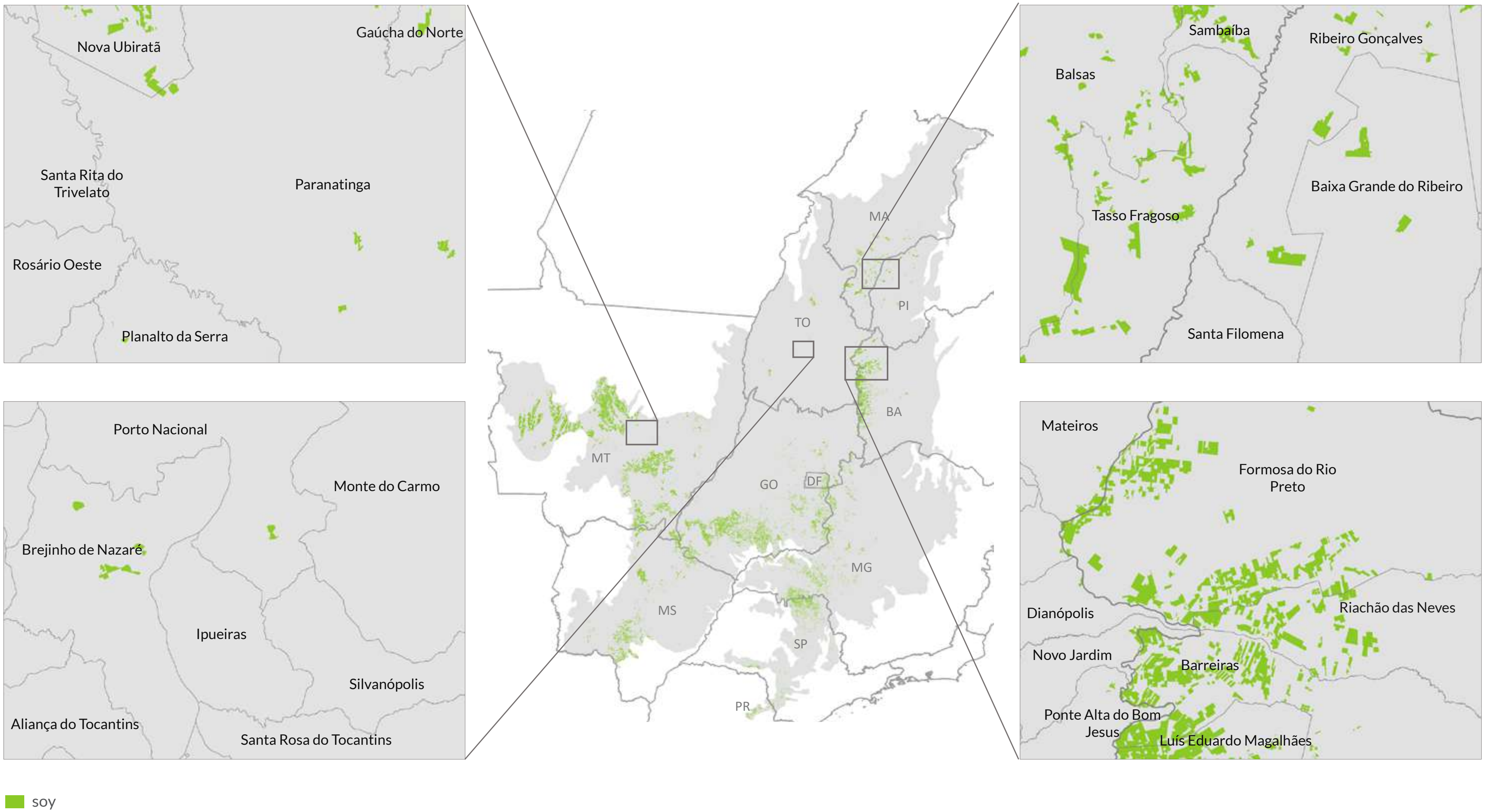


Figure 1. Soy map in the Cerrado for crop year 2000/01, highlighting the regions which have seen significant expansion in their soy production over the last 18 years.

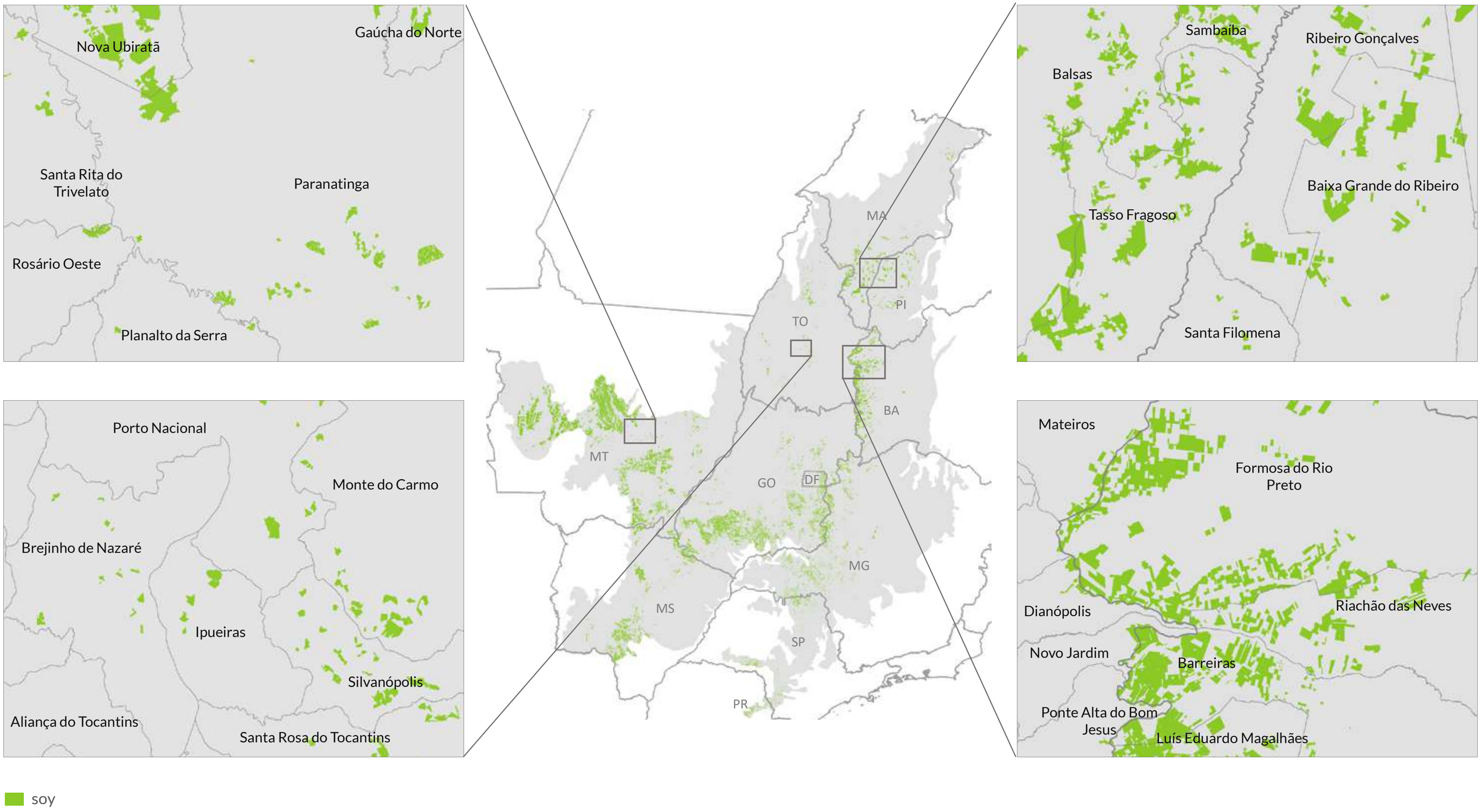


Figure 2. Soy map in the Cerrado for crop year 2006/07, highlighting the regions which have seen significant expansion in their soy production over the last 18 years.

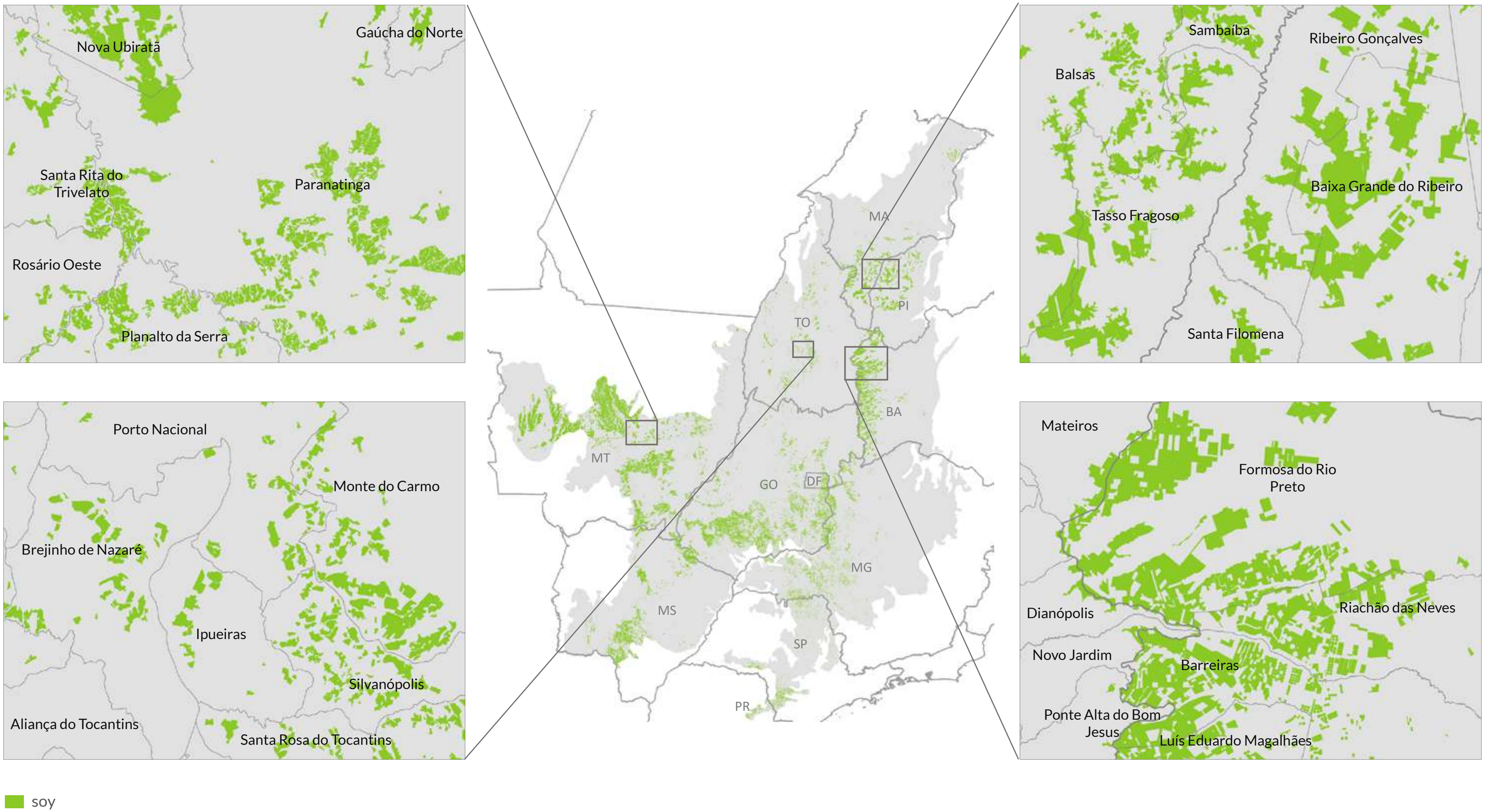


Figure 3. Soy map in the Cerrado for crop year 2013/14, highlighting the regions which have seen significant expansion in their soy production over the last 18 years.

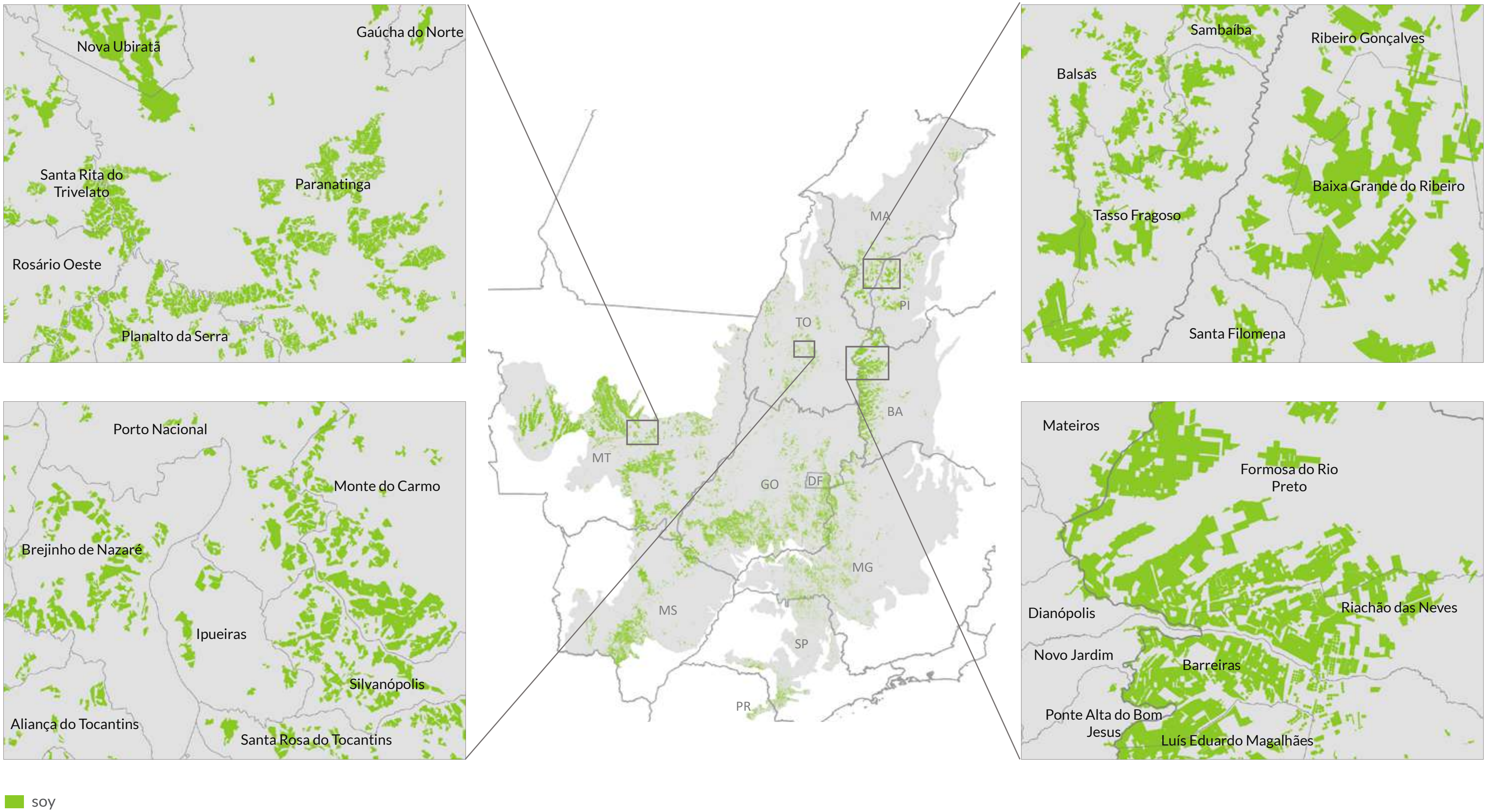


Figure 4. Soy map in the Cerrado for crop year 2016/17, highlighting the regions which have seen significant expansion in their soy production over the last 18 years.

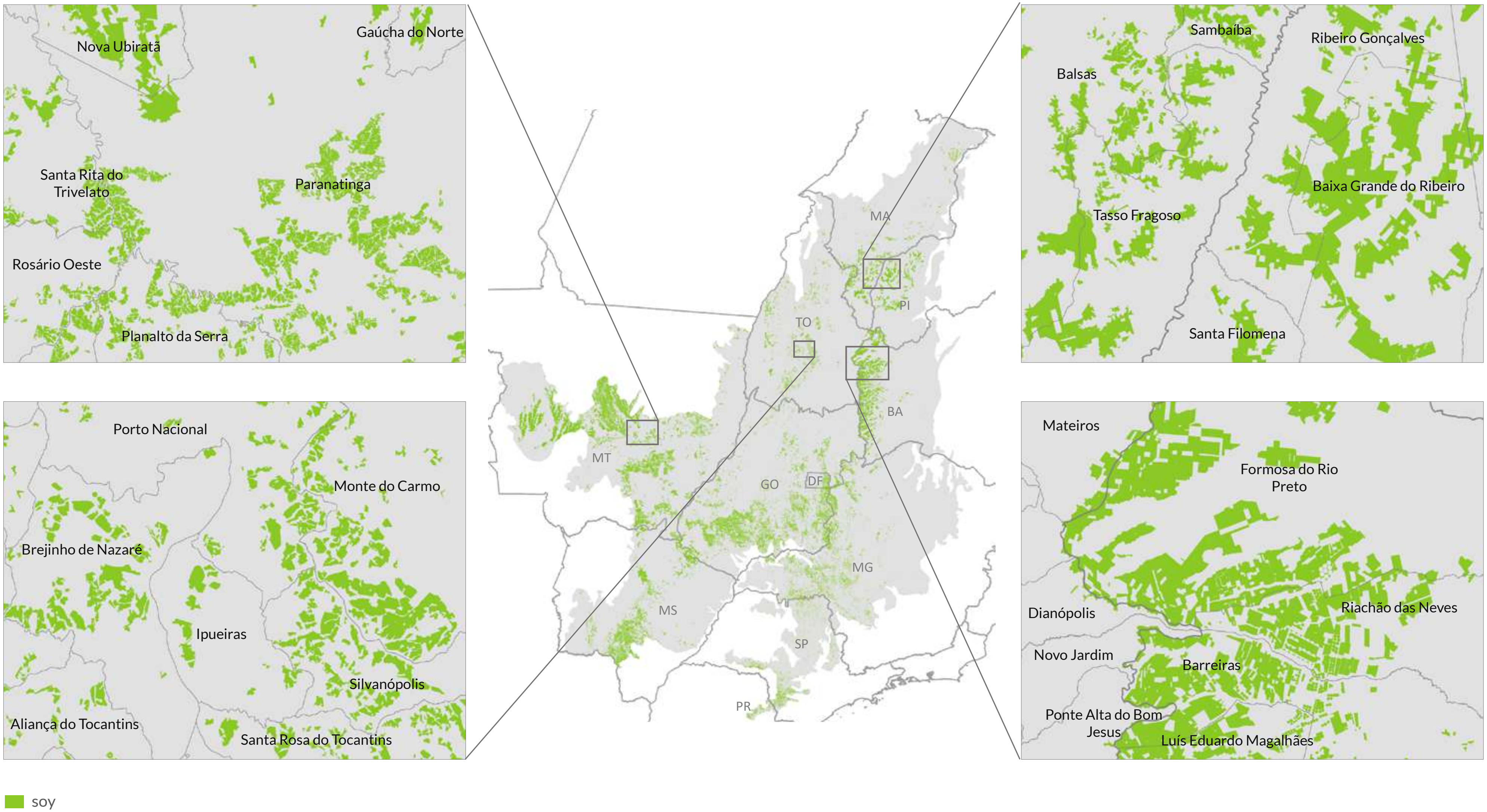
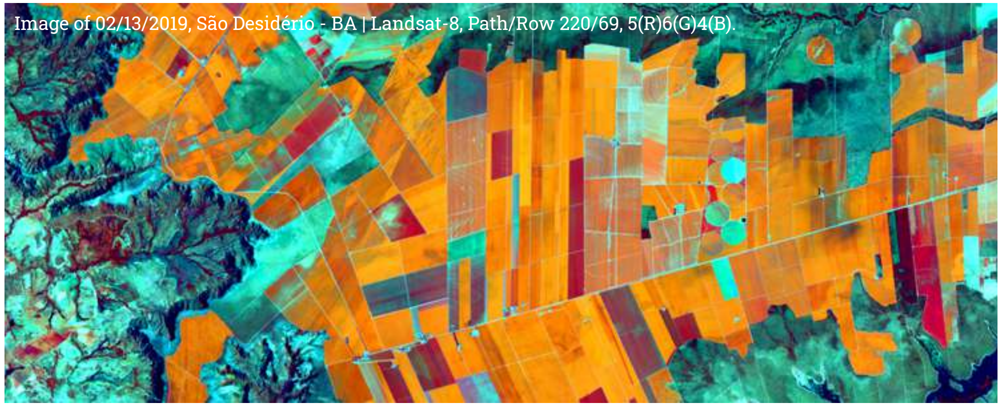


Figure 5. Soy map in the Cerrado for crop year 2018/19, highlighting the regions which have seen significant expansion in their soy production over the last 18 years.

Figure 6 shows the evolution of soy areas in Other States[4] and in Matopiba[5] for the same five crop years shown in Figures 1-5. During these 18 years, the soy area in the Cerrado Biome grew 2.4 times, going from 7.53 million hectares in 2000/01 to 18.20 million hectares in 2018/19, and currently represents 51% of Brazil's soy area[6]. During this same period, the soy area in Matopiba increased 4.3 times, going from 0.97 million hectares to 4.18 million hectares, and this region's share of the Cerrado's soy went from 13% to 23%. Other States account for 77% of the Biome's soy area, with a growth in area of 7.46 million hectares (113%) from 2000/01 to 2018/19.

On average, the annual expansion rate for soy in the Cerrado was 590 thousand hectares per year, of which 410 thousand hectares/year were in Other States and 180 thousand hectares/year in Matopiba. In the more recent period (2016/17 to 2018/19), the rate of expansion fell to 570 thousand hectares/year – slightly lower than the average from 2001 to 2019. This deceleration was driven by Matopiba, where growth over the last two crop years fell to 120 thousand hectares/year, 33% below the average for the full period. This has more than offset an acceleration of 10% in the growth of the soy area in Other States, which increased to 450 thousand hectares/year from 2016/17 to 2018/19.



4 In this study, the term Other States refers to the following states of the Cerrado Biome that are not included in Matopiba: Goiás - GO, Minas Gerais - MG, Mato Grosso do Sul - MS, Mato Grosso - MT, São Paulo - SP, Paraná - PR and Rondônia - RO, as well as the Federal District - DF.

5 Matopiba is a region made up of the states of Maranhão – MA, Tocantins – TO, Piauí – PI and Bahia – BA, in that portion of these states that lies within the Cerrado Biome and in the transition areas with the Amazon Biome, where there has been an intense transformation of the landscape caused by the expansion of high-tech agriculture. The small portion of Matopiba that lies within the Amazon Biome is not part of this study.

6 CONAB (Companhia Nacional de Abastecimento), the National Supply Company. Acompanhamento da Safra Brasileira – Grãos. V. 6. Safra 2018/19, n. 12, September 2019. Brasília, 47 p. 2019.

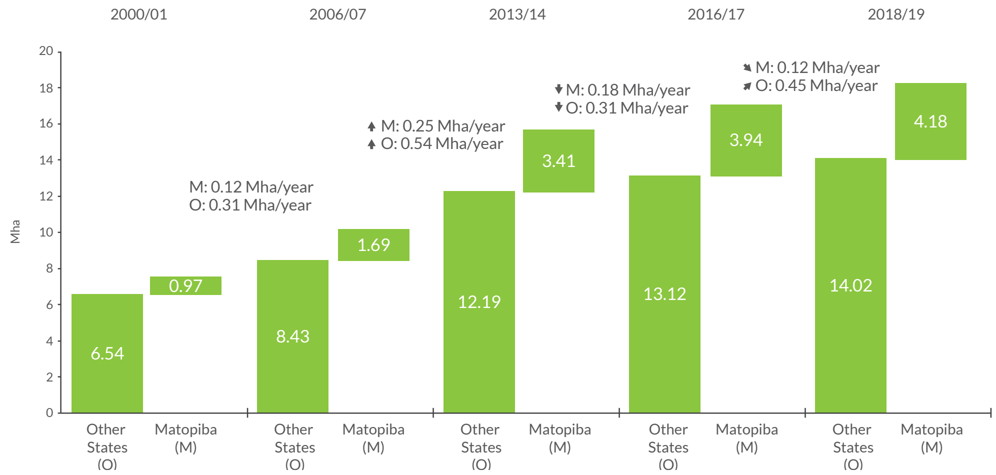


Figure 6. Soy area evolution from crop years 2000/01 to 2018/19 in Other States and in Matopiba, with the annual growth rate observed in four periods: 2000/01 to 2006/07; 2006/07 to 2013/14; 20013/14 to 2016/17; and 2016/17 to 2018/19.

An analysis based on data from Rural Environmental Registry (CAR)[7] revealed that 94.7% (17.2 million hectares) of the soy area in the 2018/19 crop year was grown on 121,893 properties, while the remaining 5.7% (0.97 million hectares) was grown on properties without CAR registration, of which 0.75 million hectares were in Other States and 0.22 million hectares in Matopiba.

Table 2 shows the results of the analysis of the soy area in crop year 2018/19, both outside and inside the Special Areas. As can be seen, 93.5% of the Biome's soy area is located outside these Special Areas. If the APA (Areas of Environmental Protection)[8] and ASS (Settlements) are removed from Special Areas because agriculture is permitted in these two areas, then this number rises to 97.9%. Soy crops in APAs is the most relevant, with 372 thousand hectares in Matopiba and 262 thousand hectares in Other States, corresponding to 3.5% of the Biome's soy crops. In second place comes soy, with 343 thousand hectares (1.9%) grown on RL (Legal Reserves) and in APP (Areas of Permanent Preservation) that

7 The Federal SICAR data used in this study were obtained from the Forest Service platform at http://www.car.gov.br/#, updated on 18th February 2020. To maximise the coverage of properties registered with CAR and because it is not possible to consider validation information on CAR, since it is at an incipient stage, all the properties on the Federal SICAR database were considered.

8 Cultivation of agricultural crops such as soy is not restricted in the APA, even though these areas are part of the Conservation Units of Sustainable Use under SNUC (National Conservation Unit System). However, this agricultural activity must follow the restrictions and guidelines stipulated in the management plan of each APA.

are registered with CAR[9] – this is more expressive in Other States where there is a higher degree of anthropization. Generally speaking, these cases are the declared Legal Reserves that, for the most part, still have to be validated by the State Environmental Secretariats so that the PRA (Environmental Recovery Plan) can be implemented and the areas recovered.

Nearly all the soy in settlements is located in Other States, concentrated in just a few areas. In all other Special Areas that are protected (Indigenous Lands – TI, Quilombola Territories – QUIL, Conservation Units with Full Protection – UC_PI, Conservation Units with Sustainable Use other than APAs – UC_US, and the overlaps among them), where the regulations for soy production are restrictive, the soy area is less than 0.3%.

Table 2. Soy area outside and inside Special Areas for crop year 2018/19 in Other States, Matopiba and the Cerrado Biome.

Category		Other States		Matopiba		Cerrado Biome	
		ha	%	ha	%	ha	%
SOY OUTSIDE SPECIAL AREAS		13,304,510	94.9	3,711,461	88.7	17,015,971	93.5
SOY INSIDE SPECIAL AREAS[10]	TI	30,833	0.2	4,576	0.1	35,409	0.2
	QUIL	2,458	0.0	268	0.0	2,726	0.0
	UC_PI	1,938	0.0	4,329	0.1	6,266	0.0
	UC_US	30	0.0	5,416	0.1	5,446	0.0
	Overlap TI-QUIL-UC_PI-UC_US	666	0.0	2,375	0.1	3,041	0.0
	APP_RL-CAR	274,621	2.0	68,836	1.6	343,457	1.9
	UC_APA	261,814	1.9	371,907	8.9	633,721	3.5
	ASS	144,645	1.0	13,003	0.3	157,649	0.9
	Overlap ASS-UC_APA	813	0.0	147	0.0	960	0.0
TOTAL		14,022,328	100.0	4,182,318	100.0	18,204,646	100.0

9 The Federal SICAR data used in this study were obtained from the Forest Service platform at http://www.car.gov.br/#, updated on 18th February 2020. To maximise the coverage of properties registered with CAR and because it is not possible to consider validation information on CAR, since it is at an incipient stage, all the properties on the Federal SICAR database were considered.

10 Special Areas: TI – Indigenous Lands; QUIL – Quilombola Territories; UC_PI – Conservation Units with Full Protection; UC_US – Conservation Units with Sustainable Use other than APAs; Overlap TI-QUIL-UC_PI-UC_US – Overlaps among these Special Areas; APP_RL-CAR – Areas of Permanent Protection and Legal Reserves registered with CAR (Rural Environmental Registry); UC_APA – Conservation Units for Sustainable Use of the APA type (Areas of Environmental Protection); ASS – Settlements; Overlap ASS-UC_APA – Overlaps among just these Special Areas.

2.2 TOTAL DEFORESTATION IN THE CERRADO

Figure 7 shows the total annual deforestation rates estimated by PRODES-Cerrado from 2001 to 2019 for the Cerrado Biome. The annual deforestation rates that were around 3,0 million hectares per year in the early 2000, have fallen in the last four years to less than a quarter, to about 0.7 million hectares per year. This decrease was pronounced in Other States. At the beginning of the millennium, this region was responsible for two-thirds of the Biome's deforestation, but the regional situation has been inverted and, over the last few years, Matopiba has become responsible for two-thirds of the deforestation, even though it represents just one-third of the Cerrado's territory.

Figure 7 also shows the total deforested area in the Cerrado Biome from 2001 to 2018 (27.7 million hectares), as well as in the three periods analysed in this study: 15.4 million hectares were deforested in the first period (2001-2006), 8.0 million hectares were deforested in the second (2007-2013) and 4.3 million hectares in the third (2014-2018).

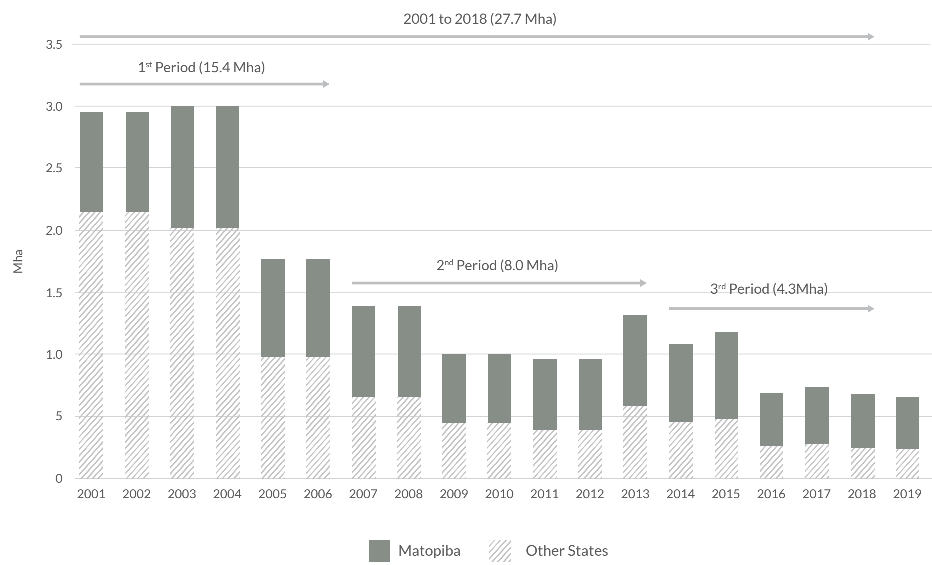


Figure 7. Annual deforestation rates in the Cerrado Biome from 2001 to 2019, highlighting total deforestation in the three periods analysed by this study.

2.3 LAND USE AND LAND COVER CHANGE ATTRIBUTED TO SOY

The land use change caused by the dynamic of soy expansion in the Cerrado Biome was analysed using the following categories: 1) land cover change from native vegetation to soy, here called "expansion with deforestation"[11]; and 2) land use change to soy, here called "expansion without deforestation"[12]. There is a third category, "areas with retraction"[13], which are the areas that were used in the past for soy crops but have subsequently been converted to other uses, either temporarily or permanently.

These categories take into consideration the availability of soy maps at Agrosatélite for specific crop years, used in previous studies, and the number of years in each period. The main focus of the current analysis is to assess the trends in soy expansion with deforestation over time. The range of each period analysed should therefore be long enough to effectively capture the land use and land cover change caused by soy expansion, but at the same time be short enough to show the variations and trends in the pattern of land use and land cover change over the 18 crop years analysed.

The analysis of the soy expansion with deforestation in crop year 2018/19 was made by crossing this information with the PRODES-Cerrado[14] databases of deforestation maps for the years 2014 to 2018, adopting the procedure reported in Agrosatélite (2018)[15].

2.3.1 DYNAMIC OF SOY EXPANSION WITH AND WITHOUT DEFORESTATION

From 2001 to 2018, 27.7 million hectares were deforested in the Cerrado Biome (Figure 7). Of this total, soy occupied 3.5 million hectares in the 2018/19 crop year. The numbers indicate that 12.6% of the deforestation that occurred in the last 18 years were converted to soy, directly or indirectly. In other words, 87.4% of the deforested area was not occupied by soy, but was destined for other uses. In other words, 80.8% of the Cerrado's soy area – equivalent to 14.7 million hectares – are free from the deforestation that has occurred since 2001.

To better capture the direct contribution of soy in the deforestation that has occurred since 2001, an analysis of the soy expansion with deforestation was made in three periods – of six, seven and five crop years, respectively, as shown in Figure 7. The definition of these periods also took into consideration the availability of soy maps for specific years (2001 to 2006, 2007 to 2013 and 2014 to 2018), following the methodology of Agrosatélite's previous studies[15].

The total of the deforested areas converted into soy in the three periods (Figure 8) was 3.0 million hectares, indicating that 86% of the total area deforested after 2001 and converted to soy was accounted for in the fractioned analysis. This suggests that the number of years in each period adequately represents the time involved in the process of converting deforested areas into soy. The older deforestation that went through transitory uses before conversion to soy (pastures, for example), were accounted for as expansion without deforestation, even when deforestation occurred after 2001.

An analysis of soy expansion in the three periods shows that the percentage of soy expansion into deforested areas in the Cerrado Biome decreased, as can be seen in Figure 8.

11 Expansion with deforestation corresponds to land cover changes in the Cerrado Biome's caused by deforestation of areas with native vegetation (regardless of the phytophysiognomy) at the beginning of each period, converted to soy by the end of the same period.

12 Expansion without deforestation corresponds to land use changes in the Cerrado Biome's caused by soy expansion into areas with other uses at the beginning of each period and converted to soy by the end of the same period. For example, pastures converted to soy consists in the intensification of land use, which occurs frequently in Other States where many pastures areas have high agricultural suitability for soy. Examples of other uses at the beginning of each period are: a) areas with annual crop rotation (e.g., cotton and first-crop corn);) fallow areas; and c) areas of sugarcane in the process of renewal.

13 Areas with retraction are those areas that had soy at the beginning of each period and were converted to other uses by the end of the same period. For example: a) areas rotating with other annual crops (e.g., cotton and first-crop corn); b) fallow areas; c) areas which reverted to sugarcane in the renewal process; and d) areas that effectively stopped being used for soy crops, either because they were abandoned or through a land use change, as occurred in the early 2000 during the large expansion of sugarcane in the Centre-South region (https://www.mdpi.com/2072-4292/2/1/290).

14 PRODES annually maps the deforestation which occurs from August of the previous year to July of the current year. PRODES-2014, for example, maps deforestation from August 2013 to July 2014.

15 Report available for public consultation on: https://agrosatelite.com.br/en/cases/#expansao-agricola.

Even in Matopiba, where soy expansion with deforestation was quite significant in the first two periods (62% from 2001 to 2006, and 52% from 2007 to 2013; Figure 8), there was a sharp fall in the third period (19%, Figure 8).

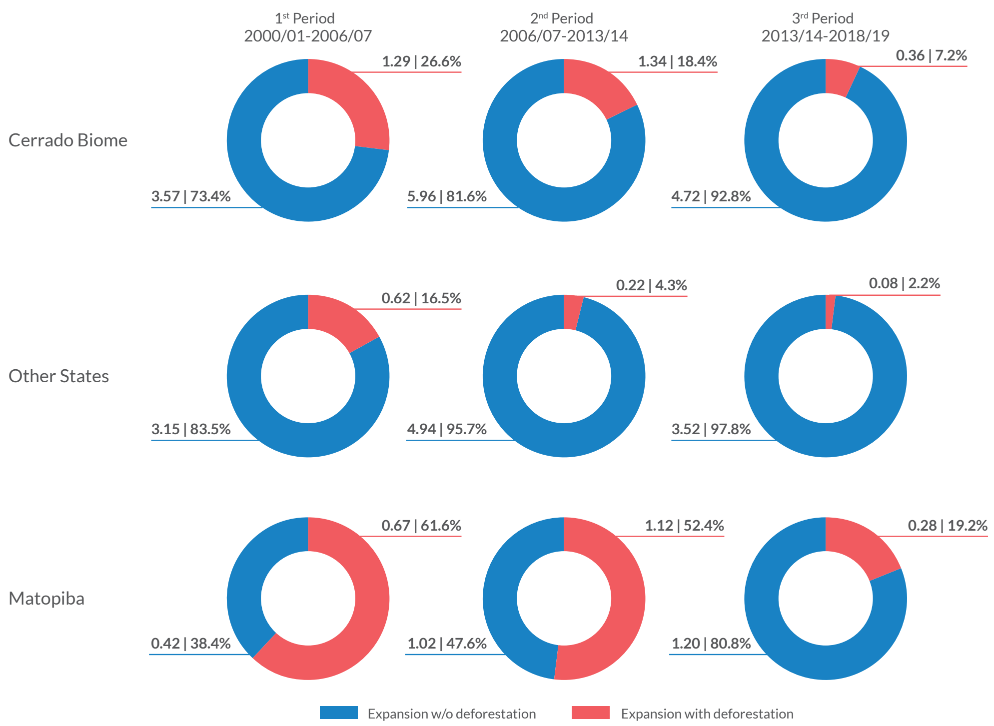


Figure 8. Soy expansion with and without deforestation in the Cerrado Biome, in Other States and in Matopiba, in the three periods from 2000/01 to 2018/19.

While Figure 8 shows the soy expansion with and without deforestation in each analysed period, Figure 9 shows the total deforestation in the Cerrado from 2014 to 2018 and the portion that was converted to soy in crop year 2018/19. In this period, when deforestation rates fell in relation to the two prior periods, the contribution of soy expansion with deforestation also fell (0.36 million hectares, or 8.2%; Figure 9). Also in this period, 2.67 million hectares were deforested in Matopiba, with 0.28 million hectares (10.6%) converted to soy. In Other States, the deforested area was 1.76 million hectares, with 0.08 million hectares (4.5%) converted to soy (Figure 9). It should be noted that part of the deforestation from 2014-2018 not converted to soy in crop year 2018/19 crop year can still be converted in future years.

Among the states in the Matopiba region, Tocantins had the largest area of soy with deforestation (96.5 thousand hectares), followed by Maranhão (77.2 thousand hectares), Piauí (55.8 thousand hectares) and Bahia (54.6 thousand hectares) (Figure 9). Tocantins also holds the record for total deforestation in the period 2014-2018, with over 1.0 million hectares. In Other States, the largest area with soy in deforested areas was in Mato Grosso (38.2 thousand hectares), followed by Goiás (22.8 thousand hectares). These two states, together, represent 76.9% of the soy area with deforestation in this region during the period analysed (Figure 9).

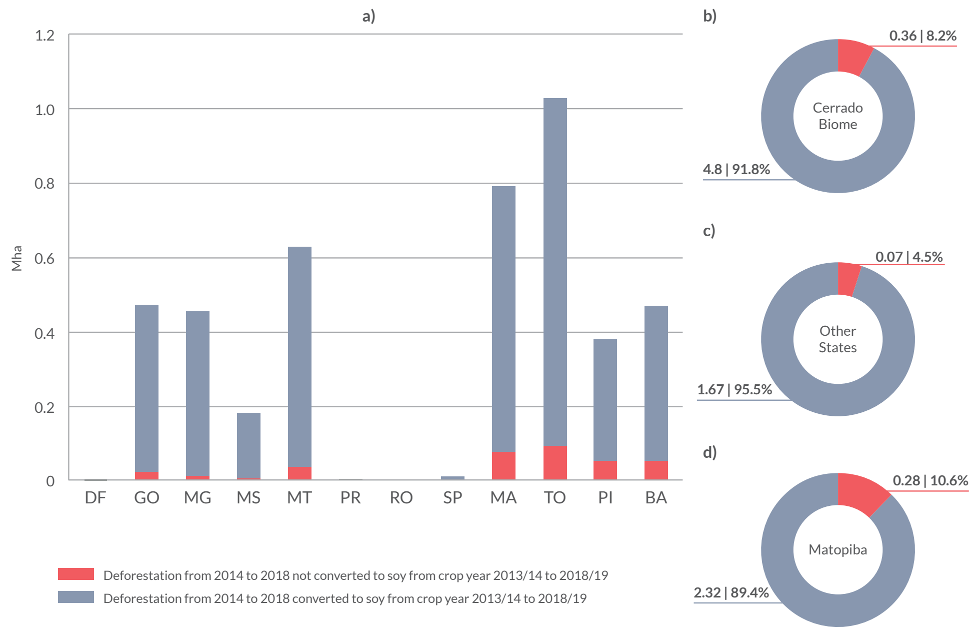


Figure 9. Total deforestation from 2014-2018 (PRODES-Cerrado/INPE) and the portion of soy in crop year 2018/19 that expanded with deforestation for: a) that part of the states that lies within the Cerrado Biome; b) Other States; c) Matopiba; and d) Cerrado Biome.

2.3.2 DYNAMIC OF LAND USE AND LAND COVER IN THE PERIOD 2000/01 TO 2018/19

Figure 10 shows the results of the dynamic of land use and land cover change in the process of soy expansion and retraction in Other States and in Matopiba, both for the five-year period from 2013/14 to 2018/19 (results of this study), and for the two prior periods – the six years from 2000/01 to 2006/07 and the seven years from 2006/07 to 2013/14 (Agrosatélite, 2015; 2018)[16].

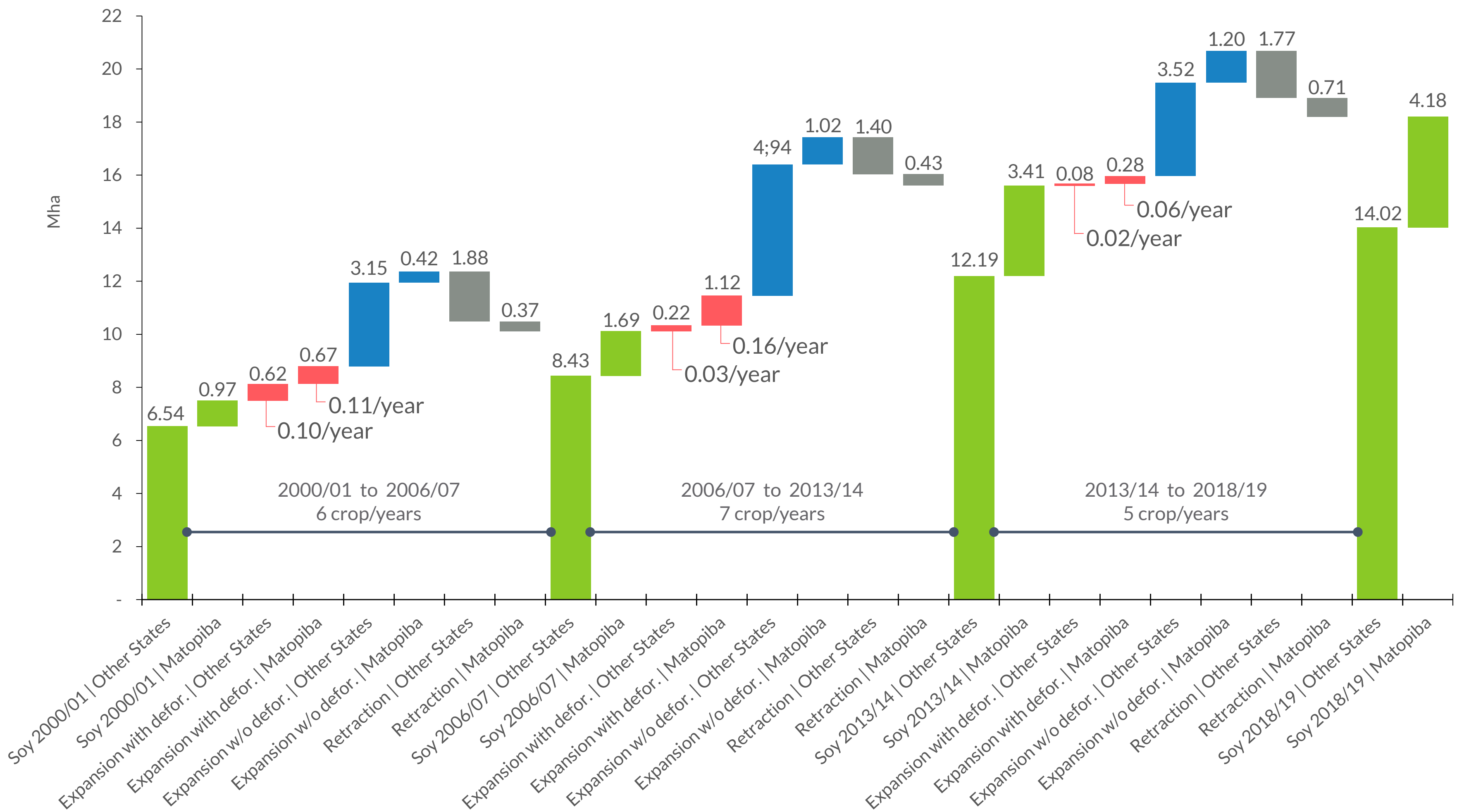


Figure 10. Land use and land cover change involving the expansion and retraction of soy in Other States and in Matopiba in three periods: 1st period from 2000/01 to 2006/07; 2nd period from 2006/07 to 2013/14; 3rd period from 2013/14 to 2018/19. Below the bars of expansion with deforestation (orange) is the annual conversion rate of native vegetation to soy.

16 Report available for public consultation on: https://agrosatelite.com.br/en/cases/#expansao-agricola.

The presence of soy in Matopiba is significantly less than in Other States, but it has been growing over the years. As seen earlier in this study (Item 2.1), the region's share in the area dedicated to soy production in the Cerrado Biome went from 13% in 2000/01 to 23% in 2018/19. Nevertheless, despite this growth, the average rate of conversion of native vegetation into soy, which reached 161 thousand hectares/year in the period from 2006/07 to 2013/14, fell to 57 thousand hectares/year in the most recent period from 2013/14 to 2018/19. In Other States, the average rate of conversion of native vegetation into soy has been gradually falling and was 16 thousand hectares/year in the most recent period (Figure 11).

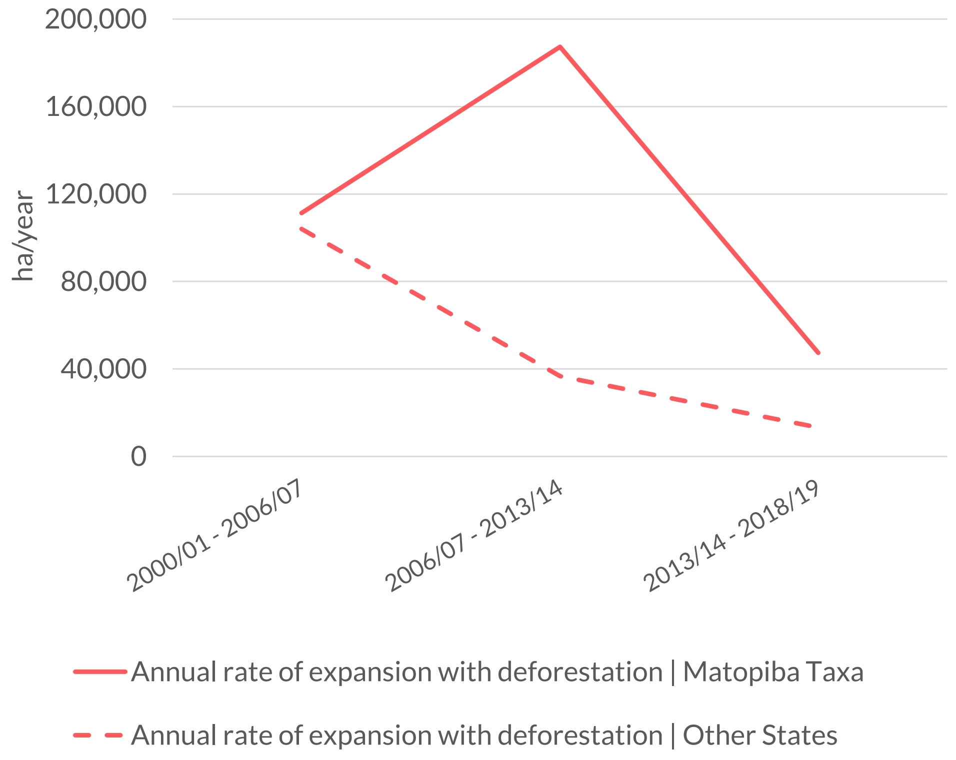


Figure 11. Average annual rate of native vegetation conversion to soy in each of the three analysed periods.

2.3.2.1 DETAILS OF THE DYNAMIC OF EXPANSION AND RETRACTION | 2013/14 TO 2018/19

Figures 12 to 20 show sections of different parts of the Cerrado Biome, in order to illustrate, through maps, both the spatial distribution of the soy fields and the soy expansion with and without deforestation, in addition to those areas which experienced retraction in the period from 2013/14 to 2018/19[17]. In these Figures, soy expansion without deforestation on pastures, fallow land and others are shown in blue without hatching; blue with hatching shows expansion on corn or first-crop cotton or sugarcane. Areas with retraction are shown in grey without hatching when they were set aside for fallow land or other uses; and grey with hatching when rotated with corn or first-crop cotton or sugarcane.

17 To quantify the dynamic of soy expansion-retraction, satellite images were used to assess the soy areas in crop year 2018/19 that expanded without deforestation in crop year 2013/14, separating them into: a) agricultural crops (corn and first-crop cotton and sugarcane); b) fallow land or other uses; and c) pastures (Áreas de Pastagens do Brasil, 2014, base LAPIG/MapBiomas). Still based on satellite images, an assessment was made of the soy areas in crop year 2013/14 that experienced retraction due to crop rotation or that were not used for soy in crop year 2018/19 (fallow land or other uses).

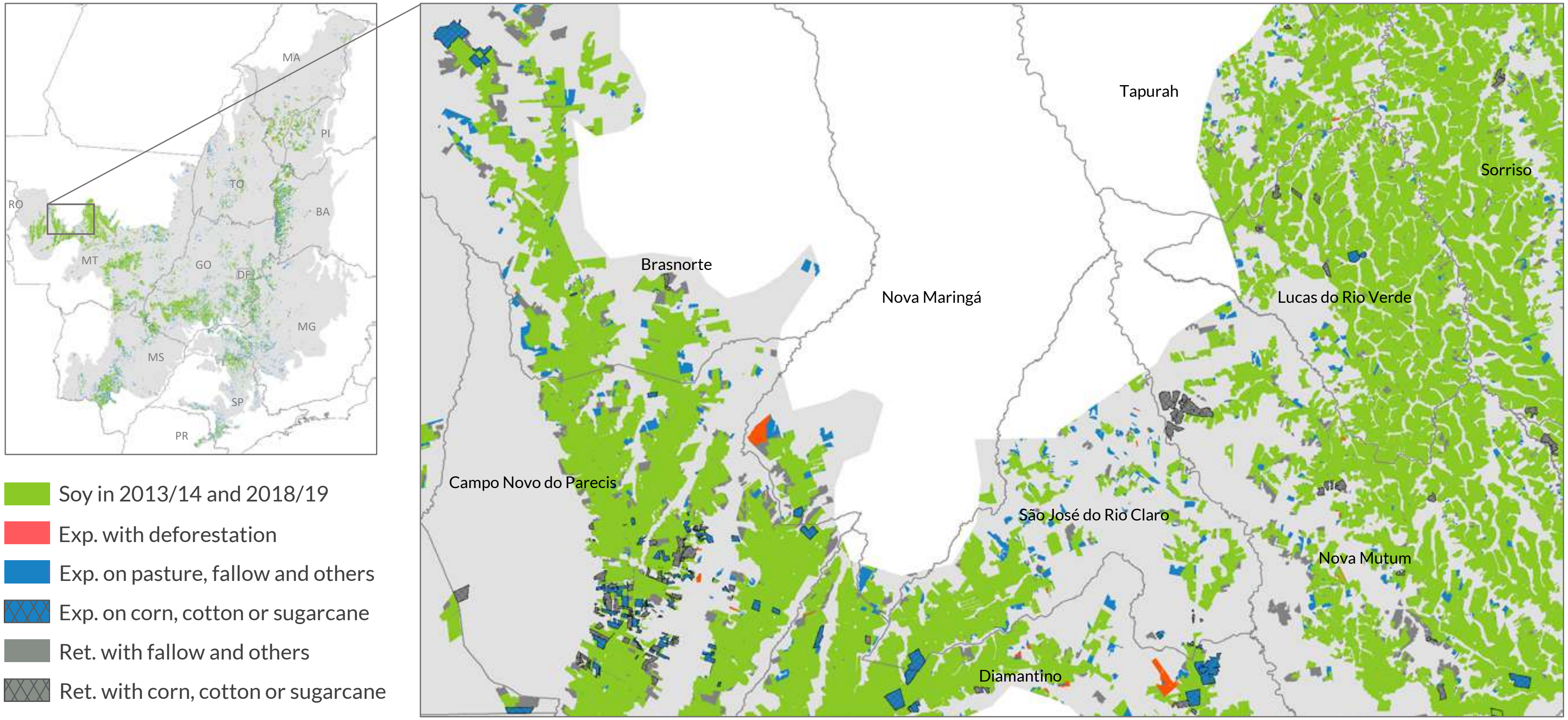


Figure 12. Territorial dynamic of soy from 2013/14 to 2018/19 in midwest Mato Grosso state regions where soy production is well consolidated, with little expansion. There are, however, some areas of retraction close to the borders of the Chapada do Parecis in the municipality of Chapada dos Parecis and in the municipality of Nova Mutum, both these regions are located in areas with sandy soils.

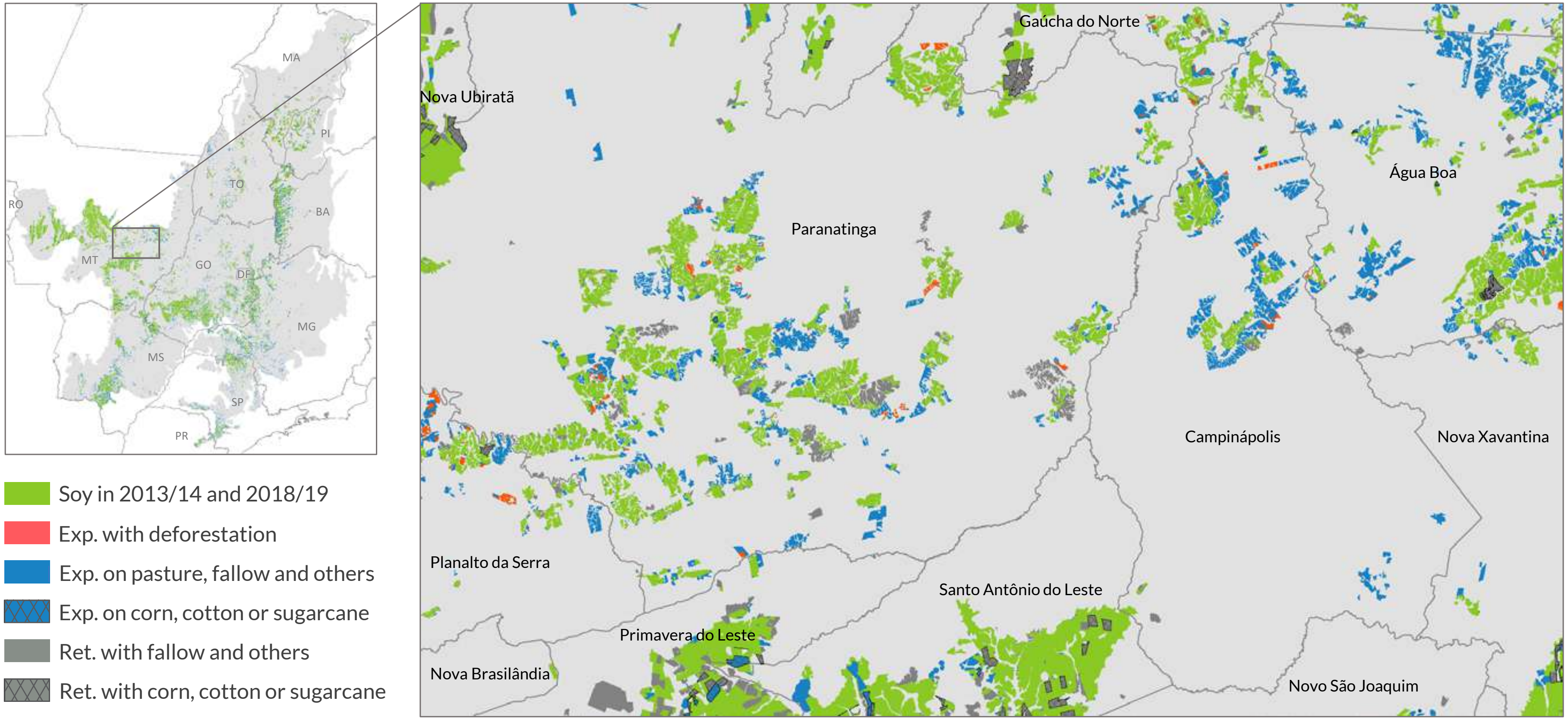


Figure 13. Territorial dynamic of soy from 2013/14 to 2018/19 in mideast Mato Grosso state with small sparse areas of expansion with deforestation (Planalto da Serra and Paranatinga municipalities) and a greater incidence of expansion without deforestation into areas mostly used for pastures, highlighting the Campinápolis and Água Boa municipalities.

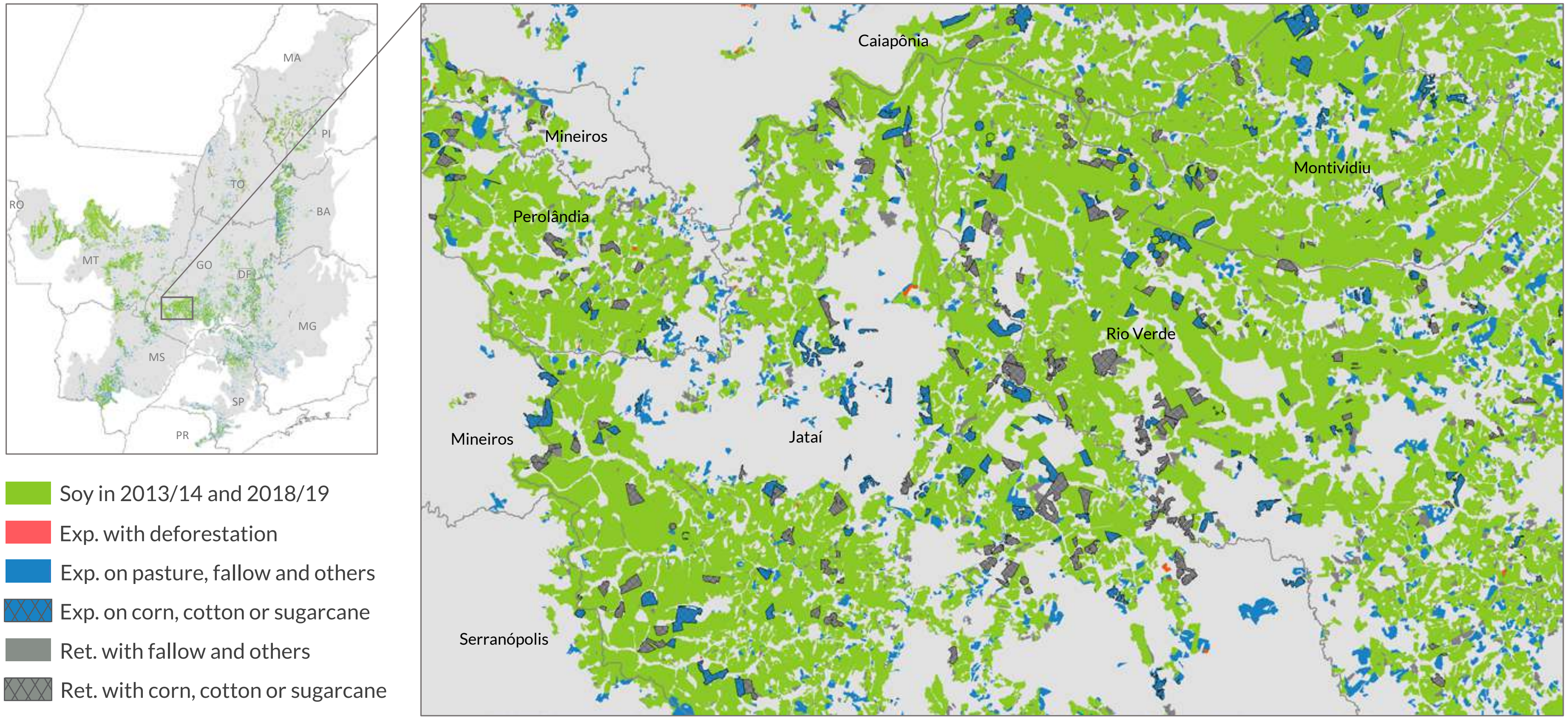


Figure 14. Territorial dynamic of soy from 2013/14 to 2018/19 in southwest Goiás state where soy production is well consolidated, but presents some soy expansion on pastures in peripheral regions of the consolidated areas. It is also permeated with sugarcane fields that can rotate with soy during the renewal process.

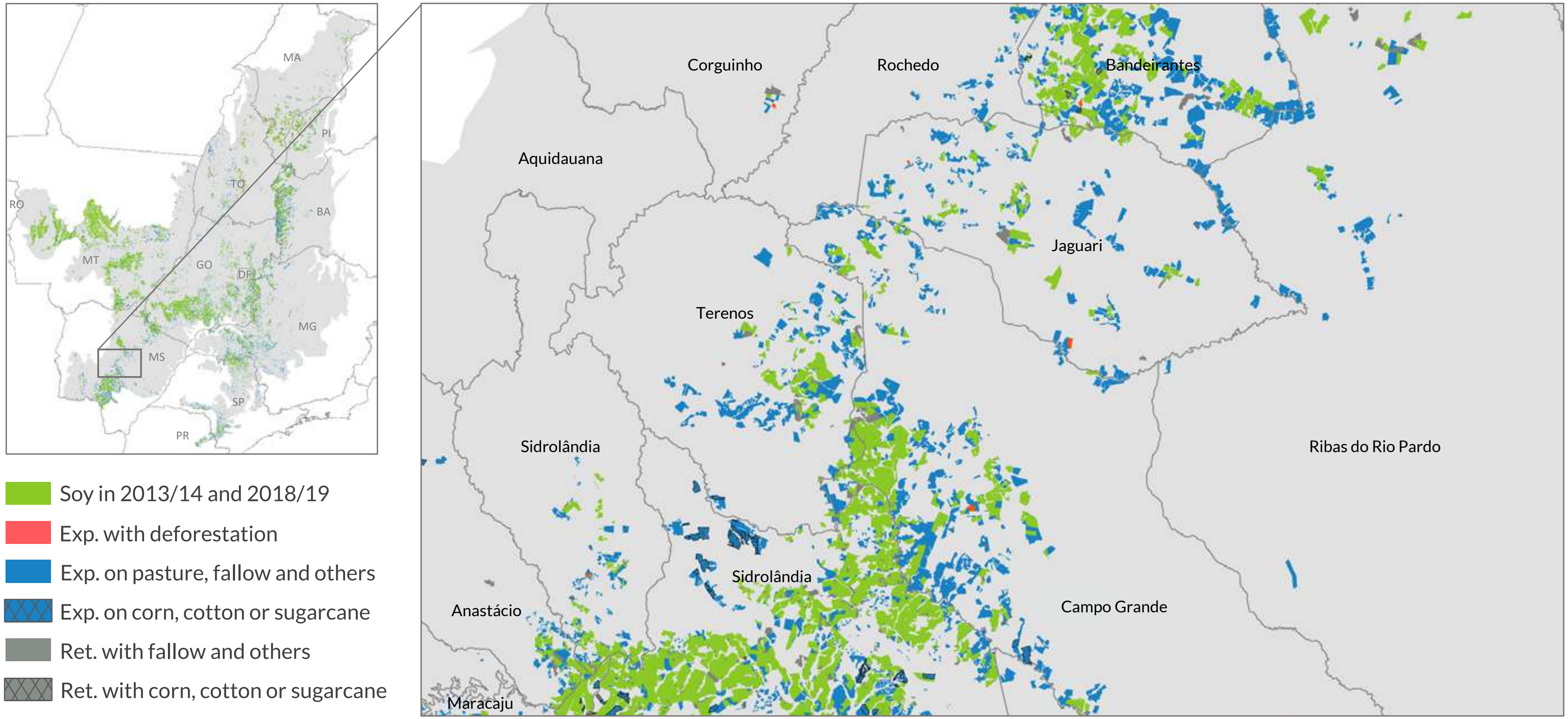


Figure 15. Territorial dynamic of soy from 2013/14 to 2018/19 in the central region of Mato Grosso do Sul state, near the state capital Campo Grande, that concentrates large areas of pastures with high agricultural suitability for soy and which, over the last few years, is experiencing a growing conversion into soy. This makes Mato Grosso do Sul the second-largest state in the Cerrado Biome with a large area of soy expansion in recent years, together with Goiás state.

Figure 16. Territorial dynamic of soy from 2013/14 to 2018/19 in north São Paulo state, with a high incidence of sugarcane fields that, as they go through the renewal process, can rotate with soy, generally for one crop season. In this case, the expansion (blue hatched) occurred in sugarcane fields in renewal in crop year 2018/19, while retraction (grey hatched) occurred in sugarcane fields in renewal in crop year 2013/14 and which, consequently, had sugarcane in crop year 2018/19.

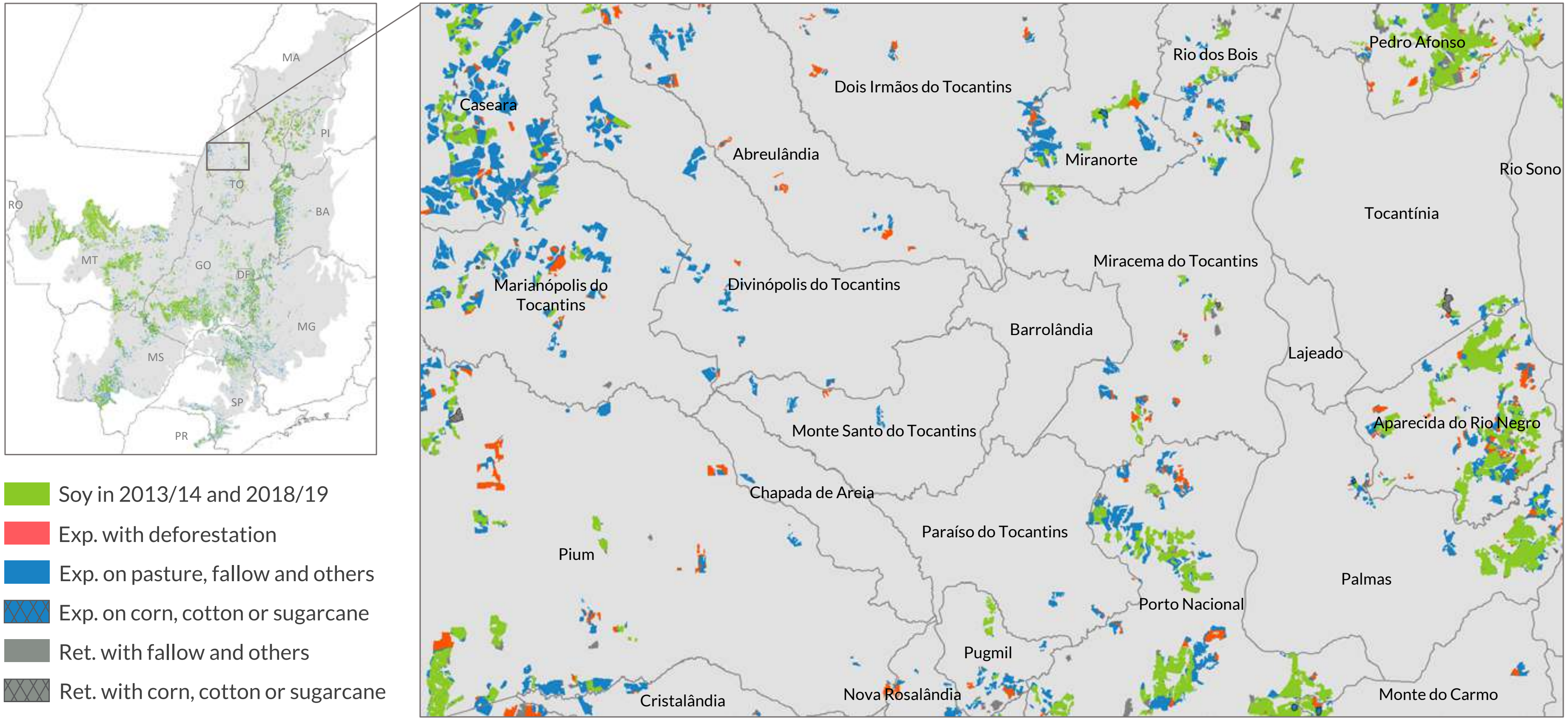


Figure 17. Territorial dynamic of soy from 2013/14 to 2018/19 in midwest Tocantins state, where soy production is becoming more relevance due to increased soy expansion (less in deforested areas, more in deforestation-free areas). Special mention should be given to the Caseara and Mirandópolis do Tocantins municipalities, where there has been a strong soy expansion in just four years, especially on pasture land.

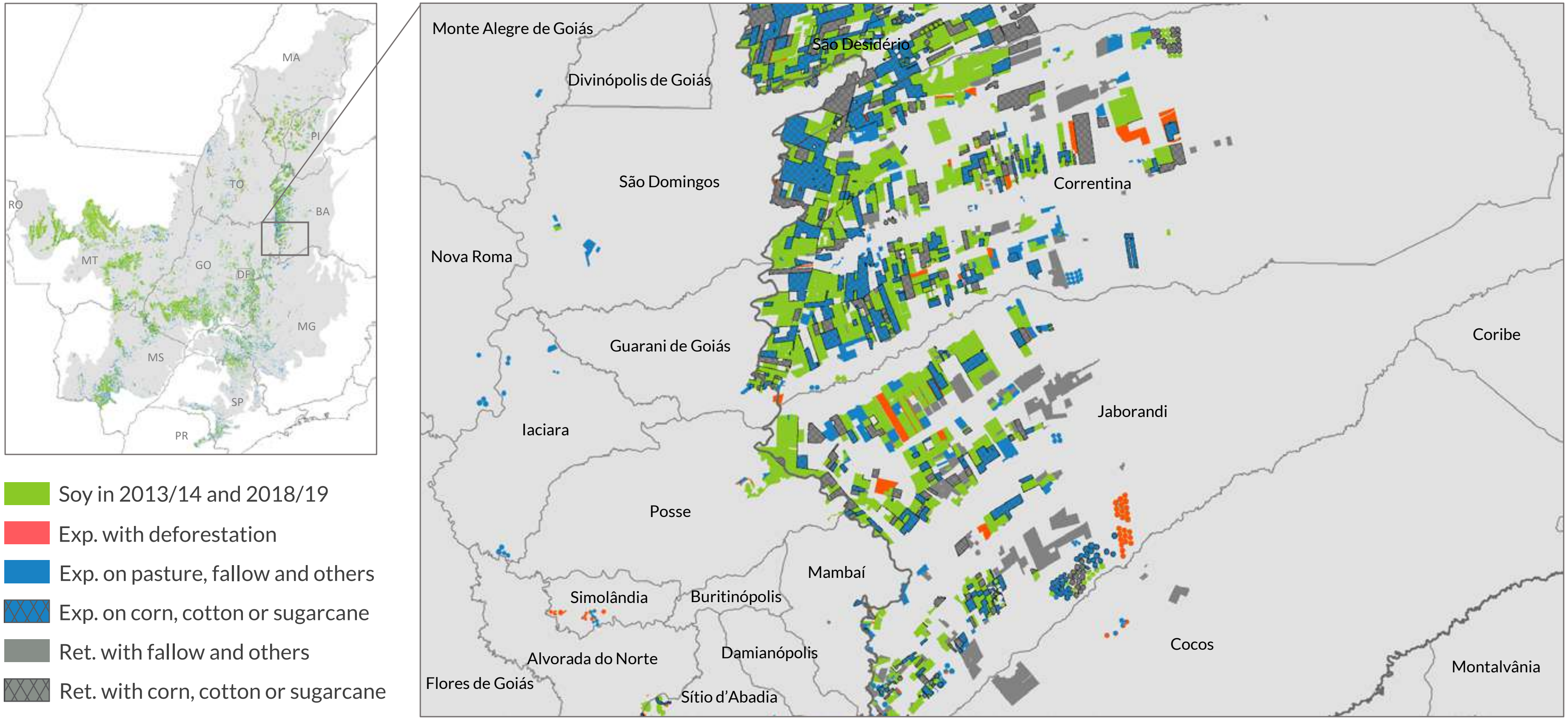


Figure 18. Territorial dynamic of soy from 2013/14 to 2018/19 in southwest Bahia state, where soy rotation with other annual crops (cotton and first-crop corn) is a common agricultural practice. Expansion without deforestation, as well as retraction, represents the vast majority of the areas in crop rotation. In some areas with retraction, further east, where climatic conditions are less favourable and the soil is sandier, soy was replaced by other crops (e.g., grasses for seed production). It is interesting to note there is one area of soy expansion with deforestation (lower part of the Figure) with high climatic risk, albeit with irrigation (irrigated areas with a central pivot).

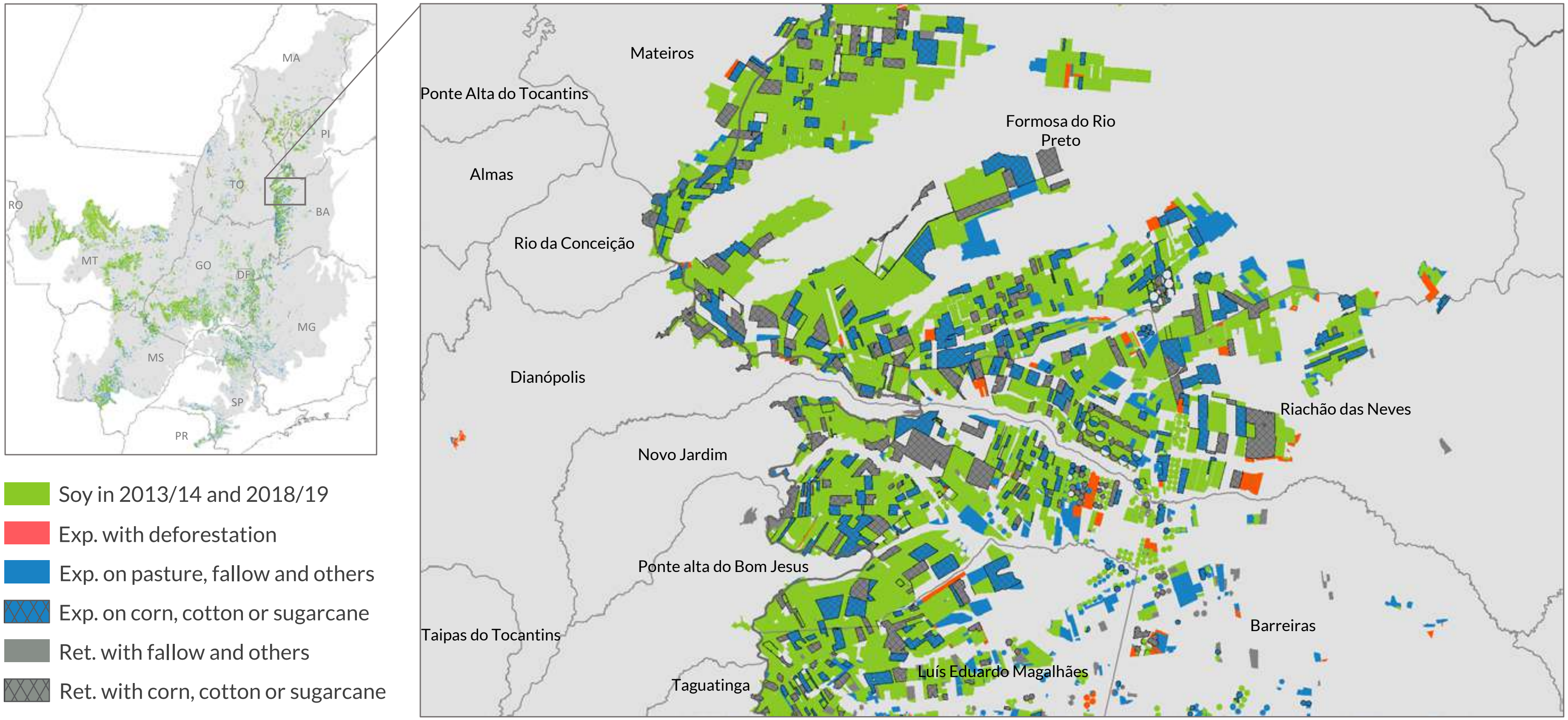


Figure 19. Territorial dynamic of soy from 2013/14 to 2018/19 in northwest Bahia state, where soy production is more consolidated and the practice of crop rotation is well consolidated. Although Formosa do Rio Preto is always among the municipalities in Matopiba with the highest deforestation converted to soy, there has been a certain deceleration in this process in recent years. Expansion with deforestation throughout this region occurred in sparse areas of relatively large size.

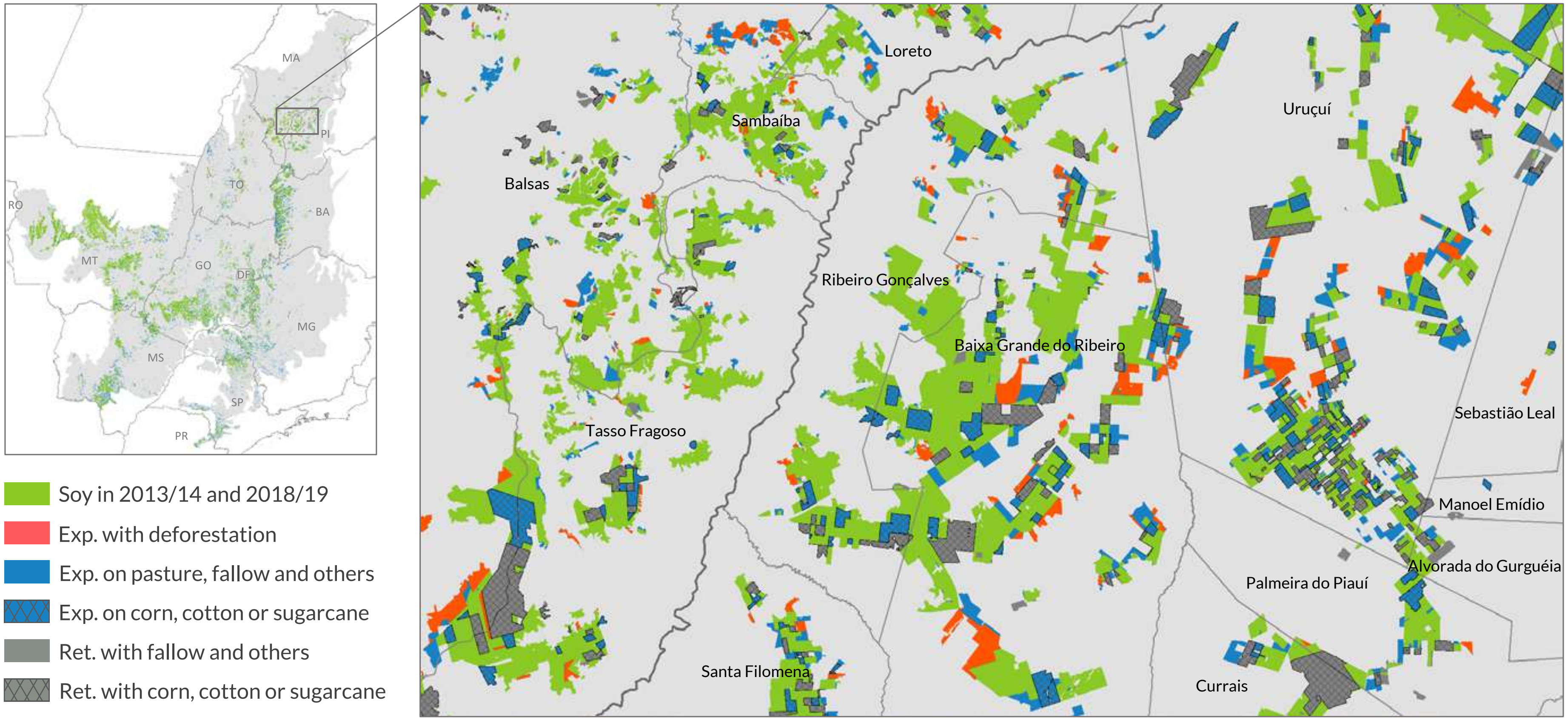


Figure 20. Territorial dynamic of soy from 2013/14 to 2018/19 in south Maranhão and Piauí states. This region is located in Brazil's newest agricultural frontier, where expansion with deforestation is most present in the Cerrado Biome and in which corn and first-crop cotton are also grown in rotation with soy.

Image of 02/13/2019, Santa Filomena - PI | Landsat-8, Path/Row 220/66, 5(R)6(G)4(B).

From 2013/14 to 2018/19, net soy expansion on new areas was 2.54 million hectares – total expansion was twice that, 5.08 million hectares, as a result of the soy production dynamic, where part of the soy fields rotate with other crops (corn and first-crop cotton and sugarcane renewal) or fallow land (see footnote No. 9 and Figures 12-20). In the same way, areas that earlier were planted with corn and first-corn cotton and sugarcane or that were left fallow could be planted with soy. The dynamic of soy expansion therefore consists of incorporating into the production system areas from the conversion of native vegetation or the intensification of land use through conversion of pastures, as well as the practice of agricultural management with the rotation of agricultural crops and fallow land. The last case is the most common in areas that are less favourable for soy crops.

The detailed results of this analysis are shown in Figure 21, which illustrates the transitions of land use and land cover associated with soy dynamic in Other States and Matopiba.

In Other States, the net soy expansion was 1.83 million hectares, corresponding to 70.4% of the soy expansion in the Cerrado Biome during the period, of which:

1. 0.37 million hectares (20.2%) without deforestation, rotated with other crops (corn and first-crop cotton and sugarcane);
2. 0.16 million hectares (8.7%) without deforestation, planted on fallow land;
3. 1.23 million hectares (67.2%) without deforestation, conversion of pasture (intensification);
4. 0.08 million hectares (4.4%) with deforestation.

In Matopiba, the net soy expansion was 0.77 million hectares, corresponding to 29.6% of the soy expansion in the Cerrado Biome during the period, of which:

1. 0.04 million hectares (5.2%) without deforestation, rotated with other crops (corn and first-crop cotton and sugarcane);
2. 0.23 million hectares (29,9%) without deforestation, planted on fallow land;
3. 0.22 million hectares (28.6%) without deforestation, conversion of pasture (intensification);
4. 0.28 million hectares (36.4%) with deforestation.

As can be seen, there is a clear distinction in the dynamic of soy expansion between these two regions. In Other States, crop rotation has a relevant role in increasing the soy area (0,37 million hectares, or 20.2%). This is partly due to the rotation of soy with first-crop corn – a system that is still very common, especially in some regions of Goiás and Minas Gerais states – or due to the renewal of sugarcane fields, intensified in the 2018/19 crop year (Canasat Project/Agrosatélite)[18]. Another point of crop rotation that needs to be considered is the substitution in recent years of first-crop cotton for soy in much of Mato Grosso state. In Matopiba, soy rotation with other annual crops occurs frequently, but has remained stable in the two crop years analysed and, therefore, has contributed little to the expansion of soy (0.04 million hectares, or 5.2%).

Soy expansion in 2018/19 on areas that were fallow in 2013/14 was more expressive in Matopiba (0.23 million hectares, or 29.9%) than in Other States (0.16 million hectares, or 8.7%).

The contribution of pasture conversions to net soy expansion was more relevant in Other States (1.23 million hectares, or 67.2%) than in Matopiba (0.22 million hectares, or 28.6%). In the Cerrado as a whole, pasture contributed with 56% of the effective soy expansion in the period.

Conversion with deforestation represents 4.4% (0.08 million hectares) of the net soy expansion from 2013/14 to 2018/19 in Other States. This region is more consolidated and has greater availability of anthropic lands with good agricultural suitability for conversion to soy without deforestation. In Matopiba, however, conversion with deforestation represents 36.4% (0.28 million hectares) of net soy expansion – which is to be expected in a region located in Brazil's most recent agricultural frontier, where the process of consolidating agriculture is in full swing and where there is less availability of anthropized lands with agricultural suitability for soy.

18 Project described and commented on: https://agrosatelite.com.br /en/cases/#canasat.

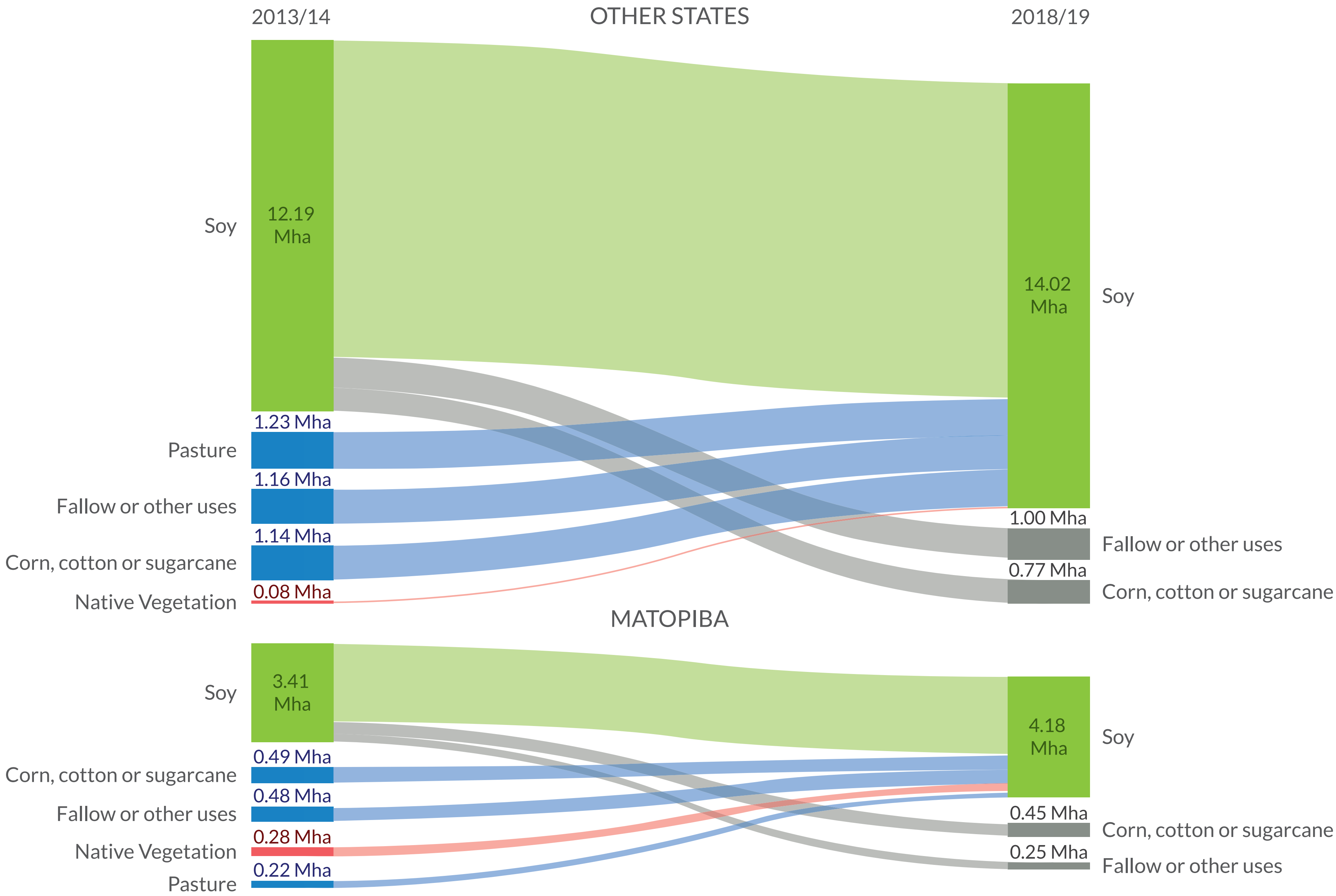


Figure 21. Sankey Diagram, illustrating soy areas in crop years 2013/14 and 2017/18, together with the transitions in land use and land cover that occurred during the period in Other States and in Matopiba.

3. AGRICULTURAL SUITABILITY FOR SOY

Photographer: Marcos Campos

3.1 BACKGROUND

The Cerrado Biome is very diversified in its edaphic, climatic and relief characteristics, whose parametrisation and analysis in accordance with the agrometeorological requirements for the crops makes it possible to assess edaphoclimatic conditions in each part of the territory. The Agricultural Zoning of Climatic Risk (ZARC) (ASSAD et al., 2008)[19], for example, takes as its base the edaphoclimatic conditions to annually recommend, or not, the planting of certain soy cultivars in each Brazilian municipality. Using ZARC methodology, Agrosatélite (2015)[20] took it a step further, assessing the edaphoclimatic conditions for soy at the landscape level, thus identifying the variations in suitability within the same municipality. In addition to the edaphoclimatic aspects, Agrosatélite included in its definition of the agricultural suitability for soy the concept of associated restrictions: slope, which can limit mechanised agriculture, and altitude, which can identify, on a regional basis, areas with greater or lesser favourability for soy production. This study has been widely used in forums, such as the GTC (Cerrado Working Group), and was used as the basis for several publications (NEPSTAD et al., 2019; RAUSCH et al., 2019; BRANDÃO JR et al., 2020)[21].

19 ASSAD, E. D.; MARIN, F. R.; PINTO, H. S.; ZULLO JR, J. Zoneamento Agrícola de Riscos Climáticos do Brasil: Base Teórica, Pesquisa e Desenvolvimento. Informe Agropecuário (Belo Horizonte), v. 29, p. 47-60, 2008.

20 Report available for public consultation on: https://agrosatelite.com.br/en/cases/#expansao-agricola.

21 NEPSTAD, L. S.; GERBER, J. S.; HILL, J. S.; DIAS, L. C. P.; COSTAS, M. H.; WEST, P. C. Pathways for recent Cerrado soybean expansion: extending the soy moratorium and implementing integrated crop livestock systems with soybeans. **Environmental Research Letters**, v. 14, 2 Jan. 2019.
RAUSCH, L. L.; GIBBS, H. K.; SCHELLY, I.; BRANDÃO JR, A.; MORTON, D. C.; FILHO, A. c.; STRASSBURG, B.; WALKER, N.; NOOJIPADY, P.; BARRETO, P.; MEYER, D. Soy expansion in Brazil's Cerrado. **Conservation Letters**, v. 12, 27 Aug. 2019.
BRANDÃO JR, A.; RAUSCH, L.; DURÁN, A. P.; COSTA JR, C.; SPAWN, S. A.; GIBBS, H. K. Estimating the Potential for Conservation and Farming in the Amazon and Cerrado under Four Policy Scenarios. **Sustainability**, v. 12, 10 Feb. 2020.

3.2 MATERIALS

The main materials or inputs used in this study were:

- Soils
  - Soil maps with a 1:250,000 scale, available on IBGE's continuous database, describe the type of soil and, mostly, provide information about its texture, enabling Agrosatélite to classify soils as sandy (type 1), medium (type 2) and clay (type 3). A reference value was attributed to each type of soil regarding its water holding capacity (CAD)[22], with 35 mm for type 1 soils (except for the Federal District, which is 40 mm), 50 mm for type 2 soils, and 75 mm for type 3 soils.

- Climatological data
  - Daily precipitation and evapotranspiration maps from XAVIER et al. (2016/17)[23], which have enough information to produce a climatological normal over 30 years. The temporal series used in this study was 1986 to 2016, in a matrix format with spatial resolution of 0.25°.

- ZARC Information
  - ZARC (Agricultural Zoning for Climatic Risk) tables, available in ordinances published by the Ministry of Agriculture, Livestock & Supply (MAPA) for soy production in each state for crop year 2018/19. These tables were used as a reference to identify the recommended planting calendars for municipalities[24], taking into account the

22 In the water balance stage, for a better adaptation to the realities of the field, an adjustment factor was adopted in CAD, according to a model for the growth of soy roots (BATTISTI, 2013) that reach a maximum depth of approximately 50 cm in the maturation phase.
BATTISTI, R. **Épocas de semeadura da cultura da soja com base no risco climático e na rentabilidade líquida para as principais regiões produtoras do Brasil.** 2013. 261 p. Dissertation (Master's degree on Agricultural Systems Engineering) - Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, 2013.

23 XAVIER, A. C.; KING, C. W.; SCANLON, B. R. Daily gridded meteorological variables in Brazil (1980- 2013). **International Journal of Climatology**, v. 36, p. 2644-2659, 2016.
XAVIER, A. C.; KING, C. W.; SCANLON, B. R. An update of Xavier, King e Scanlon (2016) daily precipitation gridded data set for Brazil. In: **Anais** do XVIII Simpósio Brasileiro de Sensoriamento Remoto – SBSR. São José dos Campos: INPE, 2017. v. 1. p. 562-569.

24 ZARC divides the recommended soy planting periods in each municipality into ten-day periods. For the Rio Verde/GO municipality, for example, the recommended soy planting period goes from 1st October to 31st December, a total of nine ten-day periods. This period can vary within the same municipality, depending on the type of soil (sandy, medium or clay) and on the crop cycle (100, 115 or 130 days).

type of soil and the length of the crop cycle.

- Digital elevation model data
  - The Topodata (VALERIANO; ROSETTI, 2011)[25] database was used to apply restrictions for: i) slope (areas with steeper slopes limit or prevent mechanised agriculture); and ii) altitude (regionally, areas at lower altitudes are considered less favourable for soy production).

- Satellite images and segmentation
  - For this study, 118 cloud free images from the satellite Landsat-8/sensor OLI were selected to cover the entire Cerrado Biome. The images were processed and segmented in accordance with the details described in the section on methodology.

- Land use and land cover data
  - Each of the segments mentioned above was classified as regards its land use and land cover in the categories: Native Vegetation (primary or in an advanced state of regeneration) and Anthropic. The Native Vegetation category was based on the native vegetation category in TerraClass-2013, from which the deforested polygons recorded by PRODES-Cerrado from 2013 to 2018 were removed[26]. The category Water was obtained from MapBiomas, Collection 4[27], and took precedence over the others. In other words, these categories were obtained using public databases.

- Special Areas
  - The segments were also assessed in relation to Indigenous Lands (FUNAI)[28], Quilombola Communities and Settlements (INCRA)[29], Conservation Units with Total

Image of 04/16/2020, Campo Grande - MS | Landsat-8, Path/Row 225/73; 5(R)6(G)4(B).

25 VALERIANO, M. C.; ROSETTI, D. F. Topodata: Brazilian full coverage refinement of SRTM data. **Applied Geography (Sevenoaks)**, v. 32, p. 300-309, 2011.

26 The TerraClass 2013 and PRODES data, both for the Cerrado Biome, were obtained from the TerraBrasilis page on: http://terrabrasilis.dpi.inpe.br/.

27 Projeto MapBiomas – Coleção 4 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil, acessado em 19/06/2020 através do link: https://plataforma.mapbiomas.org/

28 The data related to Indigenous Lands were obtained from FUNAI's page on: http://www.funai.gov.br/.

29 Information from INCRA was obtained from the Institute's Land Library page: http://acervofundiario.incra.gov.br/acervo/acv.php.

3.3 OVERVIEW OF THE METHODOLOGY

Protection or with Sustainable Use[30], as well as Areas of Environmental Protection (APA) of the Ministry of the Environment[31]. The classes of agricultural suitability were evaluated for all the Special Areas.

- National SICAR real estate database
  - The georeferenced boundaries of rural properties, together with information on Areas of Permanent Preservation (APP) and Legal Reserves (RL), were obtained from the Federal SICAR database[32].

30 Even though Areas of Environmental Protection (APA) are part of the Conservation Units for Sustainable Use, they were treated as a separate group because soy production is a reality in many of them and can be included in the management plan, when available.

31 The data on Conservation Units used in this study were obtained from the Ministry of the Environment on: http://mapas.mma.gov.br/i3geo/datadownload.htm.

32 The data from Federal SICAR used in this study were obtained from the Forest Service platform on: http://www.car.gov.br/#, updated on 18th February 2020. To maximise the coverage of properties registered with CAR, and because it is impossible to consider information on the validation of CAR as it is still in an incipient stage, all the properties available on the Federal SICAR database were considered.

3.3.1 ANALYSIS OF EDAPHOCLIMATIC CONDITION

In this study, the assessment of edaphoclimatic condition for soy in the Cerrado Biome, in addition to being updated for the year 2019, was improved in relation to Agrosatélite's previous study (2015). This was possible because of the availability of more refined climatic and edaphic databases, of recently published adjustments in the ZARC ordinances and of simulations that consider the shorter-cycle soy crops adopted by producers throughout the Cerrado Biome to reduce climatic risks and open up space for a second corn crop (intensification).

The databases were processed on the Google Earth Engine platform in a matrix format with a 100x100 m resolution[33]. In the first phase, the edaphoclimatic condition for soy production was assessed, classifying each pixel as 1) high edaphoclimatic condition – AA; 2) medium edaphoclimatic condition – MA; 3) low edaphoclimatic condition – BA; and 4) unfit – I. Soy crops with cycles of 100, 115 and 130 days were considered, planted in accordance with the agricultural calendar recommended by ZARC, which takes into account data on historical climate, soil texture and the length of the crop cycle, with the objective of adjusting for minimally favourable conditions for the crop's good production performance.

With knowledge of the ten-day periods recommended for planting soy in each municipality, the water balance methodology (THORNTHWAITE; MATHER, 1955)[34] was applied to simulate the soy crop's water demand throughout its cycle. The product of the water balance used as a reference for attributing the edaphoclimatic condition for soy was the Water Requirement Satisfaction Index (WRSI), which ranges from 0 to 1 and represents

33 Although climatic data are available with a spatial resolution of 0.25°, IBGE data on the types of soil, available in a vectorial format, have a scale of 1:250,000. To avoid degradation of the information on the soil map, all data, including those from the climatic model, were resampled to a resolution of 100x100 m.

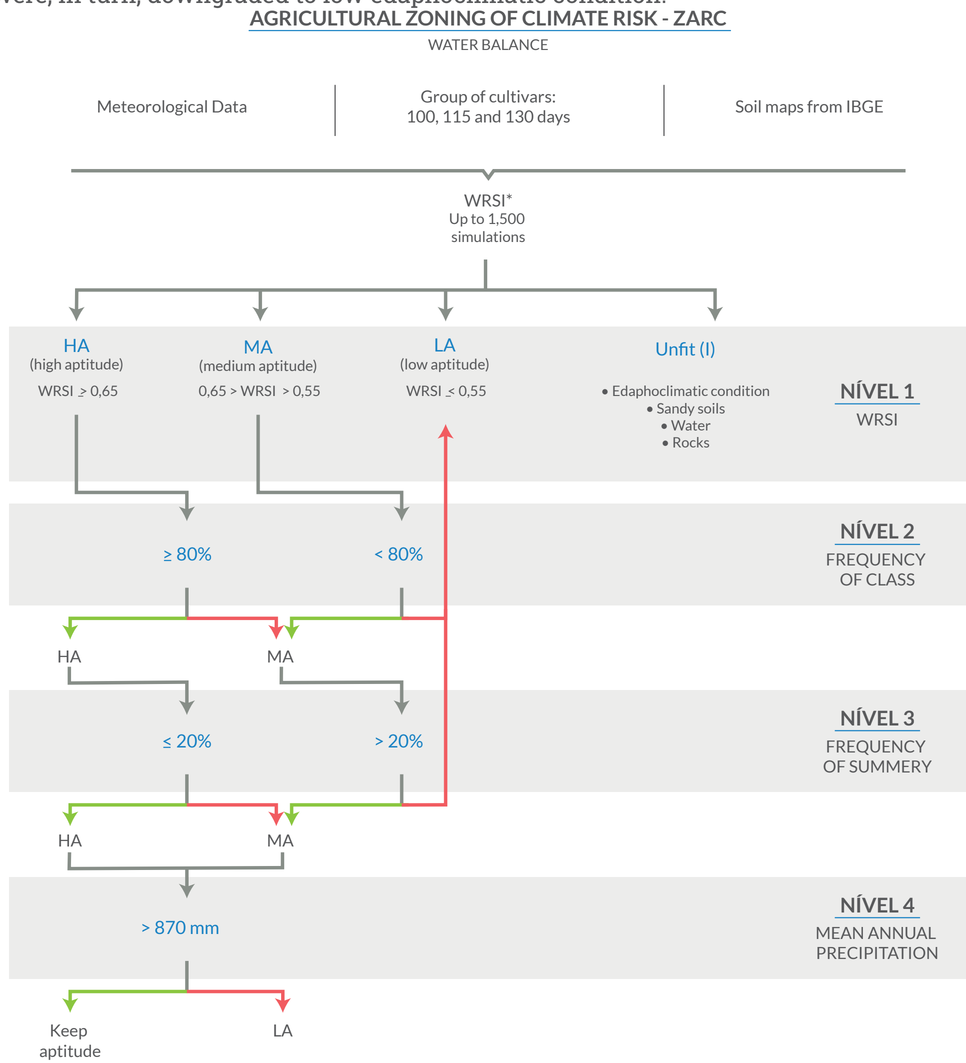
34 THORNTHWAITE, C.W.; MATHER, J. R. **The water balance.** Publications in Climatology, 8, Centerton, New Jersey, 1955.

the amount of water that a plant consumes in relation to the maximum that would be consumed in the absence of a water deficiency.

Water deficiency affects soy productivity differently during its phenological cycle, with flowering and grain filling being the most critical stage in defining productivity. This was, therefore, the stage selected for assessing the frequency and intensity of a water deficit in order to determine the edaphoclimatic condition for soy. ZARC also takes this phase into account to assess whether planting soy should be recommended in a given municipality. The criteria for defining edaphoclimatic condition for soy based on WRSI were as follows: 1) high edaphoclimatic condition (WRSI ≥ 0.65); 2) medium edaphoclimatic condition (0.65 > WRSI > 0.55); 3) low edaphoclimatic condition (WRSI ≤ 0.55) – all in accordance with ANDRADE JÚNIOR et al. (2007)[35]; and 4) Unfit used for urbanised areas, rocky outcrops and some municipalities with soil types where ZARC does not recommend planting soy.

Each municipality has a planting period recommended by ZARC, which can vary a little depending on the length of the crop cycle and the type of soil present in each part of the territory. Simulations were made using the ten-day recommended planting periods, the duration of the crop cycles and the types of soil, taking into account the 30-year historical series of climatic data. For the Rio Verde municipality (Goiás state), for example, the planting period recommended by ZARC for three crop cycles (100, 115 and 130 days) goes from 1st October to 31st December (nine ten-day periods). For each crop year, therefore, 27 simulations (9 x 3) were made for each pixel of the municipality where the type of soil was already known, a total of 810 simulations for the 30 years of the historical series assessed. The result of this step in the processing is called Level 1 of the analysis of edaphoclimatic condition, as shown in Figure 22.

In the next phase of the analysis, Level 2 (Figure 22), the categories of edaphoclimatic condition obtained from the innumerable simulations made for each pixel in the previous phase of the processing were grouped to attribute a predominant edaphoclimatic category to the pixel as a function of its greater frequency of occurrence. A category of high edaphoclimatic condition was attributed to a specific pixel, for example, when this condition reached 80% or more in the simulations. Otherwise, the category was downgraded to medium edaphoclimatic condition. The pixels that did not reach the minimum condition for medium edaphoclimatic condition in at least 80% of the simulations were, in turn, downgraded to low edaphoclimatic condition.



In the third phase, Level 3 (Figure 22), the "frequency of summery" in the flowering and grain filling stage was analysed – summery occurring in these critical periods of crop development has an important negative impact on soy productivity. The flowering and grain filling stage lasts 4-6 ten-day periods, depending on the length of the crop cycle[36].

35 ANDRADE JÚNIOR, A. S.; BASTOS, E.A. ; SILVA, C.O. Zoneamento de risco climático para a cultura da soja no Estado do Piauí. Teresina: Embrapa Meio-Norte, 2007 (Documentos, 167).

36 The flowering and grain filling phase for soy crops with a cycle of: i) 100 days (ten ten-day periods)

This means that the average value of WRSI for this period of up to six ten-day periods could be the result of a set of values that differ greatly from each other, in such a way that the average may not capture periods of water deficit longer than 20 days during the flowering and grain filling stage – a typical case in which the average can hide the reality of the extremes. Here is a hypothetical example: two series of WRSI can show high edaphoclimatic condition with an average value of 0.70 for five ten-day periods. The first series, which we can call (i), shows the following values by ten-day period: 0.69, 0.71, 0.80, 0.60 and 0.70. The second series, called (ii), shows the values: 1.00, 1.00, 0.90, 0.40 and 0.20. In series (i), the availability of water for the plant remains at stable levels, while in series (ii) there is a marked water deficit in the fourth and fifth ten-day periods, with a negative impact on the soy's potential productivity. Thus, an analysis of the "frequency of summery" is an important innovation in the assessment of edaphoclimatic condition, and simulations showing two or more consecutive ten-day periods with WRSIs below the limit for the high edaphoclimatic condition category (0.65) or the medium edaphoclimatic condition category (0.55) were considered to be Indian summers. The occurrence of summery in 20% or more of the simulations led to a downgrading of categories, from high to medium condition, or from medium to low condition (Figure 22).

Finally, the edaphoclimatic analysis named Level 4 had the objective of eliminating the small residual polygons in the high and medium edaphoclimatic condition categories. To do this, isohyets were generated with 10 mm intervals, based on the average annual precipitation of the 30-year climatological normal. From this, a cut in the isohyet value was made at 870 mm/year, in such a way that the residual polygons of high and medium edaphoclimatic condition, where the annual average was below 870 mm/year, were automatically classified at low edaphoclimatic condition, thus concluding the analysis of edaphoclimatic condition, as detailed in Figure 22.

Figure 22. Simplified flowchart illustrating the process of the edaphoclimatic analysis made in this study, from the variable inputs, through four levels of analysis, to the generation of the results for the edaphoclimatic condition for soy in the Cerrado Biome.

The results of the edaphoclimatic condition analysis were associated with the polygons obtained from the segmentation[37] of the 118 satellite images that cover the study area. In all, 17.83 million segments were produced, to which the corresponding edaphoclimatic conditions were attributed, generating a database in vectorial format that was used in subsequent processes to apply slope and altitude restrictions, in addition to land use classification.

3.3.2 SLOPE AND ALTITUDE RESTRICTIONS

One important methodological improvement over Agrosatélite's previous study (2015) is the application of restrictions related to slope, which varies according to the soil's textural classification. The criterion for slope restrictions – limited in the previous study to a cut at 12% for the entire Cerrado Biome – now varies in accordance with the texture of the soil. Thus, the restrictions are now: 1) soils with a clay texture with a slope equal to or greater than 14%; 2) soils with medium texture with a slope equal to or greater than 12%; and 3) soils with a sandy texture with a slope equal to or greater than 10%.

The rules for applying restrictions related to altitude have also been improved and refined. In Agrosatélite's previous study (2015), the altitude restriction was defined based on the minimum allotment of soy crops in each region in the 2013/14 crop year – in other words, areas with an altitude below the smallest agricultural allotment of that crop year were considered restricted in terms of altitude. This criterion was observed to be too restrictive, since from 2013/14 to 2016/17, 20% of the soy expansion in the Cerrado Biome occurred in areas with altitude restrictions according to the previous study.

The depletion of higher areas or plateaus in each region has led producers to expand soy production into lower altitudes. In this respect, Agrosatélite assessed the profile of the 20% of the soy area that, from 2013/14 to 2016/17, was grown in areas considered to have altitude restrictions. The conclusion was that, in areas with an altitude above 500 m, the smallest allotments decreased by up to 30 m in over 75% of the cases. In areas with an altitude below 500 m, the smallest allotments decreased about 24 m in over 75% of the cases. In view of this finding, the new surface model based on the smallest allotments

coincided with the ten-day periods 5, 6, 7 and 8; ii) 115 days (twelve ten-day periods) coincided with the ten-day periods 5, 6, 7, 8 and 9; and iii) 130 days (thirteen ten-day periods) coincided with the ten-day periods 6, 7, 8, 9, 10 and 11.

37 Segmentation was applied in accordance with the algorithm available in the ENVI FX software, according to details available in: ENVI Feature Extraction Module User's Guide. 2008. Available on: http://www.harrisgeospatial.com/portals/0/pdfs/envi/feature_extraction_module.pdf.

3.4 RESULTS OF AGRICULTURAL SUITABILITY FOR SOY IN THE NATIVE VEGETATION AND ANTHROPIC CLASSES

of soy crops in the 2018/19 crop year was lowered by these two constants – to 30 m for altitudes above 500 m and to 24 m for altitudes below 500 m. This new adjustment to the altitude restriction brought the agricultural suitability for soy closer to the reality of production in the Cerrado Biome, especially in the regions most densely occupied by soy and where there is a scarcity of suitable areas at a higher altitude. The change caused a significant increase in the area with edaphoclimatic condition without altitude restrictions, compared to Agrosatélite's 2015 study.

By applying the steps described above, the agricultural suitability for soy can be classified in 13 categories, as follows:

1. High edaphoclimatic condition without slope and altitude restrictions (AA/SR)
2. High edaphoclimatic condition with slope restrictions (AA/RD)
3. High edaphoclimatic condition with altitude restrictions (AA/RA)
4. High edaphoclimatic condition with slope and altitude restrictions (AA/RDA)
5. Medium edaphoclimatic condition without slope and altitude restrictions (MA/SR)
6. Medium edaphoclimatic condition with slope restrictions (MA/RD)
7. Medium edaphoclimatic condition with altitude restrictions (MA/RA)
8. Medium edaphoclimatic condition with slope and altitude restrictions (MA/RDA)
9. Low edaphoclimatic condition without slope and altitude restrictions (BA/SR)
10. Low edaphoclimatic condition with slope restrictions (BA/RD)
11. Low edaphoclimatic condition with altitude restrictions (BA/RA)
12. Low edaphoclimatic condition with slope and altitude restrictions (BA/RDA)
13. Unfit due to edaphoclimatic deficiency, regardless of slope and/or altitude restrictions (I)

At the end of the edaphoclimatic analysis and the application of slope and altitude restrictions, each segment was assigned to either a Native Vegetation category or an Anthropic category, taking into account the predominance of the overlapping category in each segment, including the Water category

The main results of the agricultural suitability for soy in the Cerrado Biome, in Other States and in Matopiba, in the Anthropic and Native Vegetation categories are shown in Figures 23-25. Agricultural suitability was separated into two big groups: "With Suitability" and "Without Suitability". This division takes into account the fact that 98.7% of the soy area in crop year 2018/19, in the Cerrado Biome, was grown in areas "with suitability". In other words, only 1.3% of the soy was grown in areas "without suitability" – and part of this percentage could be in areas that are unfit from an edaphoclimatic point of view but which are irrigated. The "with suitability" group includes the categories with high and medium edaphoclimatic condition without slope and altitude restrictions (AA/SR and MA/SR), considered the best areas for soy expansion. The "without suitability" group includes the following categories, considered to be of little interest for soy expansion: high and medium edaphoclimatic condition with slope and/or altitude restrictions; low edaphoclimatic condition regardless of restrictions (AA/RD, AA/RA, AA/RDA, MA/RD, MA/RA, MA/RDA, BA/SR, BA/RD, BA/RA, BA/RDA); and the category unfit (I).

The anthropic category has 95.73 million hectares, corresponding to 46.8% of the Cerrado Biome (Figure 23). Of this area, soy crops occupy 18.20 million hectares. The remaining 77.53 million hectares are divided into 26.57 million hectares in the "without suitability", 0.82 million hectares in TI, UC and Quil., 6.24 million hectares in APP and RL and 43.90 million hectares in the "with suitability" group, which is the more interesting group for the future expansion of deforestation-free soy. It should be noted that, of these 43.90 million hectares that are anthropized and suitable for soy production, 26.14 million hectares are currently used for pastures – this area corresponds to approximately 47.3% of all pastures in the Cerrado Biome, estimated at 55.28 million hectares (Lapig, 2019)[38].
The anthropized area "without suitability" is indirectly important for soy expansion, since the use of a good part of this area can be intensified for livestock farming. Consequently, land areas classified "with suitability" that are currently occupied by pastures will be freed up in sufficient quantity to accommodate the next soy expansion cycle in

38 Agrosatélite's areas of sugarcane and grains for the 2018/19 crop year were removed from Lapig's Atlas map of Brazilian pastures for the year 2018.

the Cerrado Biome, without impacting the livestock activity to the point of provoking new deforestation.

MAPA projections[39] indicate that Brazil's soy area will grow little more than 9.5 million hectares over the next ten years, or by the 2028/29 crop year. In this period, the area cultivated in the Cerrado Biome will need to grow between 4.5 million hectares and 5.0 million hectares for the Cerrado to maintain a 50% share of national production – today, this share is 51% but it was 54% in the 2000/01 crop year. The Biome's pastures are expected to be the major land suppliers for the next expansion cycle, assuming that deforestation associated with soy maintains its current downward trend. For this to happen, all that is needed is the intensification of pastures to improve the productivity of these areas by just 10% in the next decade. This would be enough to ensure that the 5.0 million hectares needed for expansion of deforestation-free soy becomes a reality in the Cerrado Biome.

If soy expansion continues over the next ten years at the same average annual rate as in the 2014-2018 period (0.52 million hectares/year; Figure 6), which is similar to MAPA's projections, it would use no more than one-fifth of the current area of pastures "with suitability" (26.14 million hectares) in the Cerrado Biome. However, the Cerrado's regional diversity must be taken into consideration. In the region of Other States, pastures "with suitability" (22.55 million hectares; Figure 24) is enough to maintain an average expansion rate of 0.36 million hectares/year (2014-2018; Figure 6) for 63 years. In Matopiba, however, this area (3.59 million hectares; Figure 25) would be depleted in 24 years, if the soy growth rate continues at the average expansion rate of 0.15 million hectares/year, as can be seen in 2014-2018 (Figure 6).

Pastures "with suitability" in Other States (22.55 million hectares; Figure 24) are located mostly in the states of Goiás (7.35 million hectares), Mato Grosso do Sul (6.41 million hectares), Minas Gerais (4.68 million hectares) and Mato Grosso (3.53 million hectares), as illustrated in Figure 27. All together, pastures "with suitability" in these four states correspond to 97% of the area available in Other States and 84% of the Cerrado Biome. Pastures "with suitability" in Matopiba (3.59 million hectares; Figure 25) are concentrated in Tocantins state, which has 78.8% of this area (2.83 million hectares) – the remaining 21.2% are distributed in the states of Maranhão (0.54 million hectares, or 15.0%), Bahia

39 Documents available on: https://www.gov.br/agricultura/pt-br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio/projecoes-do-agronegocio-2018-2019-2028-2029/view.

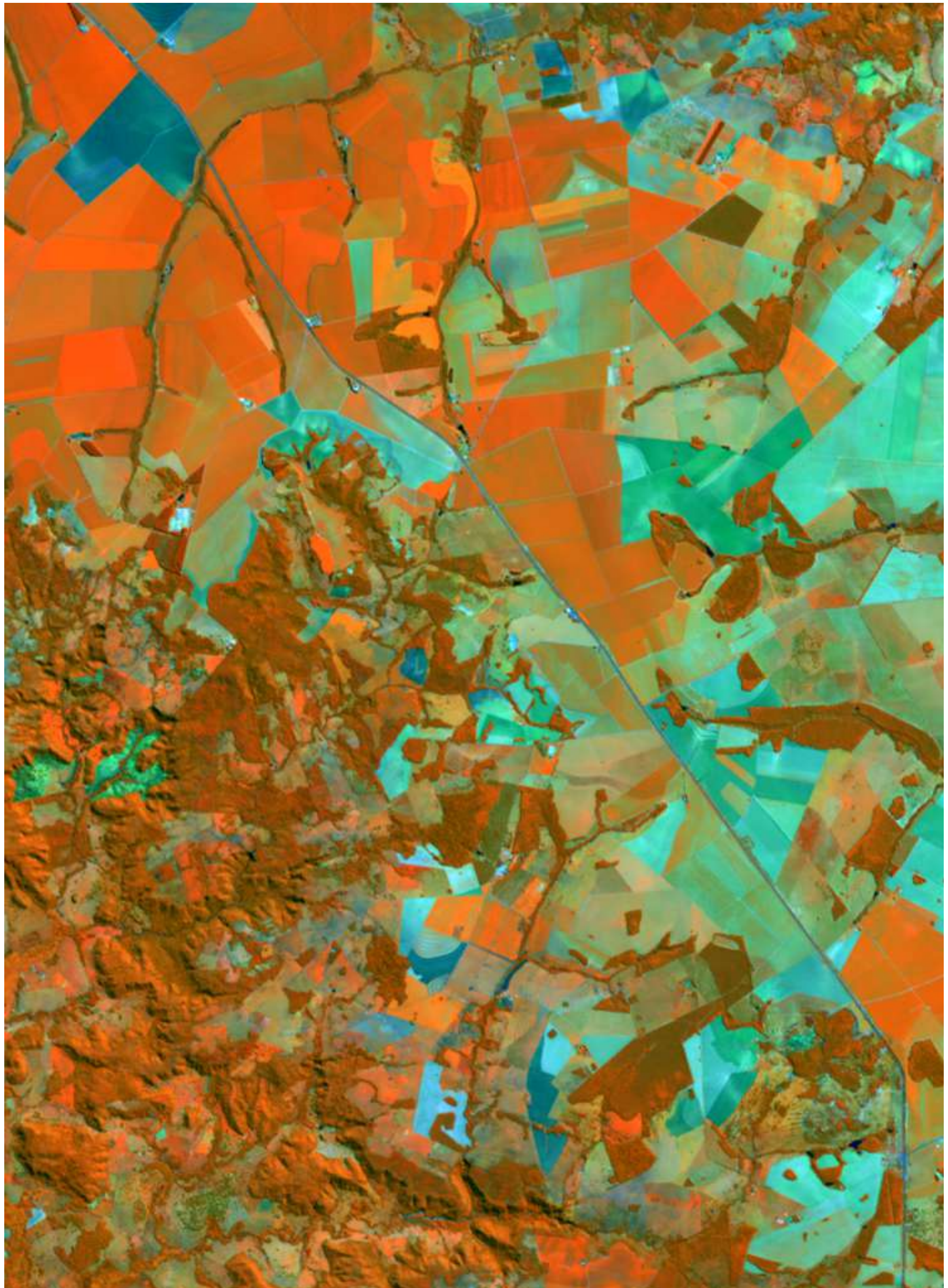


Image of 04/16/2020, Campo Grande - MS | Landsat-8, Path/Row 225/73, 5(R)6(G)4(B).

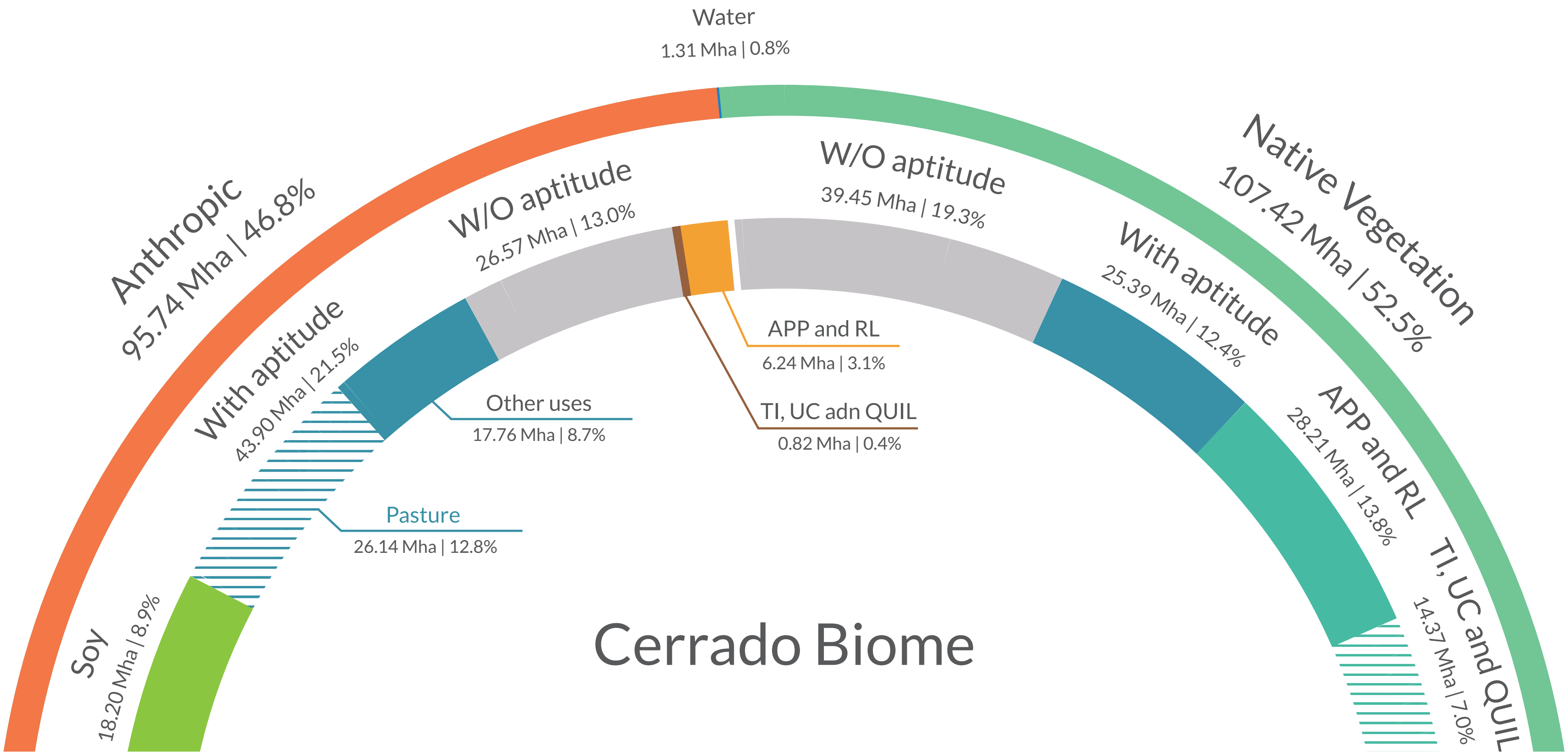


Figure 23. Representation of the Anthropic, Native Vegetation and Water categories for the Cerrado Biome. The second level divides the anthropic and native vegetation categories into the groups "With Suitability" and "Without Suitability", showing the area occupied by soy in crop year 2018/19 and the areas of APP and RL registered with CAR[40], as well as the areas of Indigenous Lands (TI), Conservation Units (UC, except the APA) and the Quilombola Communities (QUIL). In the anthropic category "with suitability", the pasture area is highlighted[41].

40 The Federal SICAR data used in this study were obtained from the Forest Service platform on: http://www.car.gov.br/#, updated on 18th February 2020. To maximise the coverage of properties registered with CAR, and because of the impossibility of considering information on CAR validation, which is still in an incipient stage, all properties available on the Federal SICAR database were considered.

41 Pasture map of the year 2018, from the Atlas Digital das Pastagens Brasileiras, is available on: https://pastagem.org/atlas/map.

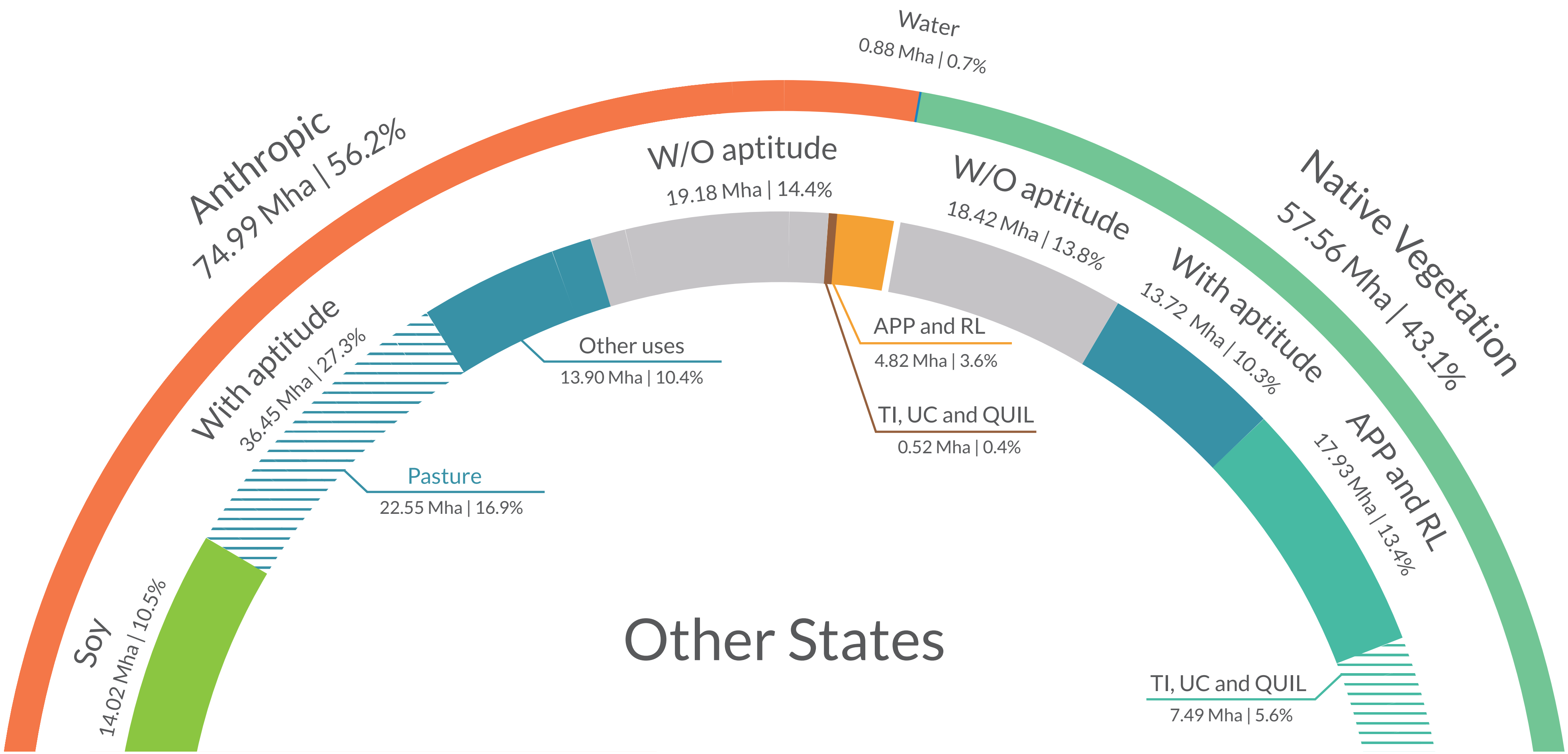


Figure 24. Representation of the Anthropogenic, Native Vegetation and Water categories for Other States. The second level divides the anthropogenic and native vegetation categories into the groups "With Suitability" and "Without Suitability", showing the area occupied by soy in crop year 2018/19 and the areas of APP and RL registered with CAR, as well as the areas of Indigenous Lands (TI), Conservation Units (UC, except the APA) and the Quilombola Communities (QUIL). In the anthropic category "with suitability", the pasture area is highlighted.

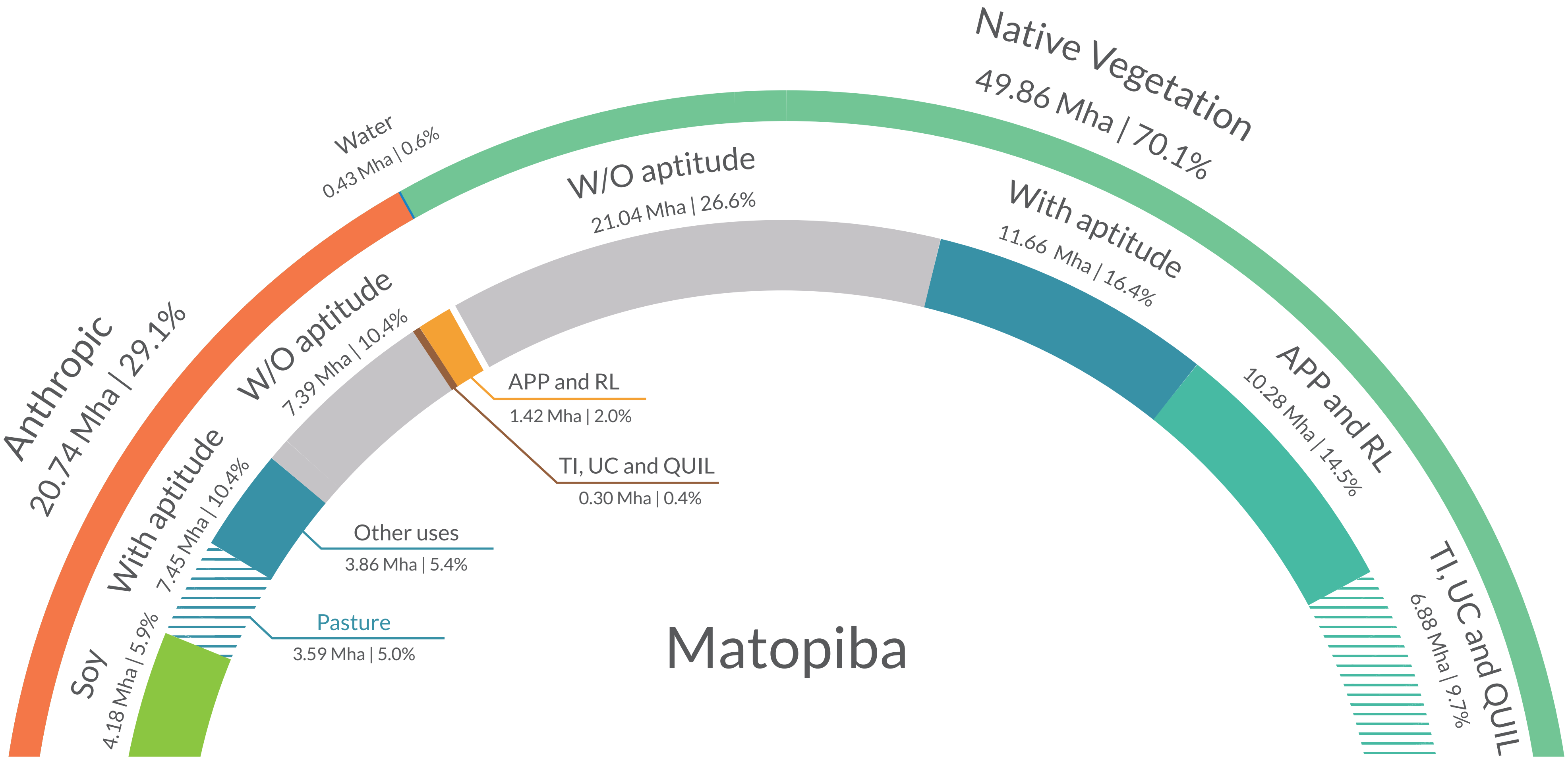


Figure 25. Representation of the Anthropic, Native Vegetation and Water categories for Matopiba. The second level divides the anthropic and native vegetation categories into the groups "With Suitability" and "Without Suitability", showing the area occupied by soy in crop year 2018/19 and the areas of APP and RL registered with CAR, as well as the areas of Indigenous Lands (TI), Conservation Units (UC, except the APA) and the Quilombola Communities (QUIL). In the anthropic category "with suitability", the pasture area is highlighted.

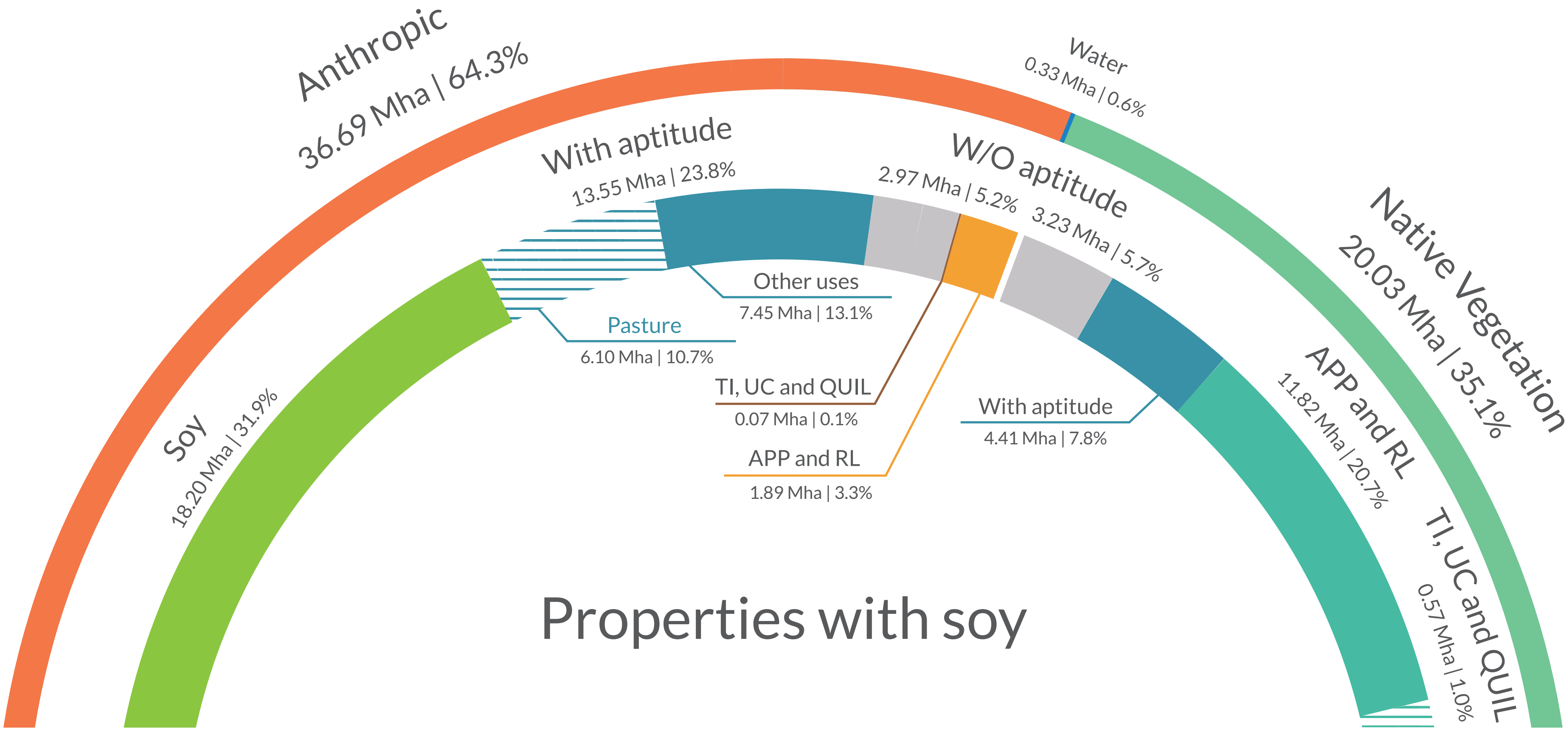


Figure 26. Representation of the Anthropic, Native Vegetation and Water categories for the 121,893 properties that currently grow soy in the Cerrado Biome, according to data registered with CAR. The second level divides the anthropic and native vegetation categories into the groups "With Suitability" and "Without Suitability", showing the area occupied by soy in crop year 2018/19 and the areas of APP and RL registered with CAR, as well as the areas of Indigenous Lands (TI), Conservation Units (UC, except the APA) and the Quilombola Communities (QUIL). In the anthropic category "With Suitability", the pasture area is highlighted.

Figure 27 shows the Native Vegetation and Anthropic categories for the “with suitability” group in each state of the Cerrado Biome, both spatially and graphically. The values were taken from Table 3 (Native Vegetation) and Table 4 (Anthropic), and represent land located outside the Special Areas, but include settlements and Areas of Environmental Protection where agricultural activities are permitted. As can be seen, in all Matopiba states, the areas “with suitability” are always smaller in the Anthropic category than in the Native Vegetation category. In Other States, however, the opposite is true: areas “with suitability” are larger in the Anthropic category in all the states of this region. Furthermore, the Anthropic category is divided into pastures and other uses, which are mostly areas with annual crops (other than soy), perennial agriculture, sugarcane and planted forests.

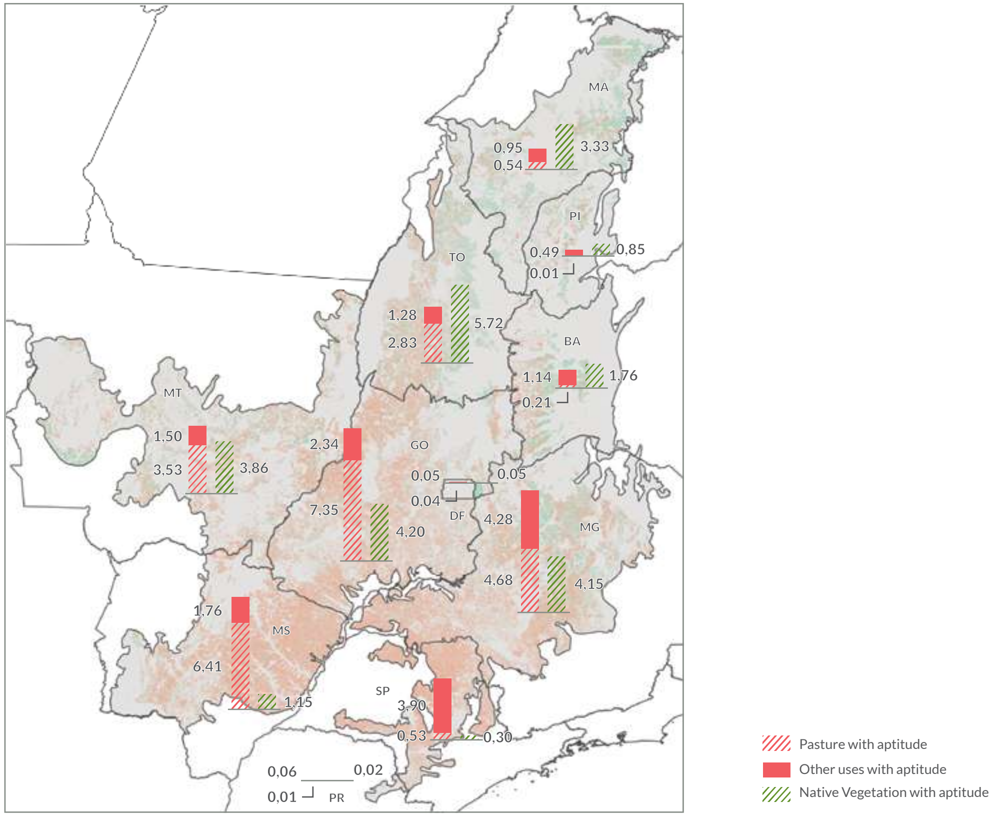


Figure27. Distribution of Native Vegetation (green) and Anthropic (red) categories in the “with suitability” group. The Anthropic category is divided into pastures and other uses (agriculture other than soy, planted forests, etc.), by state.

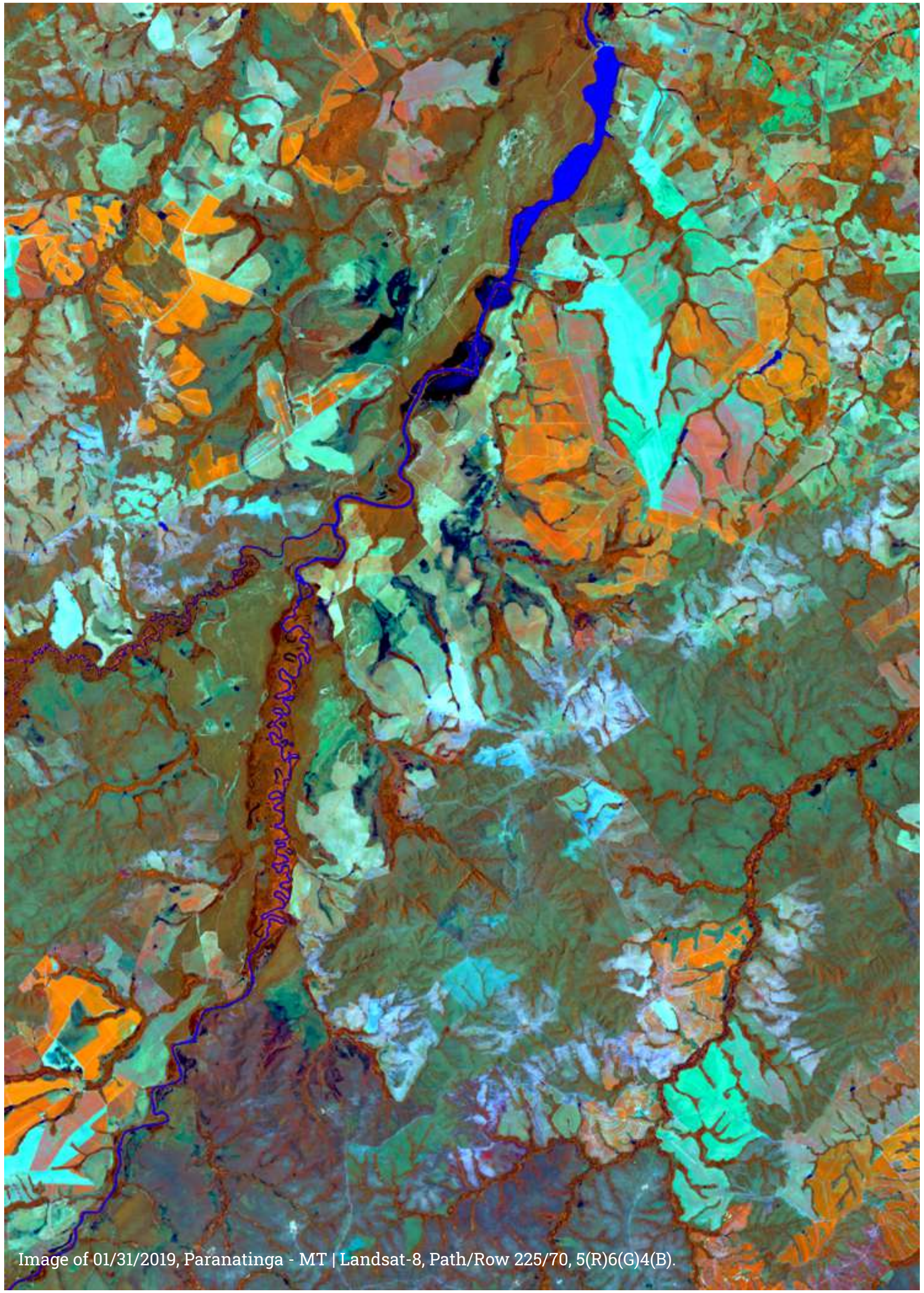


Image of 01/31/2019, Paranatinga - MT | Landsat-8, Path/Row 225/70, 5(R)6(G)4(B).

Table 3 shows the results of the analysis of the native vegetation "with suitability" category, both outside and inside the Special Areas. In the Cerrado Biome, about 70% of the Native Vegetation category has a high edaphoclimatic suitability – the remaining 30% has medium edaphoclimatic suitability. The proportions are similar in the Other States and Matopiba regions. The Native Vegetation "with suitability" category located outside the Special Areas corresponds to 58% of the Cerrado Biome: 54% in Other States and 65% in Matopiba. If Areas of Environmental Protection (APA) and Settlements, where agricultural activities are permitted, are added to these areas, these percentages increase to 64% in the Biome, 58% in Other States and 73% in Matopiba. This shows that approximately two-thirds of the current native vegetation cover with agricultural suitability in the Cerrado Biome is exposed to the risk of conversion to other uses, among which is soy production. The major part of Special Areas with native vegetation and agricultural suitability (27%) refers to Areas of Permanent Protection (APP) and Legal Reserves (RL).

Table 3. Native Vegetation "With Suitability" category, outside and inside Special Areas, by state, for the regions Other States and Matopiba, and for the Cerrado Biome.

NATIVE VEGETATION CLASS OF GROUP "WITH APTITUDE" | AREA IN HECTARES

Class		Aptitude	DF	GO	MG	MS	MT	PA	PR	RO	SP	Other States	MA	TO	PI	BA	MATOPIBA	Cerrado Biome
NATIVE VEGETATION		HA/NR	96,346	5,099,591	1,440,687	1,081,387	8,556,698	135	891	6,778	430,243	16,712,755	3,666,367	7,022,840	149,834	46,635	10,885,676	27,598,431
		MA/NR	694	242,446	4,852,921	1,651,029	0	0	34,928	0	184,206	6,966,224	1,254,297	108,207	1,169,753	2,515,424	5,047,680	12,013,905
OUTSIDE SPECIAL AREAS		HA/NR + MA/NR	11,137	3,902,856	3,770,805	1,085,159	3,771,097	17	4,984	1,091	274,424	12,821,571	2,834,041	5,109,524	828,471	1,541,034	10,313,070	23,134,641
INSIDE SPECIAL AREAS[42]	TI		0	5,588	380	18,002	2,004,810	0	0	4,679	0	2,033,459	296,233	281,548	0	0	577,781	2,611,240
	QUIL		0	43,200	1,762	717	7,951	0	0	0	0	53,630	2,774	25,456	472	0	28,702	82,331
	UC_PI		0	493	69,987	41,232	16	2	0	0	8,186	119,915	146,646	4,827	37,527	38,750	227,750	347,666
	UC_US		35	3,435	14,702	583	3	0	0	0	3,267	22,025	3	0	0	2,944	2,946	24,972
	Overlap TI-QUIL-UC_PI-UC_US		18,759	81,703	34,177	10,662	48,102	0	18	0	3,240	196,660	102,203	37,619	59,992	42,816	242,629	439,289
	APP_RL-CAR		30,650	1,008,085	2,018,520	1,512,946	2,639,267	115	15,878	1,008	303,600	7,530,069	1,045,368	1,057,630	366,847	719,373	3,189,218	10,719,288
	UC_APA		36,213	197,878	289,007	379	85,452	0	14,822	0	18,753	642,504	232,834	355,038	1,464	203,627	792,962	1,435,467
	ASS		1	87,664	93,224	62,737	0	0	0	0	2,289	245,914	189,394	185,327	24,393	13,515	412,629	658,543
	Overlap ASS-UC_APA		246	11,134	1,045	0	0	0	116	0	690	13,231	71,169	74,078	421	0	145,668	158,899
Total			**97,039**	**5,342,037**	**6,293,608**	**2,732,416**	**8,556,698**	**135**	**35,819**	**6,778**	**614,449**	**23,678,979**	**4,920,664**	**7,131,047**	**1,319,587**	**2,562,059**	**15,933,356**	**39,612,335**

42 Special Areas: TI – Indigenous Lands; QUIL – Quilombola Territories; UC_PI – Conservation Units with Full Protection; UC_US – Conservation Units with Sustainable Use, other than APAs; Overlap TI-QUIL-UC_PI-UC_US – Overlaps among these Special Areas; APP_RL-CAR – Areas of Permanent Protection and Legal Reserves registered with CAR (Rural Environmental Registry); UC_APA – Conservation Units for Sustainable Use of the APA type (Areas of Environmental Protection); ASS – Settlements; Overlap ASS-UC_APA – Overlaps among just these Special Areas.

Table 4 shows the results of the analysis of the anthropic category "with suitability", both outside and inside the Special Areas. In the Cerrado Biome, about 73% of the anthropic category has a high edaphoclimatic suitability – the remaining 27% has medium edaphoclimatic suitability. The proportions are similar in the Other States and Matopiba regions. The anthropic "with suitability" category located outside the Special Areas corresponds to 86% of the Cerrado Biome: 88% in Other States and 78% in Matopiba. If Areas of Environmental Protection (APA) and Settlements, where agricultural activities are permitted, are added to these areas, these percentages increase to 92% in the Cerrado Biome, as well as in Other States and in Matopiba. Not including the Areas of Permanent Protection (APP) and Legal Reserves (RL) that represent about 7% of the anthropic category "with suitability", all the remaining area is either already occupied with soy crops (18.20 million hectares, crop year 2018/19) or has the potential for conversion to deforestation-free soy.

Table 4. Anthropic "With Suitability" category, both outside and inside Special Areas, by state, for the regions Other States and Matopiba and for the Cerrado Biome.

ANTHROPIC CLASS OF GROUP "WITH APTITUDE" | AREA IN HECTARES

Class		Aptitude	DF	GO	MG	MS	MT	PA	PR	RO	SP	Other States	MA	TO	PI	BA	MATOPIBA	Cerrado Biome
ANTHROPIC		HA/NR	118,463	10,337,935	5,124,538	4,138,901	5,659,451	268	338	106	3,749,107	29,129,107	1,205,848	4,635,165	38,334	54,777	5,934,124	35,063,230
		MA/NR	1,373	240,658	4,668,020	4,447,018	0	0	74,376	0	971,848	10,403,293	385,533	38,807	486,011	1,337,115	2,247,466	12,650,759
OUTSIDE SPECIAL AREAS		HA/NR + MA/NR	1,618	9,340,152	8,714,172	7,955,836	4,695,980	220	29,016	63	4,130,411	34,867,467	1,318,654	3,345,145	490,476	1,218,017	6,372,291	41,239,759
INSIDE SPECIAL AREAS[43]	TI		0	1,066	1,965	18,730	148,232	6	0	0	1	170,000	11,646	30,453	0	0	42,100	212,100
	QUIL		0	5,773	3,591	509	5,879	0	0	0	81	15,833	129	4,232	22	0	4,382	20,215
	UC_PI		293	31,901	14,877	1,018	4,444	0	0	0	3,631	56,165	6,268	7,171	135	923	14,497	70,662
	UC_US		26	1,644	9,084	177	0	0	0	0	9,953	20,883	1	0	0	2,265	2,266	23,149
	Overlap TI-QUIL-UC_PI-UC_US		6,956	4,883	2,401	993	7,085	0	1	0	2,933	25,252	4,545	7,207	287	208	12,247	37,499
	APP_RL-CAR		17,123	849,019	792,062	390,235	457,726	41	9,113	43	275,948	2,791,310	71,647	518,110	28,447	37,520	655,724	3,447,034
	UC_APA		92,182	125,733	74,185	750	77,575	0	36,502	0	268,813	675,739	67,418	553,710	6	124,398	745,532	1,421,271
	ASS		3	215,816	179,797	217,670	262,531	0	9	0	27,385	903,210	100,373	146,897	4,972	8,562	260,804	1,164,014
	Overlap ASS-UC_APA		1,635	2,605	425	0	0	0	73	0	1,800	6,539	10,699	61,047	0	0	71,746	78,285
Total			**119,836**	**10,578,592**	**9,792,558**	**8,585,918**	**5,659,451**	**268**	**74,714**	**106**	**4,720,955**	39,532,399	**1,591,380**	**4,673,972**	**524,345**	**1,391,892**	8,181,590	47,713,989

43 Special Areas: TI – Indigenous Lands; QUIL – Quilombola Territories; UC_PI – Conservation Units with Full Protection; UC_US – Conservation Units with Sustainable Use, other than APAs; Overlap TI-QUIL-UC_PI-UC_US – Overlaps among these Special Areas; APP_RL-CAR – Areas of Permanent Protection and Legal Reserves registered with CAR (Rural Environmental Registry); UC_APA – Conservation Units for Sustainable Use of the APA type (Areas of Environmental Protection); ASS – Settlements; Overlap ASS-UC_APA – Overlaps among just these Special Areas.

Tables 5 and 6 show the results of the analysis of the native vegetation and anthropic categories in the “without suitability” group, both outside and inside the Special Areas. These areas are not of interest for soy expansion, except indirectly through the process of intensifying land use – i.e., through the migration of pastures from areas “with suitability” to areas “without suitability” in the anthropic category (Table 6).

Table 5. Native Vegetation “Without Suitability” category, outside and inside the Special Areas, by state, for the regions Other States and Matopiba and for the Cerrado Biome.

NATIVE VEGETATION CLASS OF GROUP “WITHOUT APTITUDE” | AREA IN HECTARES

Class	Apti-tude	DF	GO	MG	MS	MT	PA	PR	RO	SP	Other States	MA	TO	PI	BA	MATOPIBA	Cerrado Biome
NATIVE VEGETATION	HA/SR	30,691	3,167,710	1,145,100	148,455	1,329,208	11	1,863	828	185,546	6,009,412	891,837	1,536,011	49,088	3,678	2,480,615	8,490,027
	HA/AR	52,772	2,373,259	480,495	1,006,051	9,204,915	13,261	60	36,204	198,506	13,365,522	3,861,204	7,283,028	418,108	80,200	11,642,539	25,008,062
	HA/SAR	43,398	1,155,680	630,409	382,102	1,484,811	0	473	2,655	87,006	3,786,535	1,183,250	964,146	190,284	5,421	2,343,101	6,129,636
	MA/SR	348	127,415	2,478,986	388,860	0	0	57,144	0	71,196	3,123,949	317,141	57,758	132,297	75,805	583,000	3,706,949
	MA/AR	80	555,217	1,469,546	1,294,730	0	0	4,236	0	26,648	3,350,458	2,746,043	410,099	2,333,886	1,317,722	6,807,750	10,158,207
	MA/SAR	170	174,776	526,256	257,222	0	0	20,669	0	19,571	998,664	694,459	39,497	700,211	216,888	1,651,054	2,649,719
	LA/SR	1,074	51,108	1,331,325	79,507	113,485	3	29	0	3,606	1,580,137	94,492	12,402	675,345	1,270,208	2,052,448	3,632,585
	LA/RD	224	4,597	535,713	22,057	832	2	7	0	202	563,635	646	131	113,444	134,575	248,795	812,430
	LA/AR	1,008	40,231	161,435	114,449	98,819	1,316	5	605	1,426	419,294	296,197	30,084	1,037,740	622,644	1,986,665	2,405,958
	LA/SAR	6	3,426	96,915	15,912	2,352	0	2	8	115	118,737	3,565	801	334,689	54,492	393,547	512,284
	UNFIT	4,174	40,315	400,447	30,048	75,943	1,481	2	25	2,672	555,106	87,305	18,755	168,861	3,470,002	3,744,923	4,300,030
OUTSIDE SPECIAL AREAS	SUM OF CLASSES ABOVE	1,393	3,953,288	5,537,286	1,668,435	5,226,211	8,547	15,645	6,357	247,494	16,664,656	5,733,865	4,260,512	3,959,838	4,559,467	18,513,681	35,178,338
INSIDE SPECIAL AREAS[44]: TI		0	28,202	41,029	381,336	2,847,217	1	0	33,477	0	3,331,263	558,984	1,640,023	0	3,587	2,202,594	5,533,857
QUIL		0	134,943	6,685	1,673	322	0	0	0	0	143,623	10,744	66,748	1,258	64,190	142,940	286,563
UC_PI		14,093	142,147	423,272	56,449	158,429	627	2	0	10,462	805,481	628,956	715,709	664,353	119,838	2,128,857	2,934,338
UC_US		59	22,149	24,478	2,338	16	0	0	0	843	49,882	5,400	2,973	4	53	8,431	58,312
Overlap TI-QUIL-UC_PI-UC_US		19,082	191,336	195,420	34,009	287,621	28	1,427	0	1,212	730,137	278,763	735,165	179,534	127,180	1,320,643	2,050,779
APP_RL-CAR		40,752	2,544,602	2,512,734	1,558,180	3,422,822	3,123	35,147	490	277,938	10,395,787	1,986,933	2,527,018	1,168,379	1,408,982	7,091,312	17,487,100
UC_APA		57,868	480,450	393,289	7,225	367,726	3	32,229	0	56,812	1,395,602	384,652	297,786	43,716	590,015	1,316,169	2,711,770
ASS		1	169,442	109,222	29,749	0	3,744	0	0	992	313,150	405,076	96,092	134,084	361,747	996,999	1,310,149
Overlap ASS-UC_APA		697	27,174	13,212	0	0	0	41	0	743	41,867	182,765	10,685	2,787	16,576	212,813	254,680
Total		**133,945**	**7,693,734**	**9,256,626**	**3,739,393**	**12,310,365**	**16,074**	**84,492**	**40,325**	**596,495**	33,871,448	**10,176,137**	**10,352,712**	**6,153,953**	**7,251,636**	33,934,438	67,805,886

44 Special Areas: TI – Indigenous Lands; QUIL – Quilombola Territories; UC_PI – Conservation Units with Full Protection; UC_US – Conservation Units with Sustainable Use, other than APAs; Overlap TI-QUIL-UC_PI-UC_US – Overlaps among these Special Areas; APP_RL-CAR – Areas of Permanent Protection and Legal Reserves registered with CAR (Rural Environmental Registry); UC_APA – Conservation Units for Sustainable Use of the APA type (Areas of Environmental Protection); ASS – Settlements; Overlap ASS-UC_APA – Overlaps among just these Special Areas.

Table 6. Anthropic “Without Suitability” category, outside and inside the Special Areas, by state, for the regions Other States and Matopiba and for the Cerrado Biome.

ANTHROPIC CLASS OF GROUP “WITHOUT APTITUDE” | AREA IN HECTARES

Class	Aptitude	DF	GO	MG	MS	MT	PA	PR	RO	SP	Other States	MA	TO	PI	BA	MATOPIBA	Cerrado Biome
ANTHROPIC	HA/SR	9,207	1,107,271	1,063,834	76,110	239,582	0	236	1	417,920	2,914,161	226,571	227,588	1,354	3	455,515	3,369,676
	HA/AR	24,389	3,021,382	751,175	2,173,250	2,913,245	450	7	978	480,233	9,365,109	2,234,479	1,428,662	128,079	1,540	3,792,759	13,157,869
	HA/SAR	6,108	374,600	457,213	161,970	327,542	0	34	122	128,643	1,456,233	415,807	106,756	10,589	52	533,205	1,989,439
	MA/SR	74	11,340	682,895	88,916	0	0	71,040	0	154,252	1,008,518	37,333	621	3,224	5,722	46,899	1,055,417
	MA/AR	13	351,829	931,119	1,652,020	0	0	3,817	0	42,389	2,981,187	520,590	39,949	192,994	253,084	1,006,617	3,987,804
	MA/SAR	6	19,214	124,180	75,865	0	0	9,204	0	12,055	240,525	66,901	1,947	10,612	18,867	98,327	338,851
	LA/SR	12,089	30,764	1,253,589	168,081	7,887	3	182	0	17,663	1,490,259	2,359	3,877	43,581	480,899	530,716	2,020,975
	LA/RD	444	850	140,919	12,947	76	0	62	0	1,138	156,435	47	24	733	36,662	37,465	193,901
	LA/AR	1,240	28,592	234,925	182,360	10,505	187	4	0	4,978	462,792	38,524	6,530	126,703	396,499	568,256	1,031,048
	LA/SAR	46	1,100	21,439	5,544	282	0	4	0	335	28,750	420	112	10,997	23,498	35,027	63,777
	UNFIT	121,249	340,385	372,105	95,625	101,361	681	3,693	12	305,278	1,340,391	82,247	72,422	74,952	1,041,786	1,271,406	2,611,798
OUTSIDE SPECIAL AREAS	SUM OF CLASSES ABOVE	56,474	4,459,260	5,080,354	4,318,924	2,844,984	895	46,974	786	1,189,514	17,998,164	2,713,309	1,448,428	537,020	1,892,503	6,591,259	24,589,423
INSIDE SPECIAL AREAS[45]: TI		0	464	15,141	13,719	37,010	0	0	313	0	66,647	21,880	46,109	0	578	68,567	135,214
QUIL		0	23,407	5,878	621	220	0	0	0	26	30,152	5,557	7,543	553	23,556	37,209	67,361
UC_PI		233	9,071	37,579	8,614	7,127	50	0	0	1,657	64,331	33,815	25,288	926	1,046	61,075	125,406
UC_US		1,140	3,950	16,151	104	24	0	0	0	3,326	24,694	4,806	4,376	0	0	9,182	33,876
Overlap TI-QUIL-UC_PI-UC_US		5,591	7,654	21,030	2,161	6,560	6	50	0	786	43,838	18,500	15,501	4,603	9,586	48,190	92,028
APP_RL-CAR		9,528	541,892	643,710	293,511	369,434	344	13,856	16	160,605	2,032,897	374,031	233,955	39,778	113,371	761,136	2,794,033
UC_APA		100,913	128,190	119,804	9,165	134,185	8	27,376	0	204,982	724,623	172,001	55,875	3,664	62,640	294,181	1,018,804
ASS		10	110,718	92,267	45,867	200,937	20	14	0	3,071	452,905	235,703	48,274	16,683	152,032	452,692	905,597
Overlap ASS-UC_APA		976	2,722	1,481	0	0	0	14	0	917	6,110	45,676	3,138	590	3,299	52,703	58,813
Total		**174,865**	**5,287,328**	**6,033,394**	**4,692,687**	**3,600,482**	**1,322**	**88,283**	**1,114**	**1,564,884**	21,444,360	**3,625,279**	**1,888,487**	**603,817**	**2,258,612**	8,376,195	29,820,555

45 Special Areas: TI – Indigenous Lands; QUIL – Quilombola Territories; UC_PI – Conservation Units with Full Protection; UC_US – Conservation Units with Sustainable Use, other than APAs; Overlap TI-QUIL-UC_PI-UC_US – Overlaps among these Special Areas; APP_RL-CAR – Areas of Permanent Protection and Legal Reserves registered with CAR (Rural Environmental Registry); UC_APA – Conservation Units for Sustainable Use of the APA type (Areas of Environmental Protection); ASS – Settlements; Overlap ASS-UC_APA – Overlaps among just these Special Areas.

To complete the analysis of land use and land cover for the Cerrado Biome, Table 7 shows the results for the Water category.

Table 7. Water category outside and inside the Special Areas, by state, for the regions Other States and Matopiba and for the Cerrado Biome.

WATER CLASS | AREA IN HECTARES

	Class Water	DF	GO	MG	MS	MT	PA	PR	RO	SP	Other States	MA	TO	PI	BA	MATOPIBA	Cerrado Biome
OUTSIDE SPECIAL AREAS		32	220,832	218,278	33,783	98,215	9,246	112	0	100,349	680,847	67,219	185,973	29,290	29,097	311,578	992,426
INSIDE SPECIAL AREAS[46]	TI	0	585	37	106	7,381	3	0	0	0	8,111	188	9,229	0	3	9,419	17,530
	QUIL	0	459	668	0	16	0	0	0	0	1,144	45	148	42	1,186	1,421	2,565
	UC_PI	773	43	147	82	9,588	516	0	0	52	11,201	5,207	6,987	1,949	110	14,254	25,455
	UC_US	1	611	0	5	50	0	0	0	16	682	10	0	0	0	10	692
	Overlap TI-QUIL-UC_PI-UC_US	214	681	54	21	4,493	21	6	0	12	5,504	3,325	6,216	664	82	10,287	15,791
	APP_RL-CAR	142	18,945	78,044	9,896	20,469	50	111	0	2,993	130,650	2,680	7,120	543	2,436	12,779	143,429
	UC_APA	5,194	6,072	1,120	371	8,384	290	268	0	11,372	33,071	16,951	35,035	2,426	6,444	60,856	93,927
	ASS	0	2,325	854	359	1,506	126	0	0	43	5,214	839	2,206	321	1,493	4,858	10,072
	Overlap. ASS-UC_APA	0	18	1	0	0	0	0	0	1	20	5,218	388	325	55	5,986	6,006
Total		6,355	250,573	299,203	44,624	150,101	10,253	498	0	114,838	876,445	101,682	253,302	35,561	40,904	431,449	1,307,894

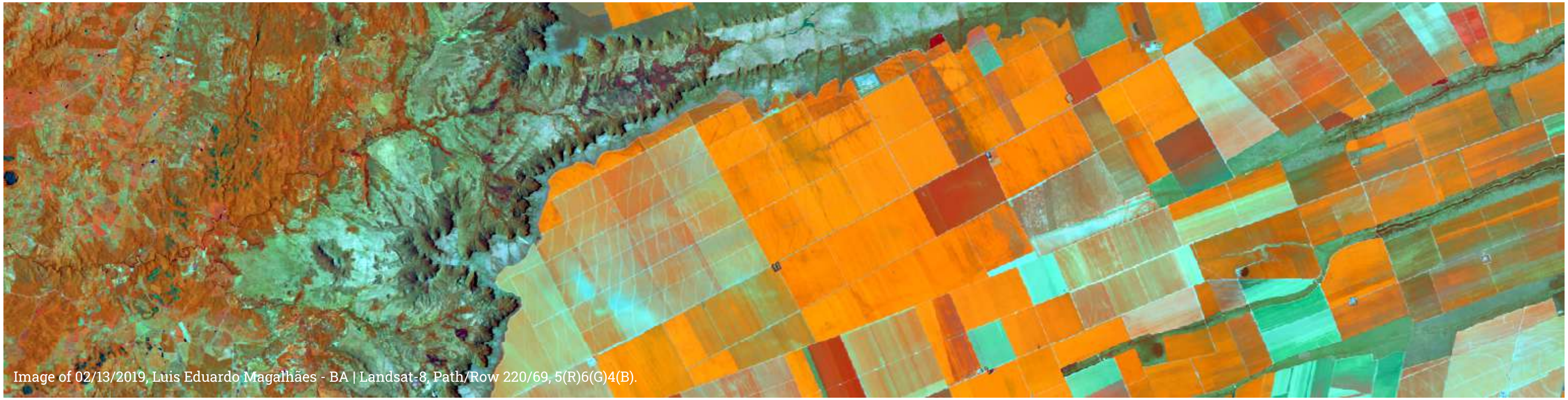


Image of 02/13/2019, Luis Eduardo Magalhães - BA | Landsat-8, Path/Row 220/69, 5(R)6(G)4(B).

46 Special Areas: TI – Indigenous Lands; QUIL – Quilombola Territories; UC_PI – Conservation Units with Full Protection; UC_US – Conservation Units with Sustainable Use, other than APAs; Overlap TI-QUIL-UC_PI-UC_US – Overlaps among these Special Areas; APP_RL-CAR – Areas of Permanent Protection and Legal Reserves registered with CAR (Rural Environmental Registry); UC_APA – Conservation Units for Sustainable Use of the APA type (Areas of Environmental Protection); ASS – Settlements; Overlap ASS-UC_APA – Overlaps among just these Special Areas.

4. SYSTEM FOR EVALUATING FINANCIAL COMPENSATION

Setting up a mechanism for providing financial compensation for the maintenance of native vegetation preserved on soy-producing properties is an idea that has been gaining strength in the markets. The possibility of granting a financial compensation to the rural producers who preserve their Legal Reserve surplus is being discussed, assuming they have an ASV (Authorisation for Depletion of Vegetation) for an area "with suitability" for soy. The financial compensation would be calculated on a regional basis, based on an indicator that represents the opportunity cost of the land (for example, cost of leasing for soy farming). The rural producer would be compensated for each hectare of surplus native vegetation preserved each year.

ABIOVE, in partnership with Agrosatélite, has developed the first version of such a system, called CCM (Cerrado Conservation Mechanism). The CCM is a web platform developed to help the various players involved in the financial compensation process offered to eligible rural producers. The system's four main objectives are: i) to be a technological facilitation link so that rural producers can apply to grain traders for these financial resources; ii) to evaluate the eligibility of the producers whose properties are candidates for receiving financial compensation; iii) to allow the operation and management of the mechanism by the traders and the fund manager; iv) to offer transparency and auditability to the financiers.

Access to the first version of CCM is restricted to ABIOVE, to its associated traders and to the fund manager, but the system could also become available to other traders willing to become part of the mechanism. ABIOVE registers and manages the traders that access the system – each trader's manager takes care of the registration and management of their own users. Figure 28 schematically illustrates the role of the different players who interact with each other and with the system, and presents a summary of the flow of information in CCM.

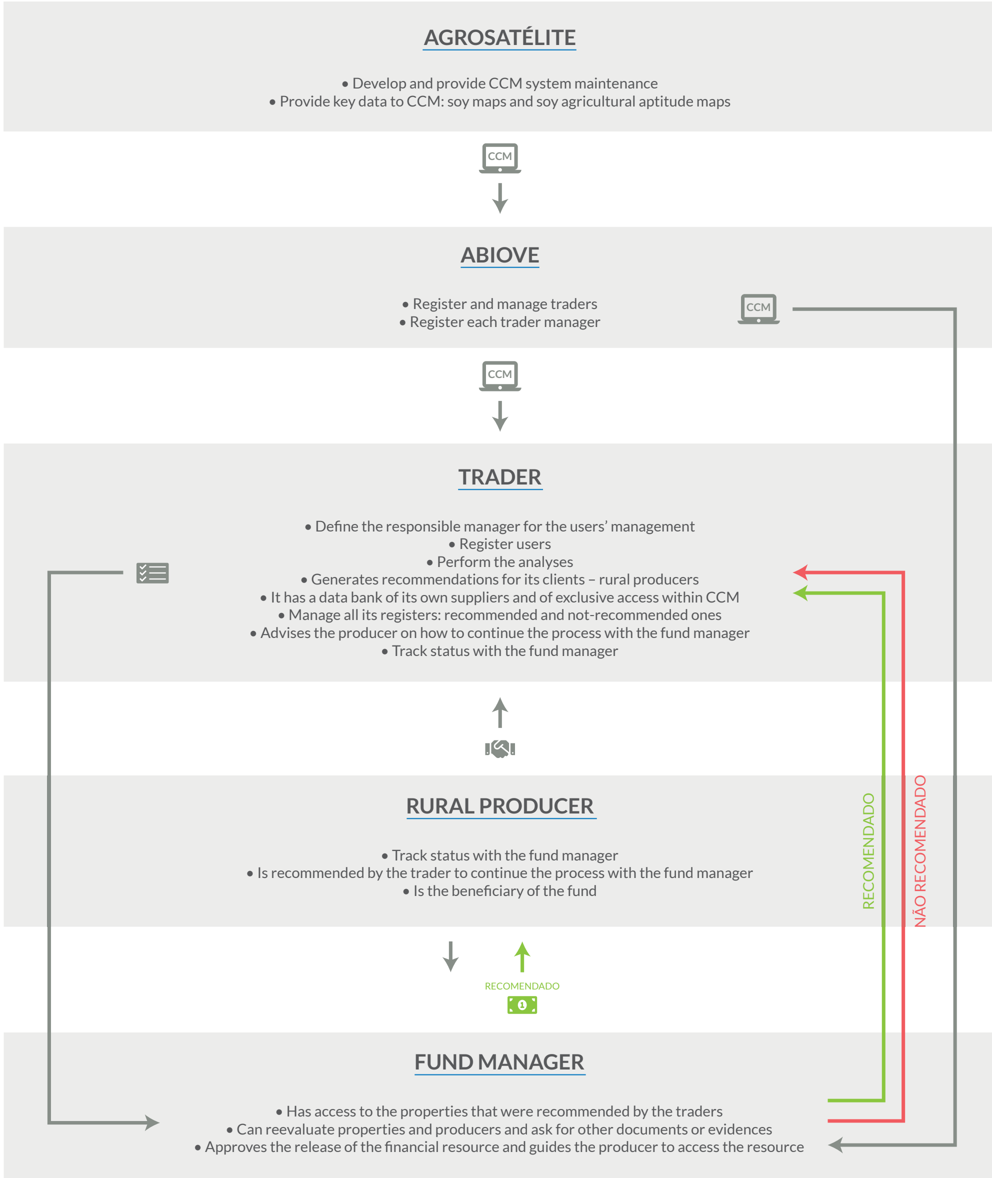


Figure 28. Schematic representation of the roles of each involved player and the relationship between the different players who interact with each other and with the CCM system.

When accessing the system, the user can check a wide range of maps, many of which were prepared within the scope of this project. Two examples are the soy map for the 2018/19 crop year and the map of the agricultural suitability for soy. Figure 29 shows the first screen, that the trader's user sees when accessing the system.

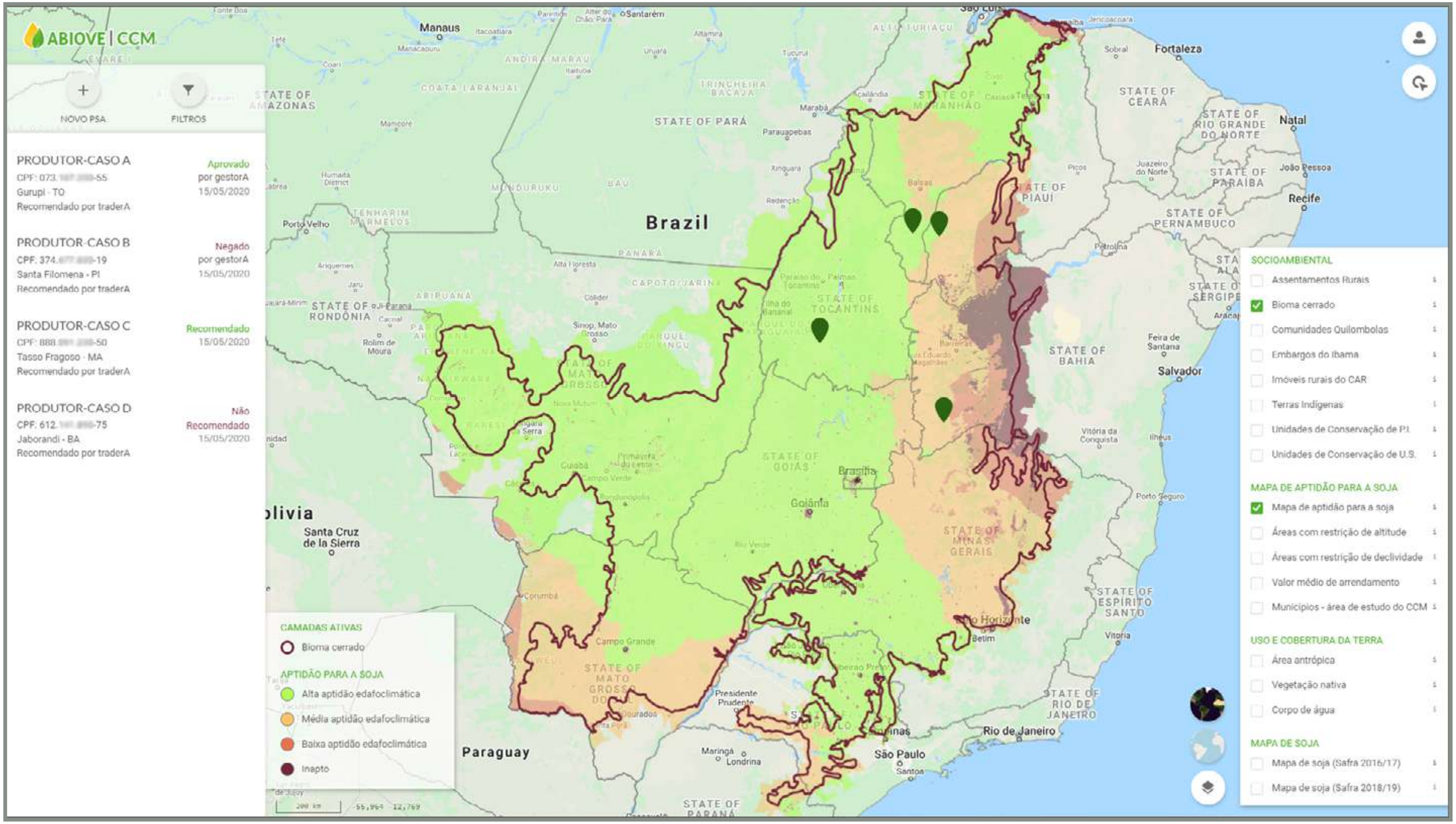


Figure 29. The system's first screen, highlighting the layers of agricultural suitability for soy and the boundaries of the Cerrado Biome (see panel on the right). The panel on the left has the properties registered by the trader with different status. In the examples on the list: 1) Producer Case A is the registration of a property and an owner assessed and recommended by the trader, with approval by the fund manager; ii) Producer Case B is a case where the trader assessed and recommended the registration, but the process was rejected by the fund manager; iii) Producer Case C is one where the trader assessed and recommended the registration, but which has not yet been evaluated by the fund manager; iv) Producer Case D is a case where the trader evaluated, but did not recommend the registered as it did not fit the mechanism's requirements – in this situation, the process is not forwarded to the fund manager.

To register a new property applying for financial compensation, the trader's user is directed to an environment which requests basic information about the property, such as the CAR code, the owner's name and CPF (individual income tax number), and the georeferenced boundaries in the ASV (Authorisation for Depletion of Vegetation) in a KML format. Attaching the ASV document issued by the competent official entity is a mandatory requirement (see Figure 30).

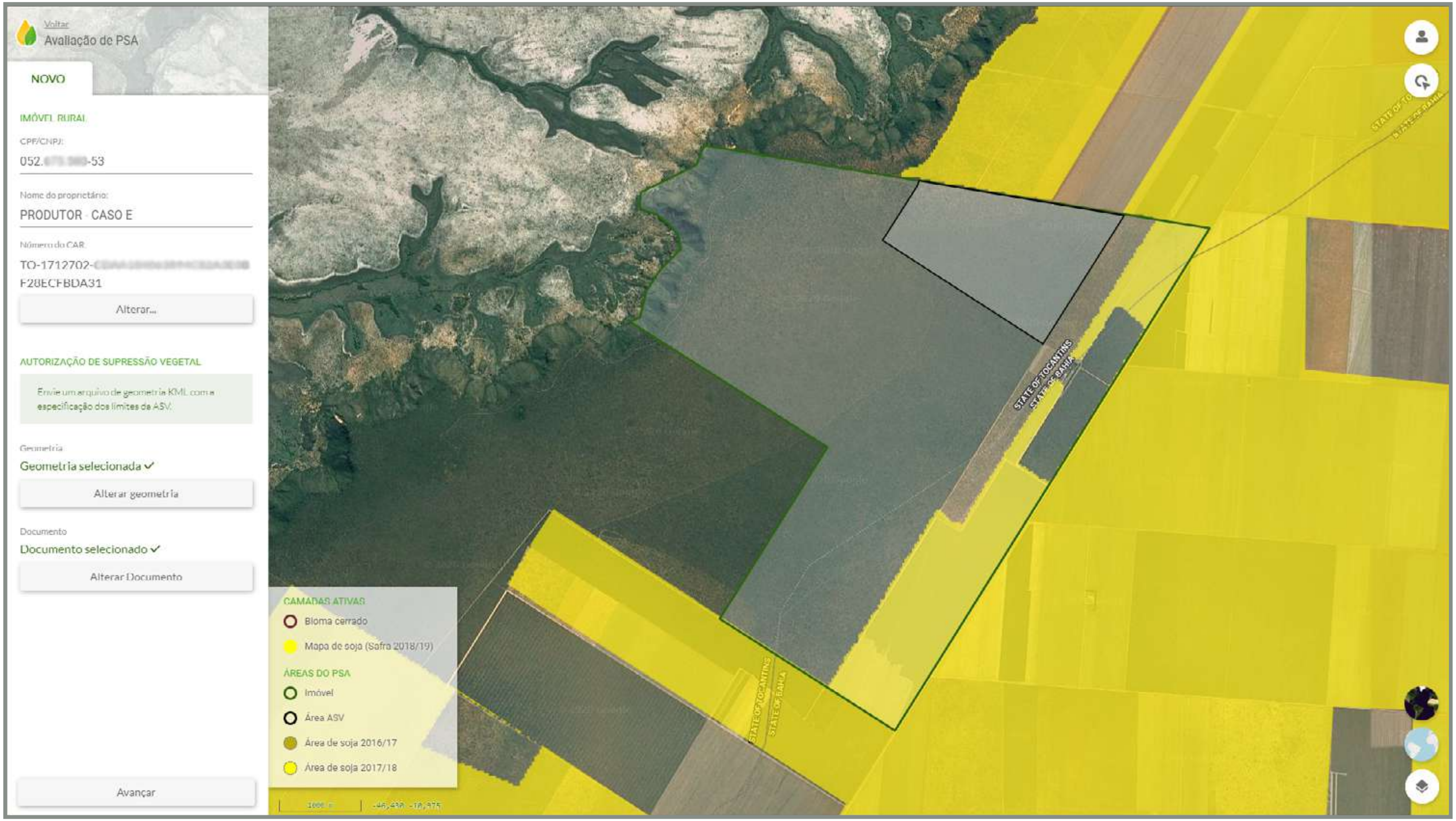


Figure 30. Screen for registration of a property applying for financial compensation from the CCM.

When the registration is completed, the system automatically makes a series of checks, ranging from a checklist of the property's socio-environmental compliance and the producer's personal or corporate income tax number (CPF or CNPJ), to a confirmation that the property grows soy, according to the soy maps for the 2016/17 and 2018/19 crop years, and an assessment of the property's agricultural suitability for soy and the ASV (see Figure 31).

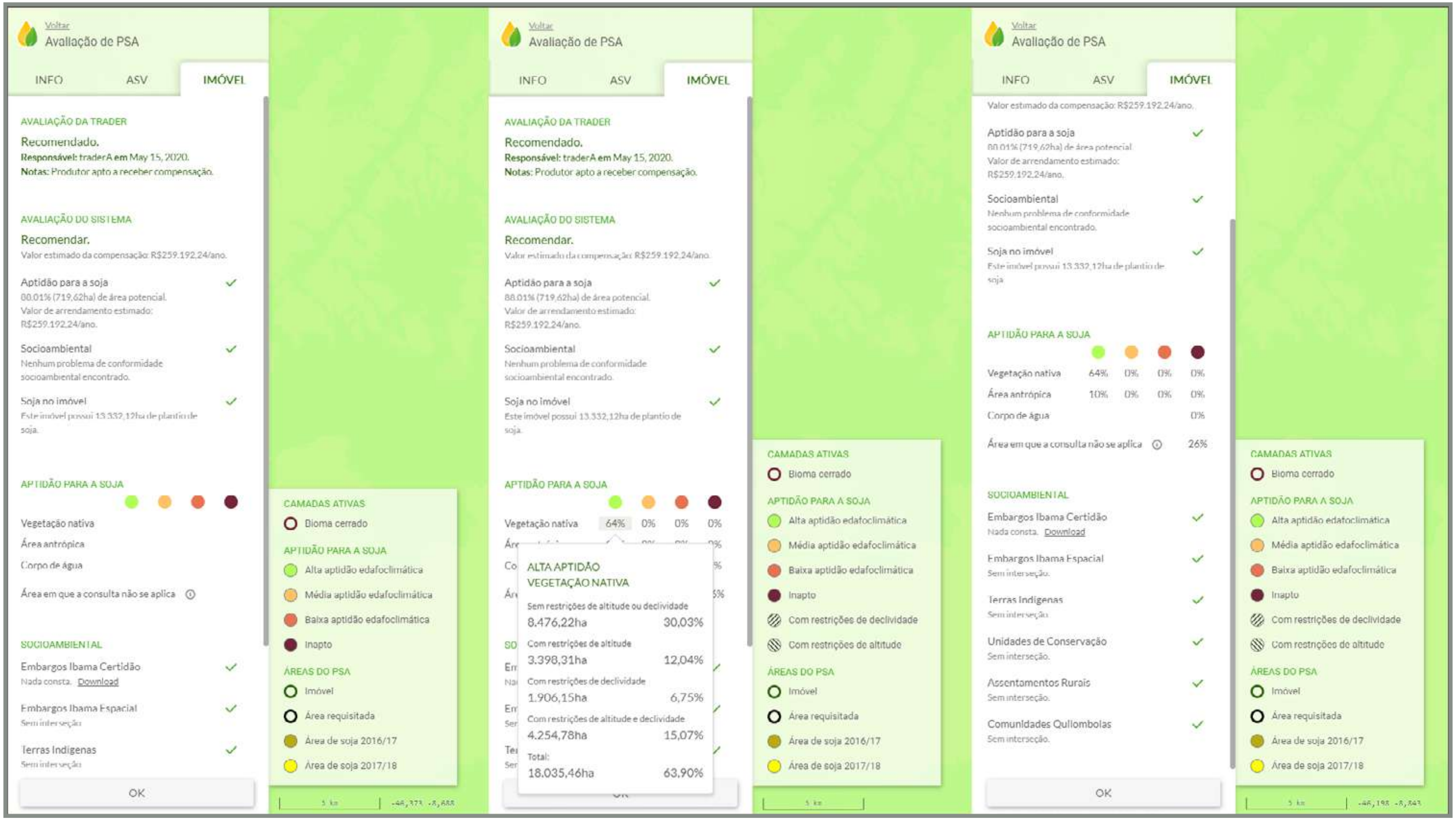


Figure 31. Summary of the results of the checks regarding eligibility for the financial compensation mechanism (CCM) for the property of a hypothetical soy producer registered and checked by the trader.

At the end of the eligibility verification process, the system offers an automatic result, showing whether the registered property assessed should be recommended or not to the fund manager. This automatic recommendation needs to be confirmed manually by the trader's user. When the system recommends the assessed registration, the system automatically calculates the amount of financial compensation to be paid to the producer, based on the eligible area in hectares and on the reference value for the land's opportunity cost, which can be obtained, for example, by the average leasing cost in each municipality, updated through research.

The CCM system's first screen for the fund manager is very similar to that of the trader's user. The manager, however, just sees and approves the registrations recommended by the traders. The manager is not able to access the environment to register new requests for financial compensation, which is the exclusive prerogative of the traders. On the other hand, the fund manager has access to the processes of financial compensation assessed and recommended by each of the CCM traders, so that a registration recommended by a trader remains available for evaluation and approval by the fund manager (Figures 32 and 33).

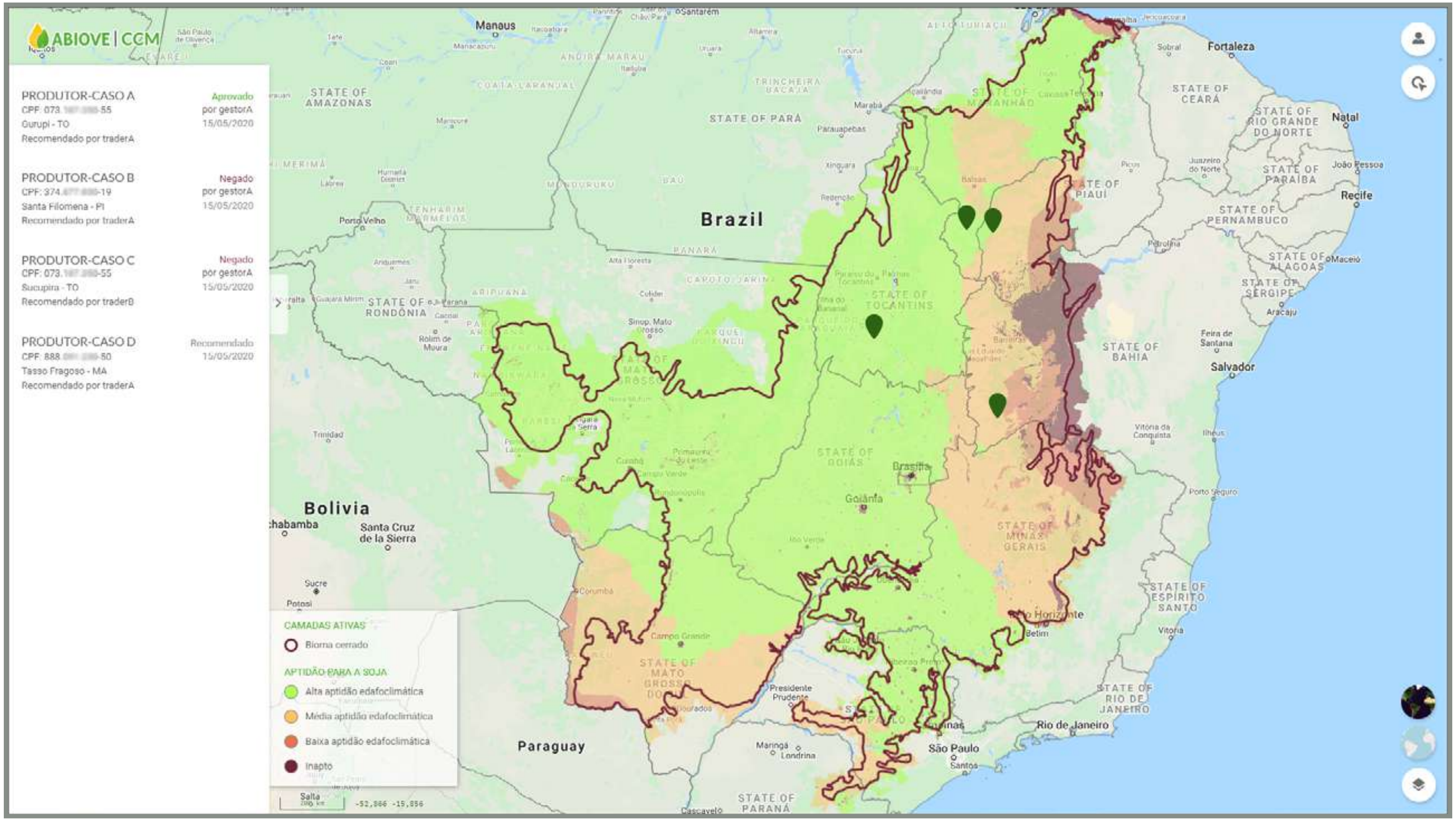


Figure 32. The first screen accessed by the fund manager has a list of the registrations recommended by the traders, showing the status of each process. In the examples on this screen: i) Producer Case A shows the registration recommended by Trader A, but which was rejected by the fund manager; ii) Producer Case B and Producer Case C are registrations recommended by Traders A and B, respectively, neither of which have been approved by the fund manager; and iii) Producer Case D shows the registration which was recommended by Trader A, but which has not yet been evaluated by the fund manager.

The CCM is a robust and innovative system, developed to enable and simplify the complex process involved in the mechanism for financial compensation. At the end of this initial phase, the system is still under discussion and subject to adjustments. Several other features are available on the platform – such as the GIS basic tools, filters, panels for registering and managing traders and users. The CCM is available on the internet at https://psacerrado.com.br. With the operationalisation of the financial compensation mechanism for soy producers in the Cerrado Biome, and with raising the necessary resources for the fund, the system is expected to offer, in the future, a presentation page of the project and versions in other languages, such as English.

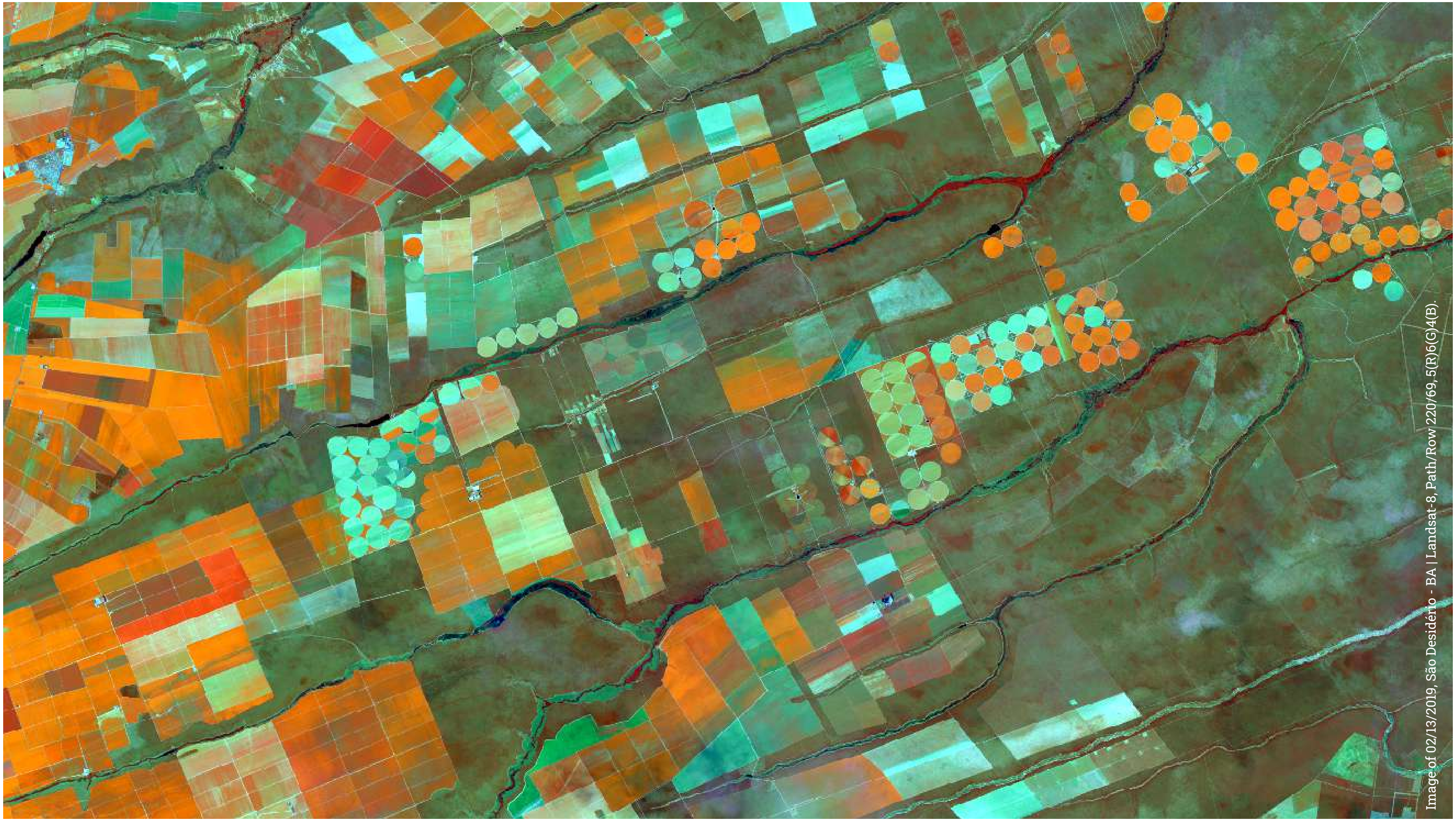


Image of 02/13/2019, São Desidério - BA | Landsat-8, Path/Row 220/69, 5(R)6(G)4(B).

5. FINAL CONSIDERATIONS AND RECOMENDATIONS

The Cerrado biome holds an outstanding position in Brazilian soy production, occupying 51% of the cultivated area in the country. Between 2000/01 and 2018/19 the area increased by 2.4 and obtained 30% in yield gains, allowing for soy production to more than triple in this biome.

The study of soy expansion dynamic in the Cerrado presented distinct temporal and territorial aspects. In the Other States regions, which occupies 77% of soy in this biome, there has been a reduction in expansion via deforestation, since the beginning of this millennium. In Matopiba however, from 2006/07 to 2013/14, there was a significant increase in the area being cultivated with soy as well as the area being deforested due to soy cultivation. Recently though, from 2013/14 to 2018/19 this region's soy expansion via deforestation has notably decreased. The anthropized area in the Cerrado Biome is 95.74 million hectares or 46.8%, that of which 26.14 million hectares of pastures are suitable for soy cultivation. If soy expansion continues to grow at the same average annual rate of 2014 to 2018 (0.52 million hectares/year) over the next 10 years, which is within MAPA's long-term projection rates, just 1/5 of these pastures will be enough to meet the demands of suitable land that can accommodate the next expansion cycle without the need for deforestation.

Implementing market policies that promote the reduction of the soy footprint associated with deforestation is a growing trend. This someday may lead to zero deforestation in the soy supply chain in the biome. However, territorial diversity poses challenges. In the Other States regions, there are enough pastures with agricultural suitability to sustain the average rate of expansion of 0.37 million hectares/year for another half a century. In the Matopiba region, however, it seems as though pastures suitable for soy production will run out faster, in approximately two decades, with an average rate of expansion of 0.15 million hectares/year. Although, it is important to consider that almost all of the suitable pastures in the Matopiba region are concentrated in Tocantins. And, the states of Piauí, Bahia and Maranhão, where soy is booming, have a limited capacity to sustain soy expansion without opening suitable areas of native vegetation.

As an important milestone of the measures taken to eliminate deforestation in the soy supply chain, a financial compensation mechanism has been formulated. This mechanism grants the preservation of surplus native vegetation, which amounts to 4.41 million hectares in just over 130 thousand soy producing properties of the biome. Thus, a system was developed together with this study that evaluates the eligibility requirements of the land owners applying for this remuneration, and offers georeferenced management to those that qualify. This system is available online at: https://psacerrado.com.br.

The study showed that the horizontal expansion of soy is largely due to the addition of new areas into the supply chain. These new areas come from the conversion of native vegetation and pastures. And when expanding into pastures, it almost always results in land use intensification. The second crop, which is becoming more common for corn and cotton, also plays an important role in reducing the demand of cultivating into new areas. This is an interesting trend of land use intensification to be considered for future studies. Another recommendation is to analyze the profile of pasture areas that are being converted to soy and what exactly is their connection to the process of increasing livestock productivity. This can encourage deforestation-free soy initiatives that are interconnected with other supply chains, such as livestock, crop-livestock or crop-livestock-forest integration.

The annual monitoring of soy crops in the Cerrado biome is crucial for the development and implementation of mechanisms that allow for mitigation to continue - or even future elimination - of recent deforestation caused by soy production.

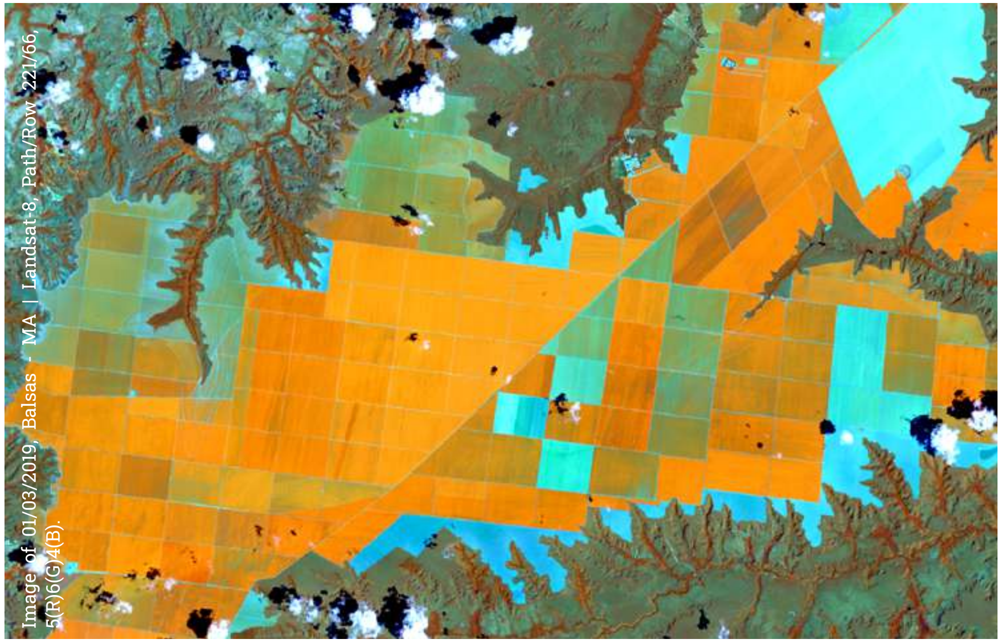
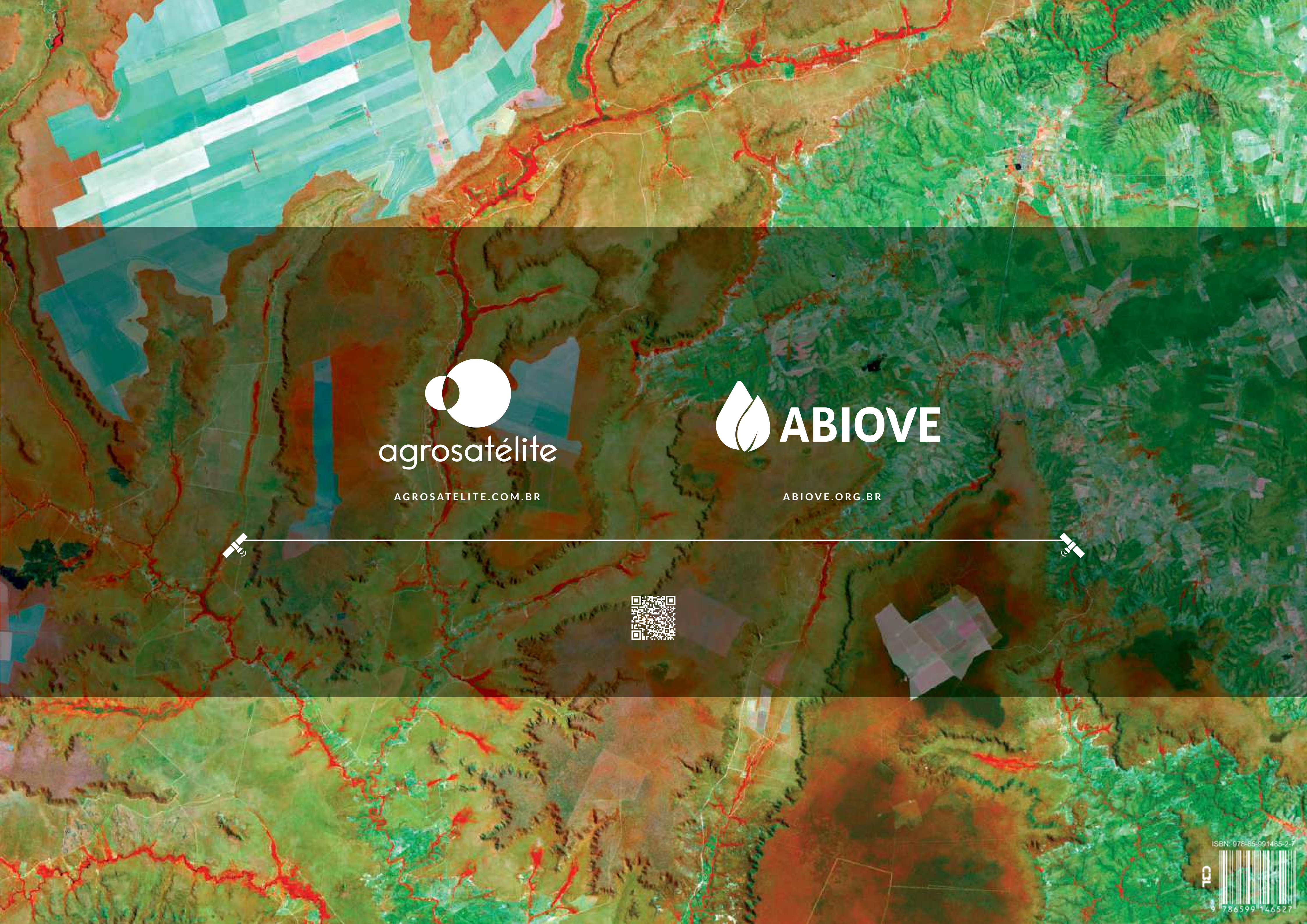


Image of 01/03/2019, Balsas - MA | Landsat-8, Path/Row 221/66, 5(R)6(G)4(B).



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