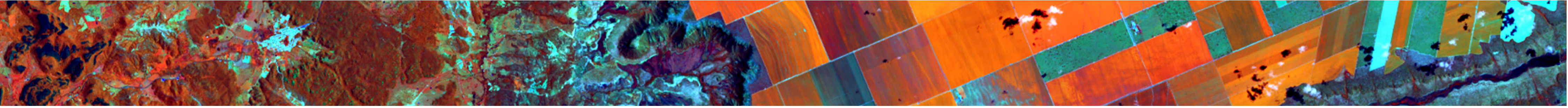


GEOSPATIAL ANALYSES OF THE ANNUAL CROPS DYNAMIC IN THE BRAZILIAN CERRADO BIOME

2000 2014

agrosatélite
applied geotechnology

Grantee:

GORDON AND BETTY MOORE FOUNDATION

General Coordinator
Bernardo Rudorff

Technical Coordinator
Joel Risso

Senior Team
Daniel Aguiar
Fabio Gonçalves
Moisés Salgado

Analist Team
Jair Perrut
Luciana Oliveira
Marco Virtuoso

Collaborative Team
Bruno Montibeller
Charles Baldi
Gabriela Rabaça
Helber de Paula
Jessica Gerente
Murilo de Almeida
Renata Bernardo
Smyllei Cúrcio
Vicente Lopes
Vinícius Chagas

Administrative Support
Wilson de Morais Jr.
Dêmick Garcia Filho

Institutional Support
Agroconsult Consultoria e Projetos

Graphic Design and Publishing
Media Eyes Comunicação Integrada
www.mediaeyes.com.br

December, 2015

Agrosatélite Applied Geotechnology Ltd.
Geospatial Analyses of the Annual Crops Dynamic in the Brazilian Cerrado Biome: 2000 to 2014 / Rudorff, B.; Risso, J. et al., 2015 - Florianópolis, Santa Catarina, Brazil, 2015.

28 p.

Summary Report.
biomas.agrosatelite.com.br

CONTENTS

FIGURE CONTENTS

TABLE CONTENTS

EXECUTIVE SUMMARY

Featured among the 34 biodiversity hotspots of the world and accounting for more than half of the soybean production in Brazil, the Cerrado biome stands out for its environmental and economic relevance. This study, based on the use of geospatial technologies, carefully analyzed about 2,500 Landsat satellite images to describe both the dynamics of annual crops expansion in years 2000/01, 2006/07, and 2013/14, as well as the associated land use and land cover change (LULCC) in the Cerrado biome during the periods 2000/01–2006/07 and 2006/07–2013/14. In addition to the historical analysis, the potential for future soybean expansion on both previously opened areas and native vegetation remnants was analysed taking into account climate, soil, slope and altitude. The main results revealed that:

- ✓ The Cerrado biome accounted for 51.9% (15.66 million hectare - Mha) of the Brazilian soybean area in the crop year 2013/14;
- ✓ The planted area of the 1st crop season of soybean, corn, and cotton increased from 9.33 Mha in 2000/01 to 12.30 Mha in 2006/07, reaching 17.43 Mha in 2013/14;
- ✓ Soybean alone increased its planted area by 108% from 2000/01 (7.53 Mha) to 2013/14 (15.66 Mha);
- ✓ The LULCC associated with annual crop expansion represented 4.61 Mha between 2000/01 and 2006/07, and 6.07 Mha between 2006/07 and 2013/14;
- ✓ Most LULCC due to annual crop expansion was from native vegetation in the MATOPIBA region (Cerrado states of Maranhão, Tocantins, Piauí, and Bahia) and from pasture in the Cerrado states outside of MATOPIBA;
- ✓ The area available for soybean expansion in the Cerrado biome amounts to 40.81 Mha, of which 15.45 Mha (5.40 Mha in MATOPIBA) is covered by native vegetation and 25.36 Mha (2.81 Mha in MATOPIBA) are previously disturbed areas.

The present study provides detailed information, from local to regional scale, about the available land with high, medium and low potential for soybean expansion, with and without further conversion of native vegetation. This information is valuable for the diverse stakeholders involved in the strategic planning and development of sustainable agriculture in the Cerrado biome, particularly at a time when agricultural expansion in the Atlantic Forest biome is nearly exhausted, and there are a number of restrictions for further agricultural expansion in the Amazon biome.

1. INTRODUCTION

The Cerrado is the second largest biome in Brazil, with an area of 204 million hectares, representing approximately ¼ of the Brazilian territory, and spanning over parts of 11 Brazilian states, including the Federal District. Since the beginning of the 1980s, the Cerrado has gone through an intense process of alteration of its original vegetation cover. Favourable climate and soil, along with significant technological advances in the development of tropical agriculture, make the Cerrado not only the most important region for agricultural production in Brazil, but also the region with the greatest potential for further expansion. However, the Cerrado, along with the Atlantic Forest biome, are also among the 34 biodiversity *hotspots* in the world, drawing the attention from both the agricultural and environmental sectors as they search for ways to both increase agricultural production and preserve native vegetation remnants.

To reconcile preservation measures with the growing pressure to increase food production in the Cerrado requires a comprehensive understanding of its current land use and land cover distribution as well as of its remaining land stock for agricultural production. In this sense, this unprecedented study, developed by Agrosatélite with funding from the Gordon and Betty Moore Foundation, aimed to provide a detailed analysis of the land-use and land-cover change (LULCC) associated with the expansion of annual crop production in the Cerrado biome since 2000. To that end, about 2,500 remote sensing images from the Landsat satellites were analyzed to identify and map LULCC associated with the expansion of soybean, corn and cotton crops between 2000 and 2014. This allowed an understanding of where and when the expansion occurred through either intensification, using previously cleared lands, or through clearing/deforestation of new areas (light green; Figure 1). The study also mapped the stock of suitable land for further soybean expansion not only in previously cleared areas, which should be prioritized for crop expansion to avoid new deforestation (blue; Figure 1), but also in native vegetation remnants (dark green; Figure 1). Thus, relevant information is made available to support analyses related to public policies, regulatory benchmarks, and sustainable development of the Cerrado biome.

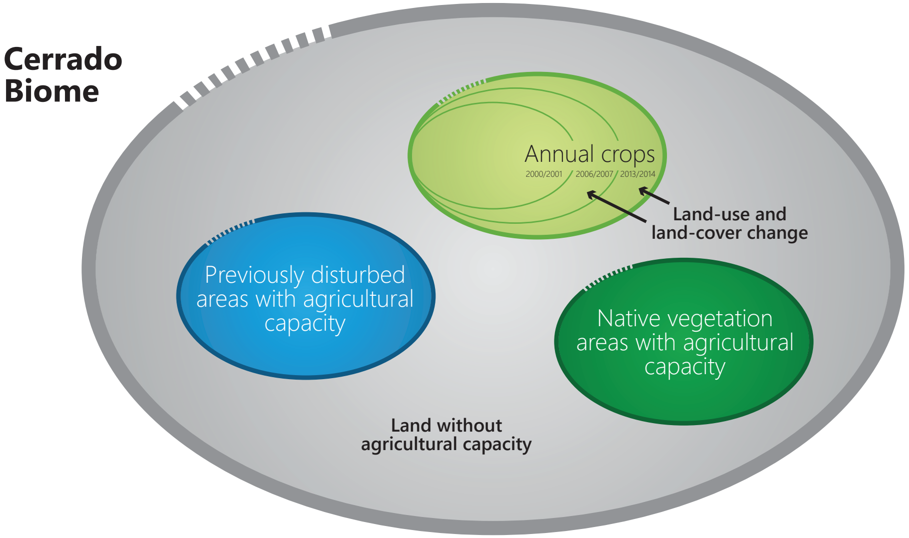


Figure 1 – Schematic illustration of the study design and outcomes.

[1]Land use intensification is associated with an increase of the land productive capacity. The simple conversion of one hectare of pasture, with a stocking rate of 1 animal unit (AU).ha^{-1} (~100 kg of meat.year^{-1}), to soybean (~3 thousand kg.ha^{-1}) results in land use intensification. The intensification also occurs, for example, through double cropping with soy (~3,000 kg.ha^{-1}) followed by corn (~6,000 kg.ha^{-1}) in the same crop year. Improving degraded pasture land by increasing the carrying capacity is a major intensification process that releases land for agricultural use.

2. STUDY AREA

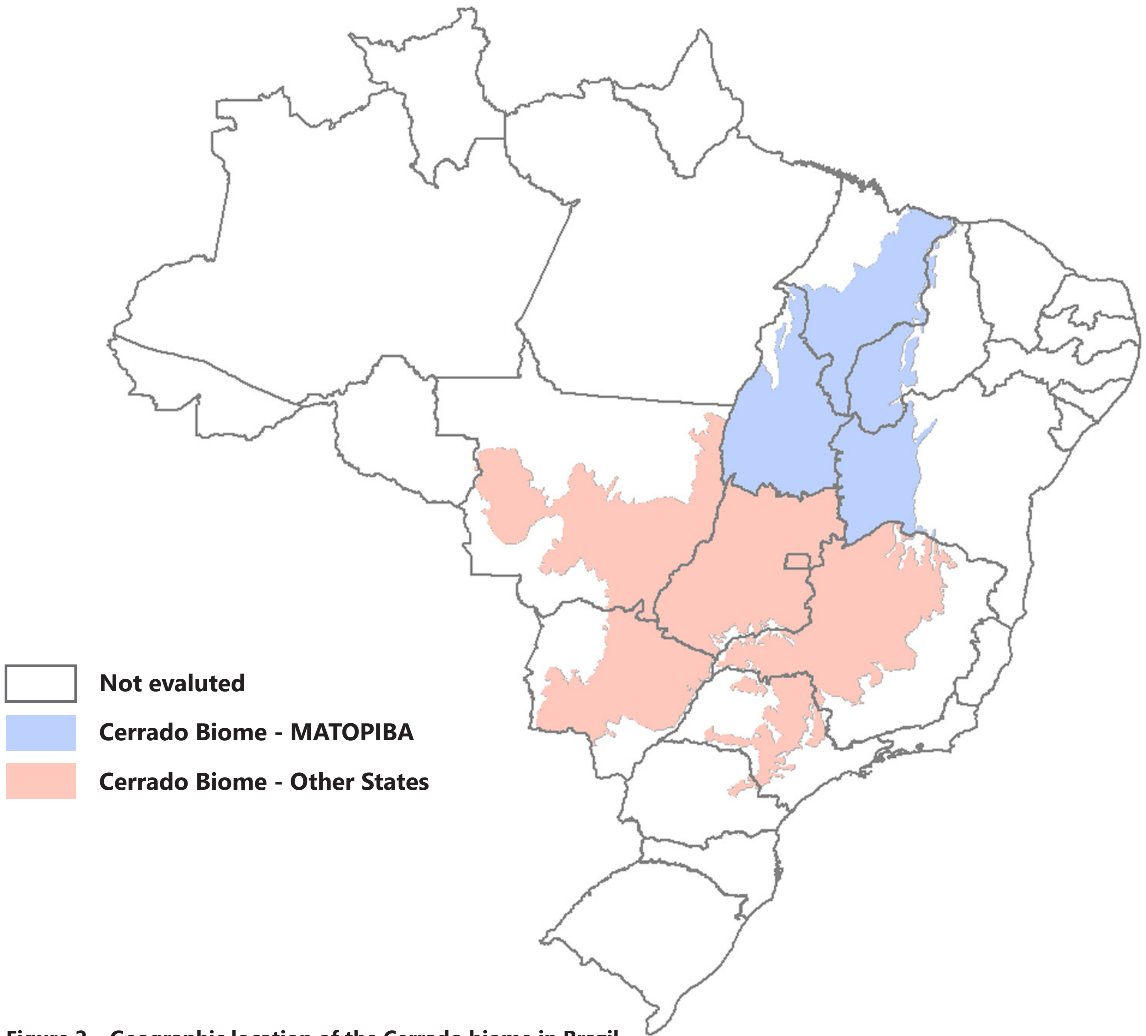


Figure 2 – Geographic location of the Cerrado biome in Brazil.

Cerrado Biome

Considered Area = 2,039,379 km²

1/4th of the Brazilia Territory

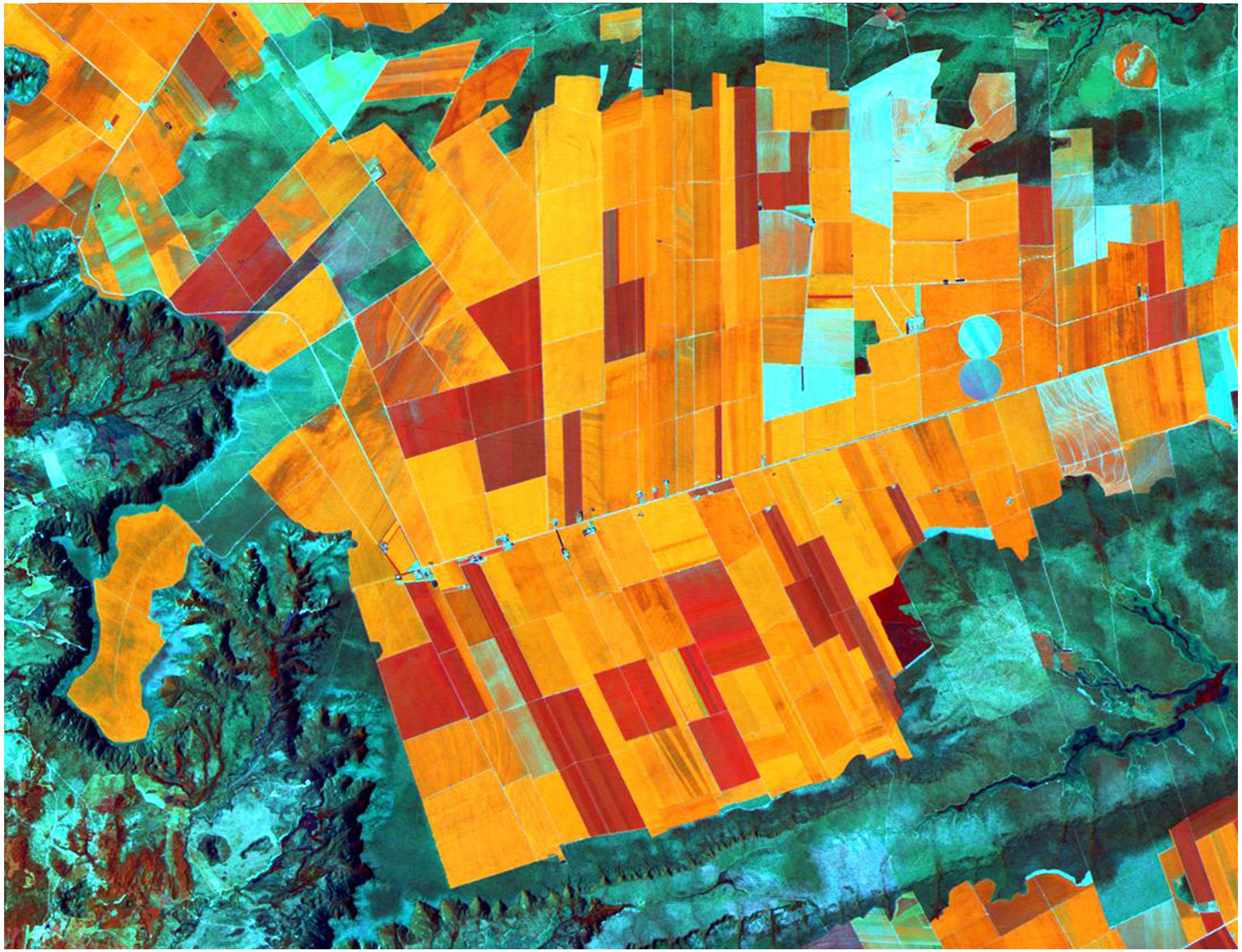
11 States and the Federal District

118 Landsat scenes

The Brazilian Cerrado corresponds to an area of 2,039,379 km², covering the entire Federal District - DF and parts of 11 states: Piauí - PI (37%); Maranhão - MA (64%); Tocantins - TO (91%); Bahia - BA (27%); Mato Grosso - MT (40%); Minas Gerais - MG (57%); Goiás - GO (97%); Mato Grosso do Sul - MS (61%); São Paulo - SP (33%); Paraná - PR (2%); and Rondônia - RO (0.2%).

3. REMOTE SENSING DATA

The area cultivated with the 1st crop season of soybean, corn, and cotton was assessed through Landsat and MODIS images acquired during the 2000/01, 2006/07, and 2013/14 crop years. Each Landsat scene covers an area of 36,000 km^2, requiring a total of 118 images to cover the entire Cerrado. Approximately 800 images per crop year were used to cover the same area of the territory several times during the crop season. The interpretative analyses of the Landsat images were complemented with a time series of MODIS images, allowing the identification and mapping of soybean, corn, and cotton fields, as well as the LULCCs caused by the expansion or contraction of crop fields between 2000/01 and 2006/07, and 2006/07 and 2013/14. The analysis of different satellite images with complementary characteristics such as Landsat and MODIS is fundamental for a study of this magnitude to be technically feasible. This is because annual crops have a short growth cycle (e.g., some soy varieties have a growth cycle of less than 100 days), which is usually coincident with the rainy season, reducing the chance of acquiring cloud-free images. Therefore, a large data set of complementary images was necessary for accurate identification and mapping of different crop types.



4. AGRICULTURAL DYNAMICS FROM 2000/01 TO 2013/14

Figure 3 shows that during the period 2000/01 – 2013/14, the cultivated area of 1st crop season of soybean, corn, and cotton went from 9.33 Mha to 17.43 Mha in the Cerrado biome, corresponding to an increase of 86.7%. This was mainly due to soy expansion, which represented 90% of the total cultivated area in the crop year 2013/14. We note that in the 2000/01 – 2013/14 period, the cultivated area with corn and cotton (1st crop season) remained relatively stable, while soy increased

Table 1 – Cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop year 2000/01.

State*	Annual Crops - 2000/01							
	Soy		Corn		Cotton		Total	
	ha	%	ha	%	ha	%	ha	%
DF	39,862	67.8	18,689	31.8	210	0.4	58,762	0.6
GO	1,678,199	78.3	437,682	20.4	26,745	1.2	2,142,626	23.0
MG	683,194	66.0	338,021	32.7	13,478	1.3	1,034,694	11.1
MS	694,317	84.8	97,116	11.9	27,547	3.4	818,980	8.8
MT	3,019,902	86.2	107,407	3.1	377,848	10.8	3,505,157	37.6
PR	50,909	65.5	26,851	34.5	0	0.0	77,761	0.8
SP	389,653	78.7	98,789	19.9	6,955	1.4	495,396	5.3
Other States	6,556,038	80.6	1,124,556	13.8	452,783	5.6	8,133,376	87.1
MA	221,542	95.9	9,519	4.1	0	0.0	231,061	2.5
TO	76,905	96.2	2,597	3.2	450	0.6	79,951	0.9
PI	57,711	92.3	4,836	7.7	0	0.0	62,548	0.7
BA	614,069	74.2	170,275	20.6	42,713	5.2	827,058	8.9
MATOPIBA	970,228	80.8	187,227	15.6	43,163	3.6	1,200,618	12.9
Cerrado Biome	7,526,265	80.6	1,311,783	14.1	495,946	5.3	9,333,994	100.0

***DF - Distrito Federal; GO - Goiás; MG - Minas Gerais; MS - Mato Grosso do Sul; MT - Mato Grosso; PR - Paraná; SP - São Paulo; MA – Maranhão; TO - Tocantins; PI - Piauí; BA - Bahia.**

by 108% (Tables 1 to 3).

These results revealed that more than half (51.9%) of the Brazilian soybean area in the crop year 2013/14 was located in the Cerrado biome. The states of Mato Grosso and Goiás alone were responsible for 53.3% of the soy expansion from 2000 to 2014

Table 2 - Cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop year 2006/07.

State*	Annual Crops - 2006/07							
	Soy		Corn		Cotton		Total	
	ha	%	ha	%	ha	%	ha	%
DF	55,101	71.4	20,659	26.8	1,416	1.8	77,176	0.6
GO	2,323,737	83.8	382,914	13.8	64,729	2.3	2,771,381	22.5
MG	803,508	63.3	449,692	35.4	15,488	1.2	1,268,687	10.3
MS	959,161	91.6	53,112	5.1	35,159	3.4	1,047,432	8.5
MT	3,982,035	89.2	75,527	1.7	405,461	9.1	4,463,023	36.3
PR	64,819	70.6	26,948	29.4	0	0.0	91,767	0.7
SP	242,462	66.1	113,666	31.0	10,830	3.0	366,957	3.0
Other States	8,430,823	83.6	1,122,517	11.1	533,083	5.3	10,086,423	82.0
MA	434,510	94.0	21,995	4.8	5,494	1.2	461,999	3.8
TO	256,767	92.0	19,150	6.9	3,138	1.1	279,055	2.3
PI	223,587	89.8	24,278	9.7	1,226	0.5	249,091	2.0
BA	771,528	63.2	179,404	14.7	270,471	22.1	1,221,404	9.9
MATOPIBA	1,686,393	76.3	244,827	11.1	280,329	12.7	2,211,549	18.0
Cerrado Biome	10,117,215	82.3	1,367,344	11.1	813,412	6.6	12,297,972	100.0

*DF - Distrito Federal; GO - Goiás; MG - Minas Gerais; MS - Mato Grosso do Sul; MT - Mato Grosso; PR - Paraná; SP - São Paulo; MA – Maranhão; TO - Tocantins; PI - Piauí; BA - Bahia.

in the Cerrado biome (Figure 4). In the MATOPIBA region (Cerrado states of Maranhão, Tocantins, Piauí and Bahia), the soy area went from 0.97 to 3.42 Mha, representing an increase of 253%. It is also evident that the soy expansion was much more significant during the 2006/07 – 2013/14 period when compared to 2000/01 – 2006/07, not only in the MATOPIBA region but also in the other Cerrado states (Figure 3).

Figures 5 to 7 illustrate the maps of cultivated area with the 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop years 2000/01, 2006/07 and 2013/14, respectively.

Table 3 - Cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop year 2013/14.

State*	Annual Crops - 2013/14							
	Soy		Corn		Cotton		Total	
	ha	%	ha	%	ha	%	ha	%
DF	80,490	82.7	16,827	17.3	0	0.0	97,317	0.6
GO	3,484,301	93.4	216,163	5.8	31,251	0.8	3,731,716	21.4
MG	1,271,285	74.3	430,400	25.2	8,476	0.5	1,710,161	9.8
MS	1,378,985	96.9	20,501	1.4	23,398	1.6	1,422,883	8.2
MT	5,544,823	97.0	19,778	0.3	154,548	2.7	5,719,149	32.8
PR	71,138	75.3	23,371	24.7	0	0.0	94,508	0.5
SP	404,038	87.1	59,777	12.9	12	0.0	463,827	2.7
Other States	12,235,060	92.4	786,817	5.9	217,684	1.6	13,239,561	76.0
MA	683,462	92.7	36,562	5.0	17,266	2.3	737,291	4.2
TO	678,604	97.6	13,489	1.9	3,103	0.4	695,197	4.0
PI	619,741	86.1	88,525	12.3	11,352	1.6	719,619	4.1
BA	1,438,335	70.6	316,457	15.5	281,405	13.8	2,036,197	11.7
MATOPIBA	3,420,144	81.7	455,033	10.9	313,127	7.5	4,188,303	24.0
Cerrado Biome	15,655,204	89.8	1,241,850	7.1	530,811	3.0	17,427,865	100.0

***DF - Distrito Federal; GO - Goiás; MG - Minas Gerais; MS - Mato Grosso do Sul; MT - Mato Grosso; PR - Paraná; SP - São Paulo; MA – Maranhão; TO - Tocantins; PI - Piauí; BA - Bahia.**

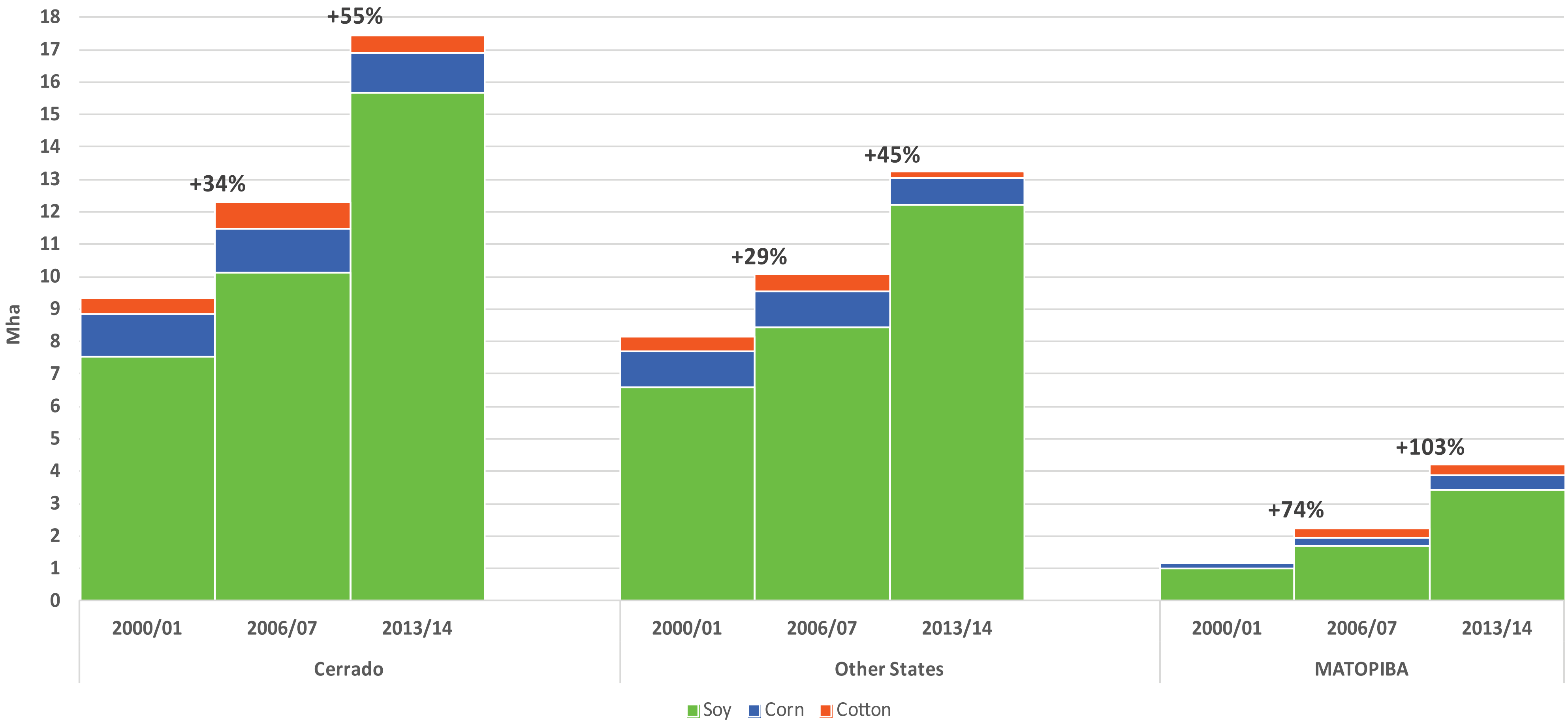


Figure 3 – Cultivated area of 1st crop season of soybean, corn, and cotton for the Cerrado biome, the states outside of the MATOPIBA region (other states), and the states included in the MATOPIBA region in the crop years 2000/01, 2006/07, and 2013/14.

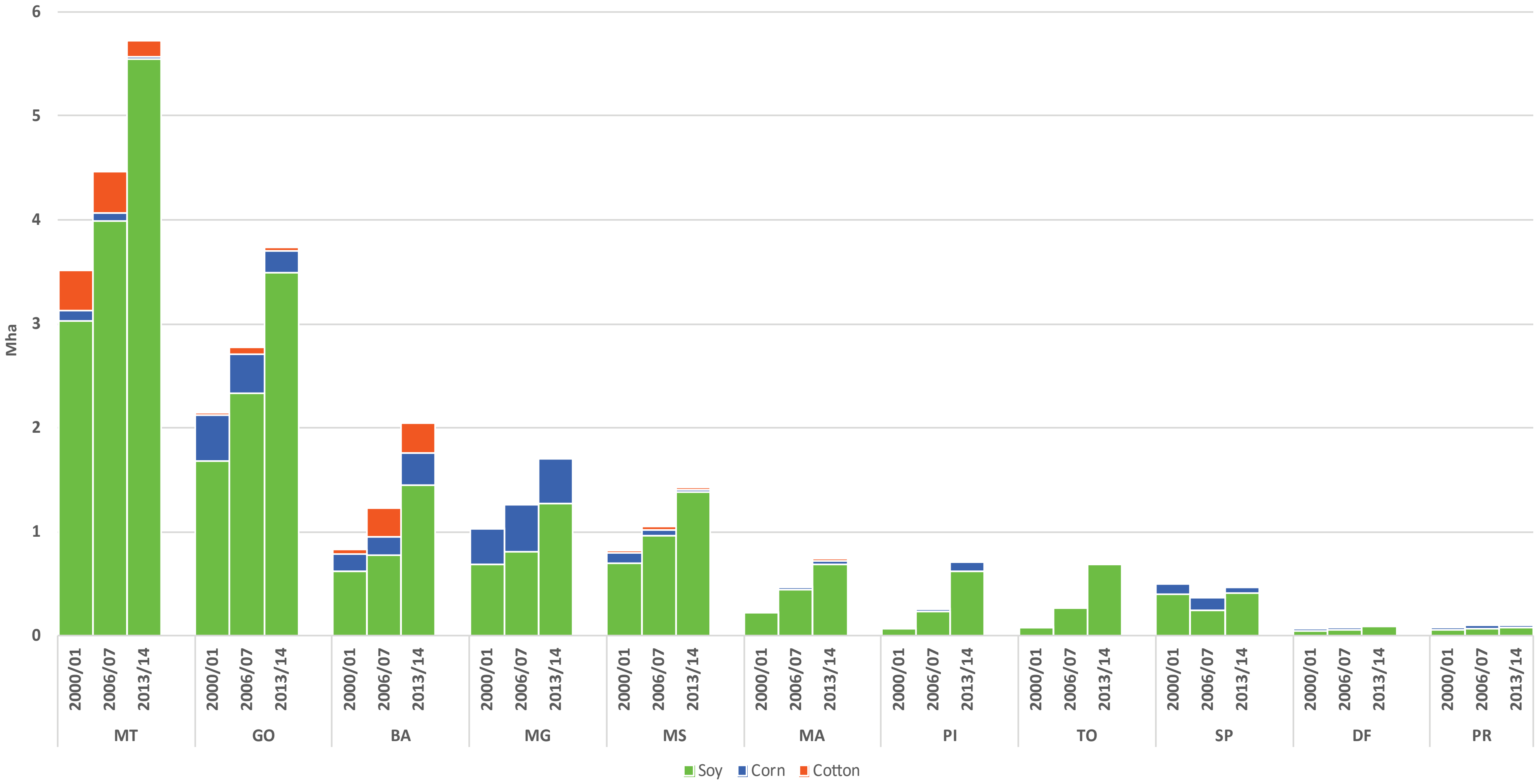


Figure 4 – Cultivated area of 1st crop season of soybean, corn, and cotton by state and for the Federal District in the crop years 2000/01, 2006/07, and 2013/14.

Crop Year 2000/01

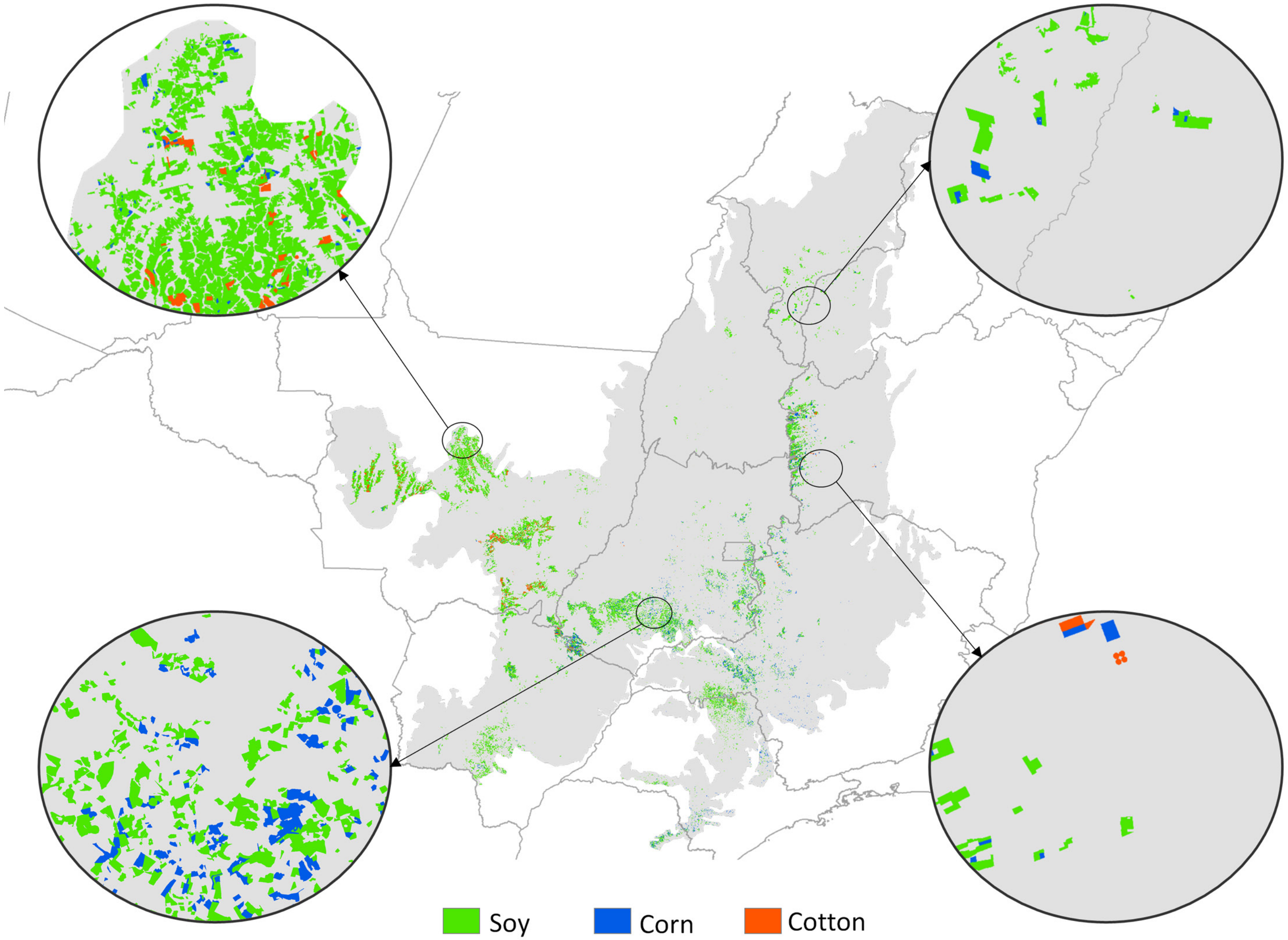


Figure 5 – Map of the cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop year 2000/01.

Crop Year 2006/07

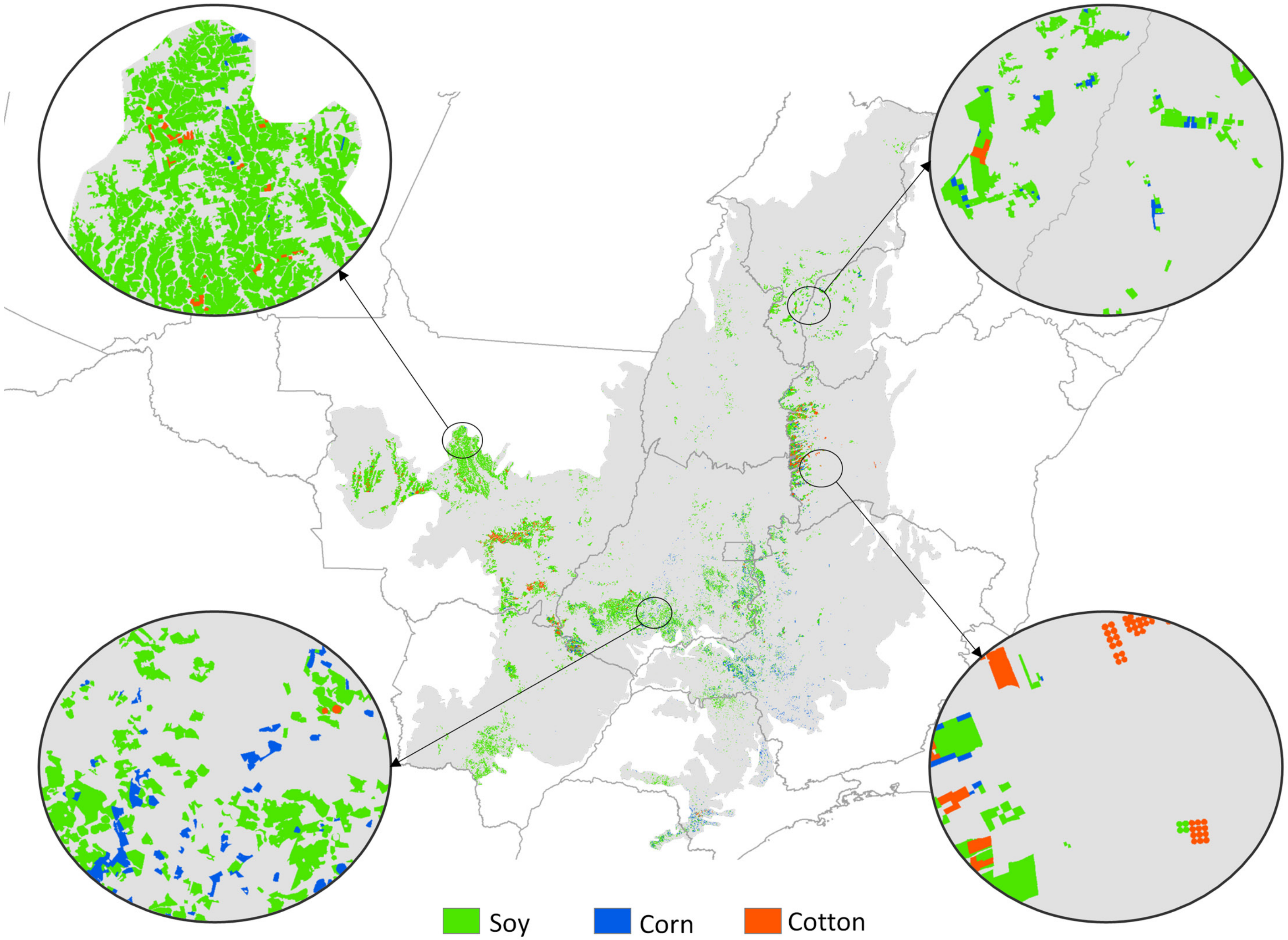


Figure 6 - Map of the cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop year 2006/07.

Crop Year 2013/14

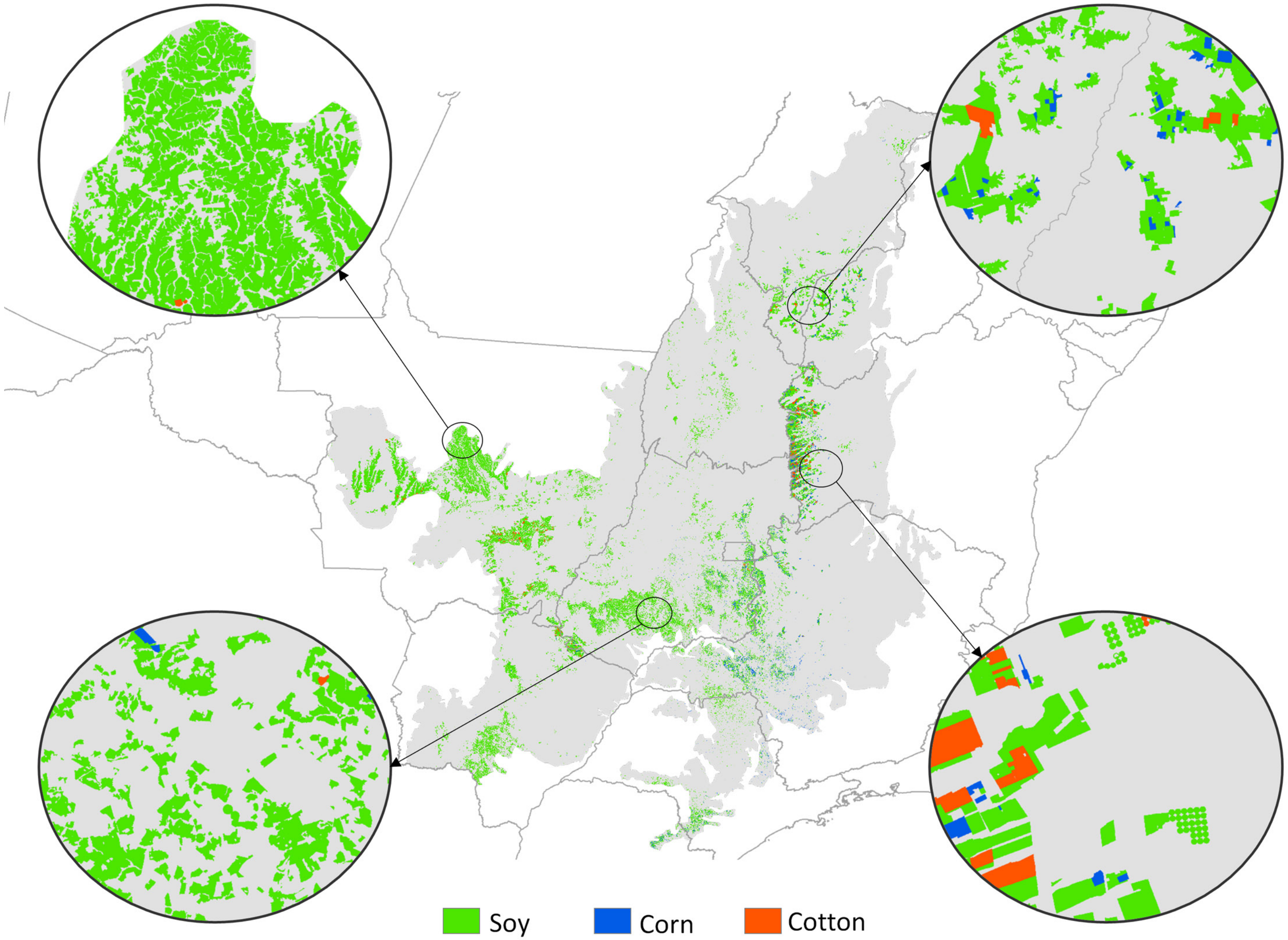


Figure 7 - Map of the cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome in the crop year 2013/14.

5. LAND-USE AND LAND-COVER CHANGE DURING THE PERIODS 2000/01 - 2006/07 AND 2006/07 - 2013/14

The land-use and land-cover change (LULCC) mapped in this study refers to the changes that occurred as a result of the expansion of the 1st crop season of soybean, corn and cotton in the Cerrado biome. As previously observed, the increase of these annual crops between 2000 and 2014 was essentially due to the expansion of soy (8.13 Mha), given that the area of the 1st crop season of corn and cotton remained virtually the same. However, the LULCC occurred over 10.68 Mha, with 4.61 Mha being altered in the first period (2000 – 2007; Table 4) and 6.07 Mha in the second period (2007 – 2014; Table 5). This means that during the 2000 – 2014 period, in addition to the 8.13 Mha expansion of soybean, there were another 2.55 Mha of LULCC associated with more diverse transitions involving the 1st season crops of soybean, corn, and cotton. We highlight as an example the significant sugarcane expansion for ethanol production, as observed in the Cerrado since 2003. In this case, the expansion of sugarcane that occurred over degraded pastures may have gone through an intermediary condition of one or two years of soybean crop to improve the physical conditions of the soil. Another example is the use of soybean in a crop rotation process to renew old sugarcane fields. Still, the fact that the cultivated area of 1st season crops of corn and cotton did not alter between 2000 and 2014 does not mean that they did not cause LULCC. For example, corn fields could have been substituted by soybean or even abandoned, migrating to new areas (see Figures 5, 6 and 7).

The following classes of LULCC, which correspond to the changes caused by the 1st season crops of soy, corn, and cotton, were identified in the Landsat images and used in this study: *native vegetation; pasture* (cultivated); *other agriculture* (rice, fallow etc.); *sugarcane; planted forest; cleared native vegetation* (newly-cleared native vegetation); and *other uses* (urban, mining etc.).

When comparing the LULCC in the two analyzed periods, we note that the classes *pasture* and *other agriculture* accounted for about 70% of the changes in the Cerrado biome (Figure 8). However, while in the states outside of MATOPIBA these classes accounted for 80 to 89% of the expansion, in the MATOPIBA region the conversion of *pasture* + *other agriculture* was only 32 to 37% (Figure 8). This demonstrates that the MATOPIBA region has unique LULCC characteristics that have to be taken into account. For this reason, we divided the Cerrado biome into two separate regions for the analysis: 1) states outside of MATOPIBA, and 2) MATOPIBA.

In the states outside the MATOPIBA, the LULCC resulting from *native vegetation* + *cleared native*

vegetation (deforestation) corresponded to 652,000 ha in the first period (2000 – 2007) and to 233,000 ha in the second period (2007 – 2014); however, during this last period the total LULCC was much greater (Figure 8; Tables 4 and 5). This means that in this region the conversion from *native vegetation* + *cleared native vegetation* to "soybean" (*i.e.*, 1st season crops of soybean, corn or cotton) was reduced from 18.9% to 5.8% from the first to the second period, respectively (Tables 4 and 5). Conversely, 81.1% of the LULCC during the first period, and 94.2% during the second period, took place without the conversion of *native vegetation* + *cleared native vegetation*, indicating land use intensification, mainly through the conversion of pastures. In this region, Mato Grosso was the state most responsible for the conversion of *native vegetation* + *cleared native vegetation* to "soybean", with 576,000 ha (88.3%) in the first period and 159,000 ha (68.2%) in the second period (Tables 4 and 5). If we exclude Mato Grosso from this analysis, 96.5% and 97.2% of the LULCC during the first and second periods, respectively, took place without deforestation in the states outside of the MATOPIBA. The native vegetation remnants in this region were under greater pressure between 2000 and 2007 when compared to 2007 - 2014. Furthermore, this pressure was much more obvious in Mato Grosso than in the remaining states.

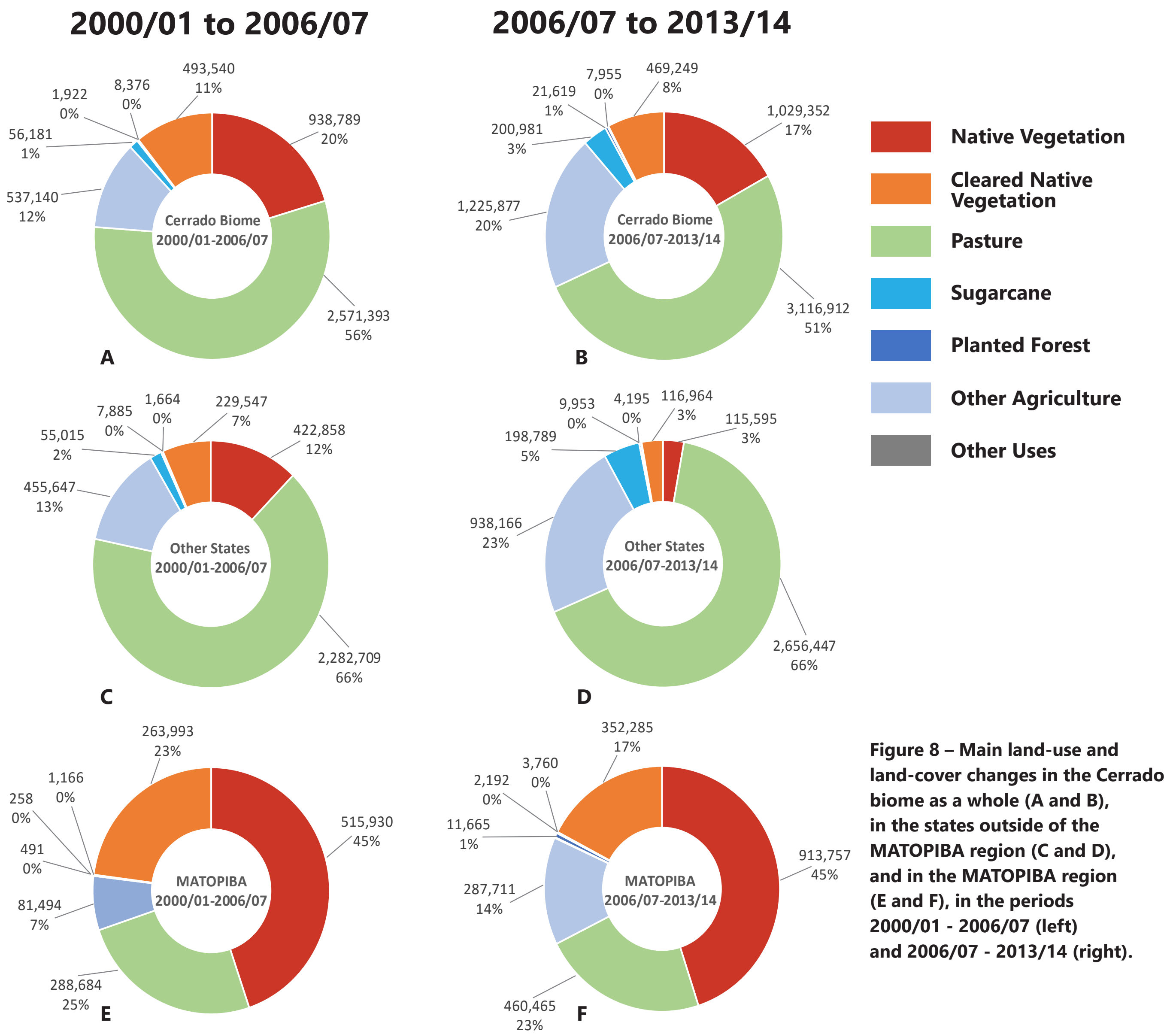


Figure 8 – Main land-use and land-cover changes in the Cerrado biome as a whole (A and B), in the states outside of the MATOPIBA region (C and D), and in the MATOPIBA region (E and F), in the periods 2000/01 - 2006/07 (left) and 2006/07 - 2013/14 (right).

In the states outside of MATOPIBA, the conversion of the *other agriculture* class to annual crops in the second period was twice as much as in the first period (Figure 8). This is largely due to the retraction of the soybean area observed between the crop years 2005/06 and 2006/07 after a period of significant expansion due to favorable soy prices in 2004 and 2005, which was followed by a decline in the prices, resulting in a significant increase of fallow land during the 2006/07 crop year – *e.g.* the . soybean area in the state of Mato Grosso alone was reduced by about 1 Mha between 2005/06 and 2006/07. However, the area gradually returned to production during the following crop years. It should be highlighted that, within this group of states outside of the MATOPIBA region, almost 200,000 ha of sugarcane were converted to annual crops (particularly soybean), most of which were for sugarcane renewal (Figure 8) in rotation with soybean.

In the MATOPIBA region, the *native vegetation* + *cleared native vegetation* classes represented 68% (0.78 Mha) and 62% (1.27 Mha) of the conversion to annual crops in the first and second periods, respectively (Figure 8). This clearly shows that the current agricultural frontier of the Cerrado is located in the MATOPIBA. In this region, commercial agriculture arrived first in the state of Bahia, which currently represents 49% of the agricultural area of the region. During the 2000 – 2014 period, the agricultural area in Bahia expanded by a factor of 1.5 while in Maranhão,

Table 4 – Main land-use and land-cover changes observed in the period 2000/01 - 2006/07 in the portion of the Cerrado biome in each state and in the Federal District.

State*	Land-Use and Land-Cover Change | 2006/07 - 2013/14								
	Native Vegetation	Pasture	Other Agriculture	Sugarcane	Planted Forest	Other Uses	Cleared Native Vegetation	Total	
	ha	ha	ha	ha	ha	ha	ha	ha	%
DF	34	19,023	6,347	0	9	0	0	25,413	0.6
GO	32,856	801,634	173,348	12,153	2,813	431	5,693	1,028,928	22.3
MG	25,188	407,616	122,371	1,895	3,100	135	3,240	563,545	12.2
MS	5,878	320,998	24,736	3,239	1,101	189	1,119	357,260	7.8
MT	356,695	616,218	77,101	11,403	8	621	219,398	1,281,444	27.8
PR	990	15,912	2,004	38	171	39	96	19,251	0.4
SP	1,218	101,308	49,739	26,286	683	250	0	179,484	3.9
Other States	422,858	2,282,709	455,647	55,015	7,885	1,664	229,547	3,455,325	75.0
MA	132,235	48,957	6,457	1,166	0	5	62,968	251,789	5.5
TO	54,429	125,180	14,970	0	14	119	22,781	217,494	4.7
PI	99,328	30,837	27,015	0	477	5	39,379	197,041	4.3
BA	229,939	83,709	33,051	0	0	129	138,865	485,693	10.5
MATOPIBA	515,930	288,684	81,494	1,166	491	258	263,993	1,152,016	25.0
Cerrado Biome	938,789	2,571,393	537,140	56,181	8,376	1,922	493,540	4,607,341	100.0

***DF - Distrito Federal; GO - Goiás; MG - Minas Gerais; MS - Mato Grosso do Sul; MT - Mato Grosso; PR - Paraná; SP - São Paulo; MA – Maranhão; TO - Tocantins; PI - Piauí; BA - Bahia.**

Tocantins, and Piaui, the agricultural area expanded by a factor of 3.2, 8.7, and 11.5, respectively (Figures 8 and 9). In Maranhão and Piauí, this expansion occurred overwhelmingly (about 77.5% and 70.3%, respectively) in the classes *native vegetation + cleared native vegetation*. In Tocantins, about 35.5% of the agricultural area expanded over recent deforestation, while the rest expanded primarily over pasture lands (Figures 9 and 10).

Table 5 - Main land-use and land-cover changes observed in the period 2006/07 - 2013/14 in the portion of the Cerrado biome in each state and in the Federal District.

State*	Land-Use and Land-Cover Change | 2006/007 - 2013/14								
	Native Vegetation	Pasture	Other Agriculture	Sugarcane	Planted Forest	Other Uses	Cleared Native Vegetation	Total	
	ha	ha	ha	ha	ha	ha	ha	ha	%
DF	134	6,758	11,239	0	0	19	0	18,150	0.3
GO	25,803	905,191	288,359	37,685	385	775	9,788	1,267,987	20.9
MG	17,172	365,084	198,268	43,904	5,189	1,552	13,184	644,354	10.6
MS	3,114	412,559	62,183	8,091	45	134	2,016	488,141	8.0
MT	66,706	883,555	315,162	22,691	2,491	1,044	91,856	1,383,507	22.8
PR	207	8,170	3,194	58	221	23	33	11,905	0.2
SP	2,458	75,130	59,761	86,361	1,621	648	86	226,065	3.7
Other States	115,595	2,656,447	938,166	198,789	9,953	4,195	116,964	4,040,109	66.5
MA	148,606	37,943	32,622	2,192	122	17	50,977	272,478	4.5
TO	121,768	245,357	62,352	0	0	511	26,843	456,831	7.5
PI	291,887	31,322	48,876	0	0	52	97,031	469,167	7.7
BA	351,497	145,844	143,861	0	11,544	3,180	177,435	833,360	13.7
MATOPIBA	913,757	460,465	287,711	2,192	11,665	3,760	352,285	2,031,836	33.5
Cerrado Biome	1,029,352	3,116,912	1,225,877	200,981	21,619	7,955	469,249	6,071,945	100.0

***DF - Distrito Federal; GO - Goiás; MG - Minas Gerais; MS - Mato Grosso do Sul; MT - Mato Grosso; PR - Paraná; SP - São Paulo; MA – Maranhão; TO - Tocantins; PI - Piauí; BA - Bahia.**

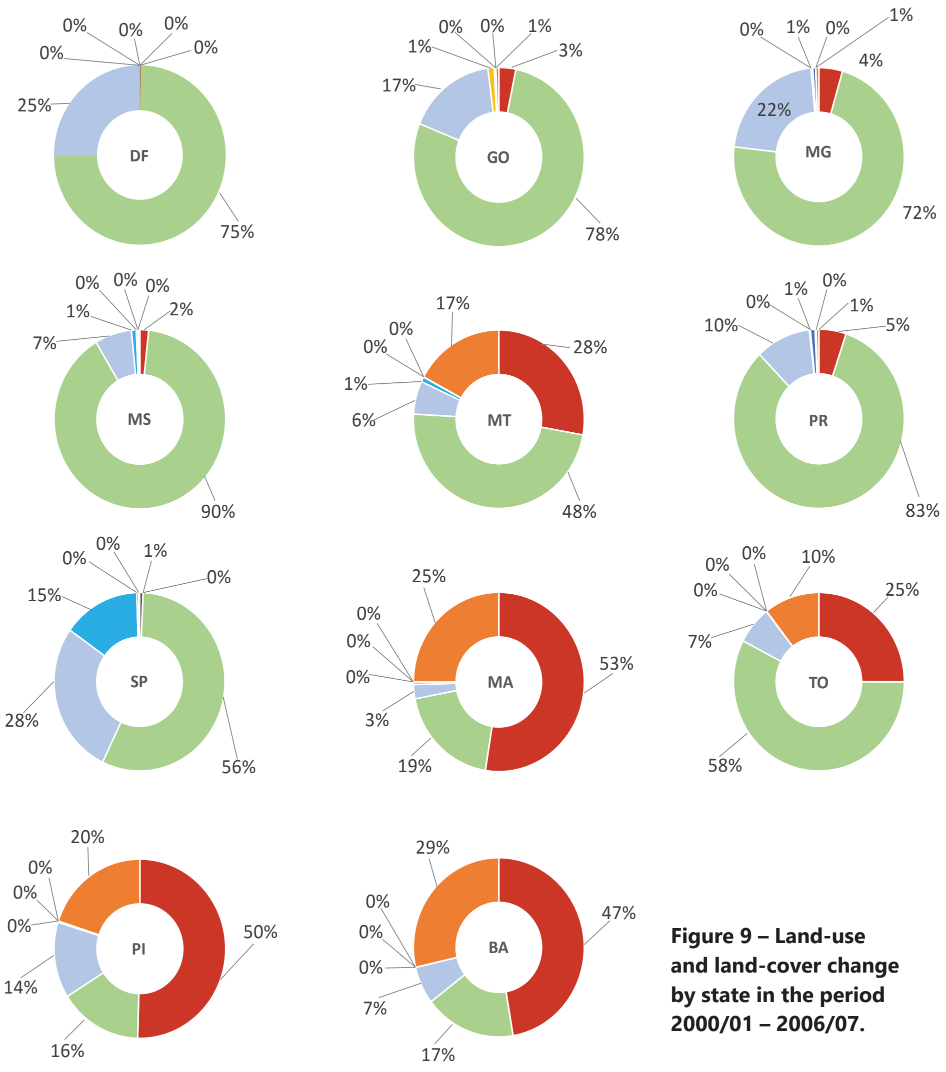


Figure 9 – Land-use and land-cover change by state in the period 2000/01 – 2006/07.

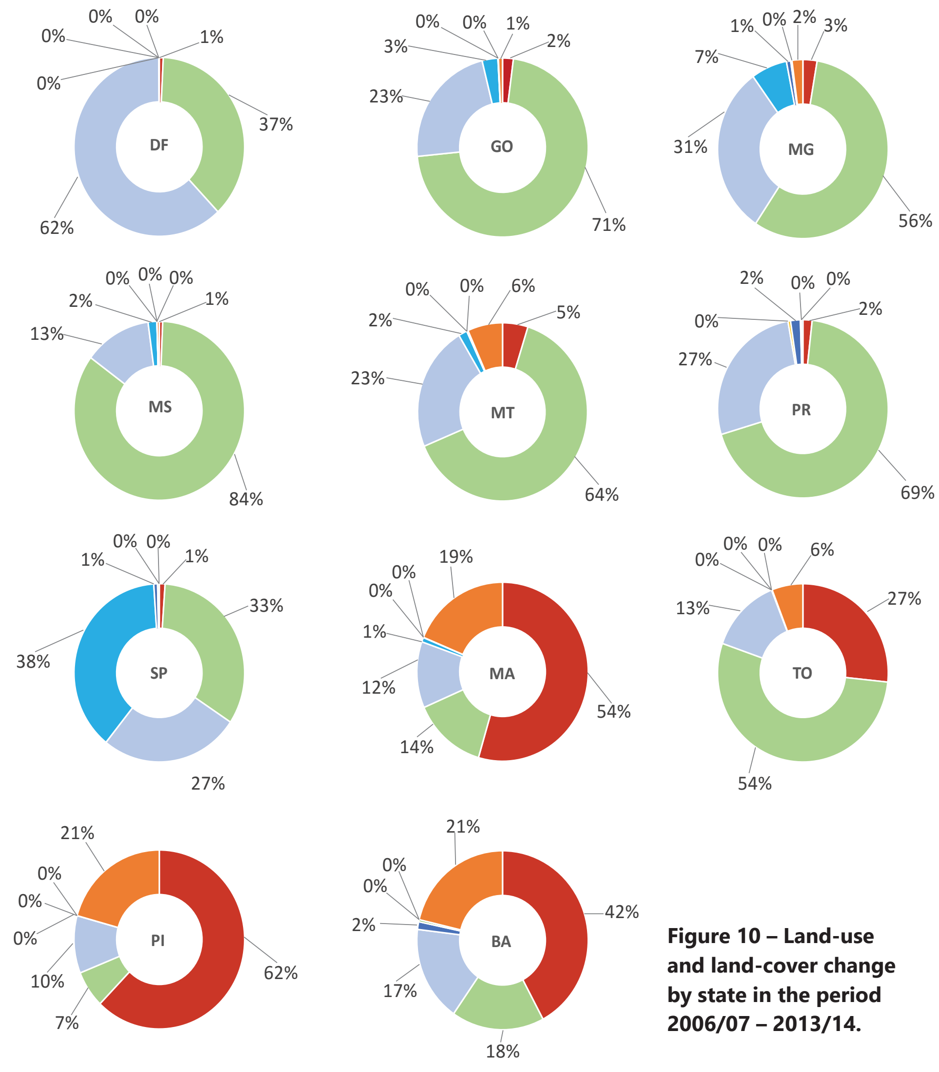
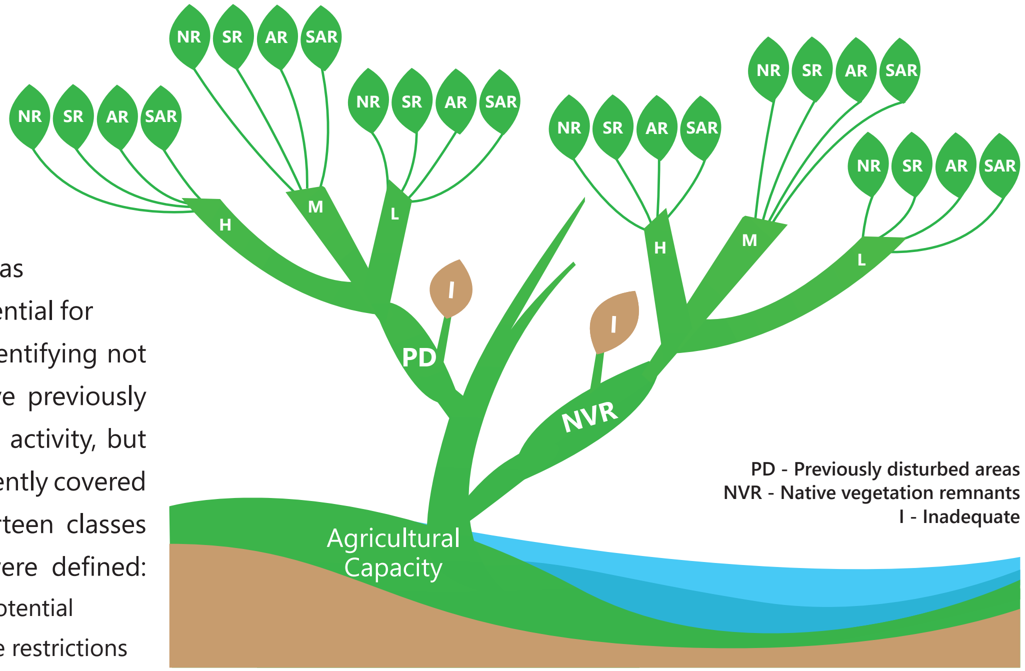


Figure 10 – Land-use and land-cover change by state in the period 2006/07 – 2013/14.

Native Vegetation **Cleared Native Vegetation** **Pasture** **Sugarcane** **Planted Forest** **Other Agriculture** **Other Uses**

6. AGRICULTURAL CAPACITY IN THE CERRADO BIOME



The edaphoclimatic potential was divided into four classes: 1) high potential - H; 2) medium potential - M; 3) low potential - L; and 4) inadequate - I. These classes are based on a methodology similar to that adopted in the Agricultural Zoning of Climate Risk (Zoneamento Agrícola de Risco Climático - ZARC) for soybean crop in Brazil. The ZARC is established according to the soil type and the historical climatic conditions in terms of high- and low-risk for soybean production within well-defined planting periods of regional soy crop calendars.

In addition to the edaphoclimatic condition, the agricultural capacity considered: i) slope restrictions (*i.e.*, areas with slope less than 12% were considered without restrictions), and ii) altitude restrictions. Altitude is an important parameter highly correlated to the commercial value of land for grain production, particularly soybean, which prefers land with higher altitude. In the MATOPIBA region, for example, soybean is produced exclusively on plateaus or tablelands. The criteria for defining the altitude restrictions was based on both the spatial distribution of the soybean, corn, and cotton fields in the crop year 2013/14, and in the minimum altitude of these fields in the different regions of the Cerrado.

This approach allowed the identification of areas that have the greatest potential for conversion to soybean, identifying not only those areas that have previously been disturbed by human activity, but also the areas that are currently covered by native vegetation. Thirteen classes of agricultural capacity were defined:

1) High edaphoclimatic potential without slope and altitude restrictions (**H, NR**);
2) High edaphoclimatic potential with slope restriction (**H, SR**);
3) High edaphoclimatic potential with altitude restriction (**H, AR**);
4) High edaphoclimatic potential with slope and altitude restrictions (**H, SAR**);
5) Medium edaphoclimatic potential without slope and altitude restrictions (**M, NR**);
6) Medium edaphoclimatic potential with slope restriction (**M, SR**);
7) Medium edaphoclimatic potential with altitude restriction (**M, AR**);
8) Medium edaphoclimatic potential with slope and altitude restrictions (**M, SAR**);
9) Low edaphoclimatic potential without slope and altitude restrictions (**L, NR**);
10) Low edaphoclimatic potential with slope restriction (**L, SR**);
11) Low edaphoclimatic potential with altitude restriction (**L, AR**);
12) Low edaphoclimatic potential with slope and altitude restrictions (**L, SAR**);
13) Inadequate due to edaphoclimatic deficiency, independent of slope and/or altitude restrictions (**I**).

Based on the 13 classes, we verified that 81.5% of the 1st crop season of soybean, corn, and cotton in the crop year 2013/14 were found in the class of high edaphoclimatic potential without slope and altitude restrictions (H, NR), which are the areas of greatest commercial value for agriculture. The class of medium edaphoclimatic potential without slope and altitude restrictions (M, NR) ranked in second place, representing 11.0% of the area of these annual crops. Therefore, more than 90% of the current fields were found in only two classes of edaphoclimatic potential (high and medium), both without slope and altitude restrictions.

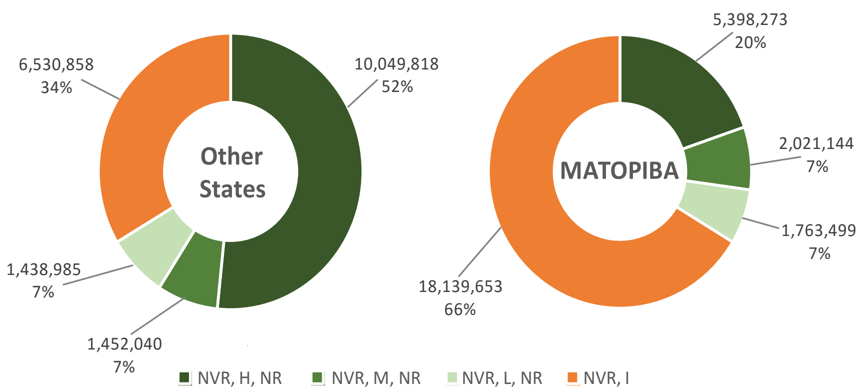


Figure 11 – Land stock with high (H), medium (M) and low (L) agricultural capacity, without slope and altitude restrictions (NR) for annual crops in states outside of the MATOPIBA region (other states), and in the MATOPIBA region, in areas of native vegetation remnants (NVR).

6.1. AGRICULTURAL CAPACITY OF CURRENT NATIVE VEGETATION AREAS

Figure 11 illustrates the land stock with high, medium and low agricultural capacity for production of annual crops, and without slope and altitude restrictions, which are currently covered by native vegetation in the states outside of the MATOPIBA region (other states) and within the MATOPIBA region. The current area of native vegetation with high agricultural capacity and without slope or altitude restrictions represents 8.4% (10.05 Mha) and 8.1% (5.40 Mha) of the total area of the states outside of MATOPIBA and within the MATOPIBA, respectively. This indicates that, in relative terms, the native vegetation land stock with high agricultural capacity is as exhausted in the MATOPIBA region as it is in the other states. Of the 36.7 Mha of Cerrado land inadequate for agricultural use, 24.7 Mha are covered by native vegetation remnants (NVR), while 12.1 Mha were previously disturbed by human activity (Table 7). The region outside of MATOPIBA (other states)

contains similar amounts of agriculturally inadequate land with and without NVR, being 6.53 and 6.03 Mha, respectively. Of the agriculturally inadequate land within the MATOPIBA region, the area with NVR is almost three times larger (18.1 Mha) than the area without NVR (6.0 Mha).

6.2. AGRICULTURAL CAPACITY OF PREVIOUSLY DISTURBED AREAS

Figure 12 illustrates the land stock with high, medium and low agricultural capacity for annual crops, and without slope and altitude restrictions in areas previously disturbed by human activity in the states outside of the MATOPIBA region (other states) and in the MATOPIBA region. We note that the available land with high agricultural capacity without slope and altitude restrictions in the states outside the MATOPIBA region corresponds to 18.9% (22.55 Mha), while this land stock within the MATOPIBA region amounts to only 4.2% (2.81 Mha). When considering the entire Cerrado biome, this land stock represents 25.4 Mha (Figure 13), around 5 Mha of which are cultivated with sugarcane, and the remaining area is primarily pasture. Considering that the pasture is a less demanding land use with respect to edaphoclimatic conditions, and is also less restrictive in terms of slope and altitude, there is still an enormous stock of disturbed land whose use can be prioritized for the intensification process of cattle ranching in the Cerrado biome.

Figure 13 presents an overview of the results achieved in this study in terms of agriculture capacity of the Cerrado. The different sizes and colors of the elements in this figure represent the proportional area of each agricultural capacity class in relation to the Cerrado as a whole. The gray area in Figure 13 represents the 94.3 Mha that have some restriction in terms of slope and/or altitude for annual crop (soybean) production, independent of the edaphoclimatic potential. Areas inadequate for annual crop production due to their edaphoclimatic condition correspond to 36.8 Mha. Of that total 24.7 Mha are covered by native vegetation (yellow; Figure 13), and 21.1 Mha were previously disturbed by human activity (orange; Figure 13). The current land stock of native vegetation cover with agricultural capacity for annual crop production, without slope and altitude restrictions, amounts 12.1 Mha, of which there are 4.1 Mha located in special areas (indigenous lands or conservation units; Figure 13). Most important for annual crop expansion in the Cerrado biome are the 33.4 Mha of previously disturbed areas with high, medium and low agricultural capacity without slope and altitude restrictions, of which 25.36 Mha (76%) have high agricultural capacity (Figure 13). These areas are the ones that should be prioritized for the Brazilian soy expansion. Figure 13 also illustrates the 17.4 Mha that were occupied by annual crops under different agricultural capacity conditions in the crop year 2013/14.

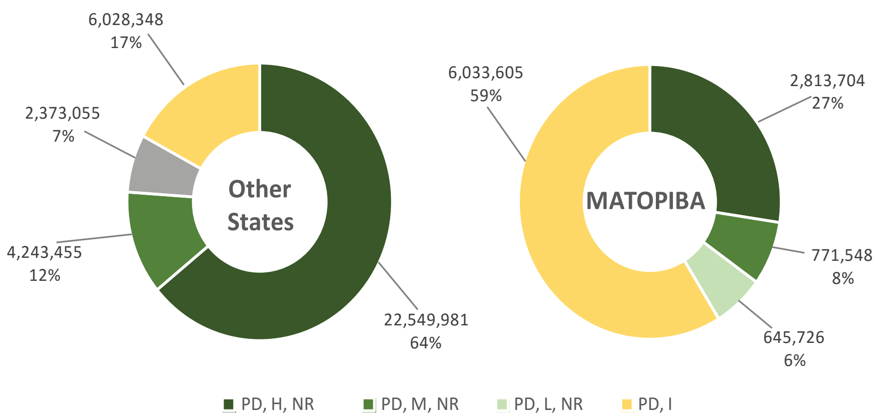


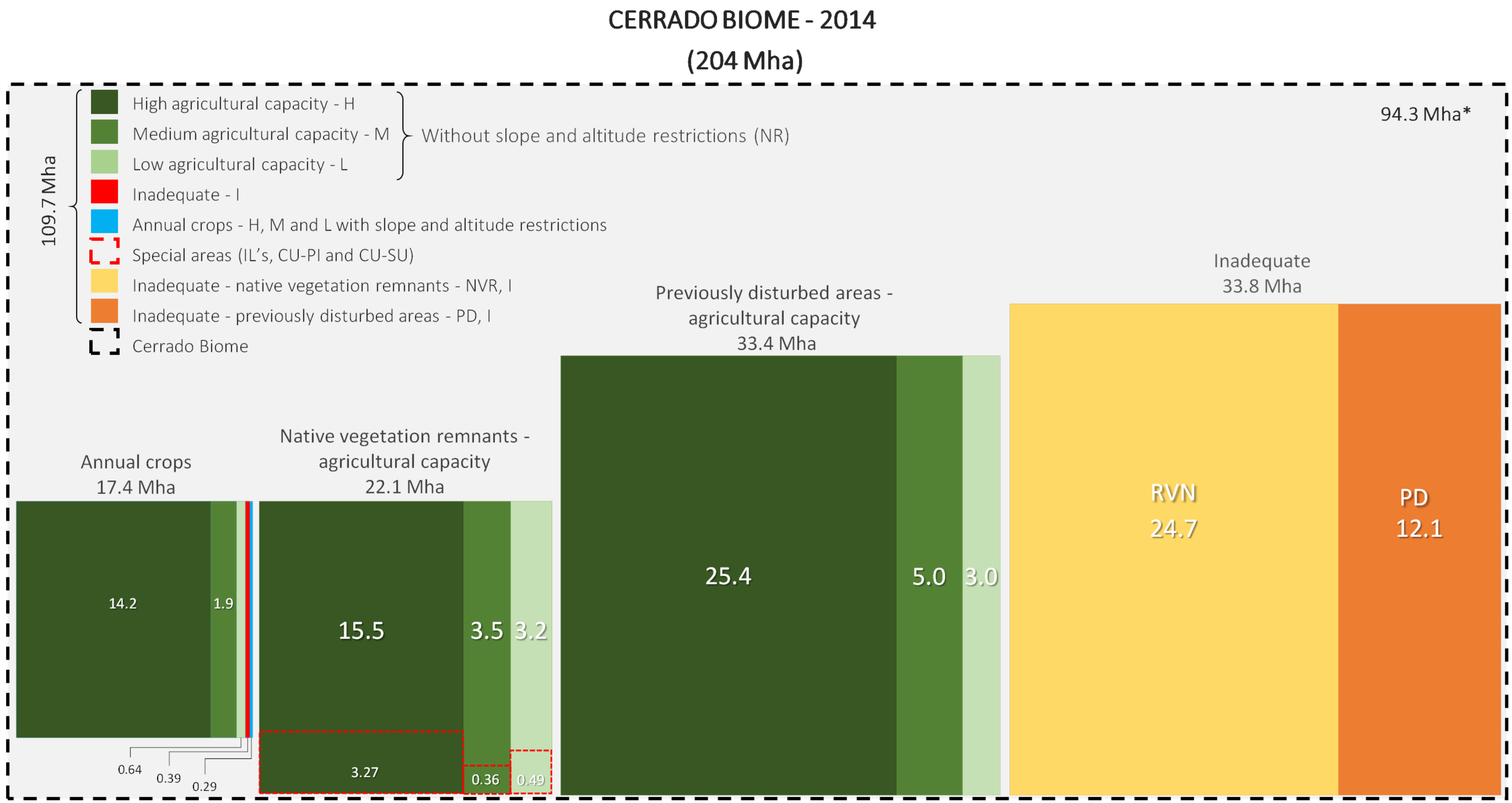
Figure 12 – Land stock with high (H), medium (M) and low (L) agricultural capacity, without slope and altitude restrictions (NR) for annual crops outside the MATOPIBA region (other states), and within the MATOPIBA region, in previously disturbed areas (PD).

It should be highlighted that the previously disturbed land with high agricultural capacity for annual crop production is very important for the Brazilian soybean expansion because the Atlantic Forest biome has almost exhausted its potential for expansion, and there are restrictions for expansion in the Amazon biome (due to the Soy Moratorium and other measures to contain deforestation). For example, during the period 2006/07 - 2013/14, the Brazilian soybean area increased by 9.5 Mha. Of that total, 5.5 Mha (58%) were in the Cerrado biome; approximately 2 Mha (21%) were in the Amazon biome; and the other 2 Mha (21%) were mainly in traditional soy production regions in the Atlantic Forest biome, where the stock of land for expansion has been continuously declining.

Finally, we must emphasize that the present study provides detailed information from the local to the regional scale, about the agricultural capacity associated not only to slope and/or altitude restrictions, but also to current land use and land cover for the entire Cerrado biome.

Table 6 - Land stock of previously disturbed areas (PD) and of native vegetation remnants (NVR) for the 13 classes of agricultural capacity in private properties and in special areas (indigenous lands IL's, and conservation units of integral protection – CU-IP –, and sustainable use CU-SU).

Agricultural capacity in the Cerrado biome																
Class	DF	GO	MG	MS	MT	PR	RO	SP	Other States	MA	TO	PI	BA	MATOPIBA	Total	
	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	%
NVR, H, NR	79,481	2,567,335	939,393	853,468	5,216,586	15,955	0	377,599	**10,049,818**	1,455,369	3,110,584	226,651	605,669	**5,398,273**	**15,448,091**	**8.3**
IL's	0	2,733	600	2,306	1,414,799	0	0	7	1,420,446	12,851	799,710	0	0	812,561	2,233,006	-
CU-PI	35,824	108,088	36,059	3,905	19,226	0	0	9,836	212,939	2,358	281,780	1,330	1,747	287,215	500,153	-
CU-US	73,356	138,641	7,334	19	109,099	9,294	0	37,551	375,293	30,434	57,708	508	71,910	160,560	535,853	-
NVR, H, SR	31,053	2,403,111	1,043,605	98,853	900,720	31,837	0	209,550	**4,718,729**	631,067	837,375	35,240	1,807	**1,505,489**	**6,224,219**	**3.3**
NVR, H, AR	39,244	3,798,938	607,574	965,049	12,293,551	12,801	18,650	512,324	**18,248,130**	3,299,084	5,359,113	290,379	501,487	**9,450,064**	**27,698,194**	**14.9**
NVR, H, SAR	41,207	1,784,202	778,742	201,418	1,484,309	44,517	1,341	217,779	**4,553,514**	977,554	577,706	69,529	22,199	**1,646,988**	**6,200,503**	**3.3**
PD, H, NR	99,804	6,894,486	4,559,706	4,279,548	3,636,993	52,106	0	3,027,338	**22,549,981**	607,018	1,746,246	45,293	415,147	**2,813,704**	**25,363,685**	**13.6**
PD, H, SR	15,769	1,179,368	1,371,922	60,777	224,331	53,444	0	375,452	**3,281,064**	168,282	149,152	1,160	63	**318,657**	**3,599,720**	**1.9**
PD, H, AR	50,170	6,928,337	1,633,884	3,014,823	4,810,015	16,676	190	1,982,796	**18,436,891**	1,271,554	2,009,757	133,155	108,690	**3,523,156**	**21,960,047**	**11.8**
PD, H, SAR	14,181	863,548	926,111	115,257	377,698	41,994	30	295,797	**2,634,616**	218,087	76,238	6,751	844	**301,921**	**2,936,537**	**1.6**
NVR, M, NR	533	20,272	536,279	759,002	111,753	41	0	24,160	**1,452,040**	1,017,898	20,272	407,427	575,546	**2,021,144**	**3,473,184**	**1.9**
IL's	0	0	0	1,662	332	0	0	0	1,993	150,319	0	0	0	150,319	152,312	-
CU-PI	0	0	14,701	24,006	4,746	0	0	63	43,516	7,638	39	80,953	14,855	103,484	147,001	-
CU-US	533	501	10,517	830	0	0	0	196	12,576	1,402	276	230	48,735	50,643	63,219	-
NVR, M, SR	95	25,395	486,976	190,558	124,523	254	0	17,509	**845,310**	160,002	15,373	39,089	14,180	**228,644**	**1,073,953**	**0.6**
NVR, M, AR	362	73,525	499,006	746,639	205,726	180	0	19,826	**1,545,264**	2,853,724	142,734	855,545	760,307	**4,612,310**	**6,157,574**	**3.3**
NVR, M, SAR	44	71,496	486,693	153,756	39,566	207	0	14,463	**766,224**	657,881	32,899	359,771	78,973	**1,129,523**	**1,895,747**	**1.0**
PD, M, NR	528	26,001	1,405,421	2,524,113	111,391	54	0	175,948	**4,243,455**	401,095	4,313	145,580	220,560	**771,548**	**5,015,003**	**2.7**
PD, M, SR	56	7,257	302,698	41,567	9,815	150	0	32,144	**393,686**	31,242	2,968	5,401	474	**40,086**	**433,771**	**0.2**
PD, M, AR	343	99,996	987,454	1,827,139	256,010	257	0	69,675	**3,240,873**	765,094	37,405	210,223	176,555	**1,189,277**	**4,430,150**	**2.4**
PD, M, SAR	72	17,404	310,082	52,396	9,205	432	0	23,832	**413,422**	86,222	6,625	33,510	8,135	**134,492**	**547,915**	**0.3**
NVR, L, NR	1	346	1,254,143	184,495	0	0	0	0	**1,438,985**	92,694	0	745,514	925,291	**1,763,499**	**3,202,484**	**1.7**
IL's	0	0	1,686	6,226	0	0	0	0	7,911	74,342	0	0	920	75,262	83,174	-
CU-PI	0	0	36,885	0	0	0	0	0	36,885	0	0	36,442	2,736	39,178	76,063	-
CU-US	1	0	314,824	479	0	0	0	0	315,304	0	0	24	15,283	15,307	330,611	-
NVR, L, SR	0	57	459,075	47,069	0	0	0	0	**506,200**	17,884	0	176,902	117,721	**312,507**	**818,707**	**0.4**
NVR, L, AR	22	458	1,100,031	822,039	0	0	0	0	**1,922,550**	471,644	0	1,842,551	768,601	**3,082,796**	**5,005,345**	**2.7**
NVR, L, SAR	5	226	544,415	65,761	0	0	0	0	**610,408**	48,714	0	511,666	58,940	**619,319**	**1,229,727**	**0.7**
PD, L, NR	23	143	1,799,001	573,888	0	0	0	0	**2,373,055**	16,521	0	254,791	374,414	**645,726**	**3,018,781**	**1.6**
PD, L, SR	5	40	213,204	20,396	0	0	0	0	**233,644**	905	0	16,121	29,277	**46,304**	**279,948**	**0.2**
PD, L, AR	43	735	1,516,709	906,639	0	0	0	0	**2,424,126**	41,483	0	484,958	452,513	**978,954**	**3,403,080**	**1.8**
PD, L, SAR	11	407	258,709	13,278	0	0	0	0	**272,405**	2,846	0	60,052	27,721	**90,619**	**363,025**	**0.2**
NVR, I	18,686	1,098,919	4,083,709	1,013,405	258,062	3,676	23,802	30,598	**6,530,858**	4,406,160	7,288,029	1,473,372	4,972,092	**18,139,653**	**24,670,511**	**13.2**
PD, I	89,146	1,374,218	3,559,561	647,288	111,676	4,443	933	241,083	**6,028,348**	775,456	3,177,860	198,565	1,881,724	**6,033,605**	**12,061,954**	**6.5**
Total	480,883	29,236,220	31,664,103	20,178,619	30,181,930	279,024	44,945	7,647,872	**119,713,596**	20,475,482	24,594,650	8,629,197	13,098,929	**66,798,259**	**186,511,855**	**100.0**



* Areas with some restriction in terms of slope and/or altitude for annual crop (soybean) production, independent of the edaphoclimatic potential (H, M, L).

Figure 13- Overview of the results achieved in this study in terms of agriculture capacity of the Cerrado in 2014. The different sizes and colors of the elements in this figure represent the proportional area of each agricultural capacity class in relation to the entire Cerrado.

7. CONSIDERATIONS AND RECOMMENDATIONS

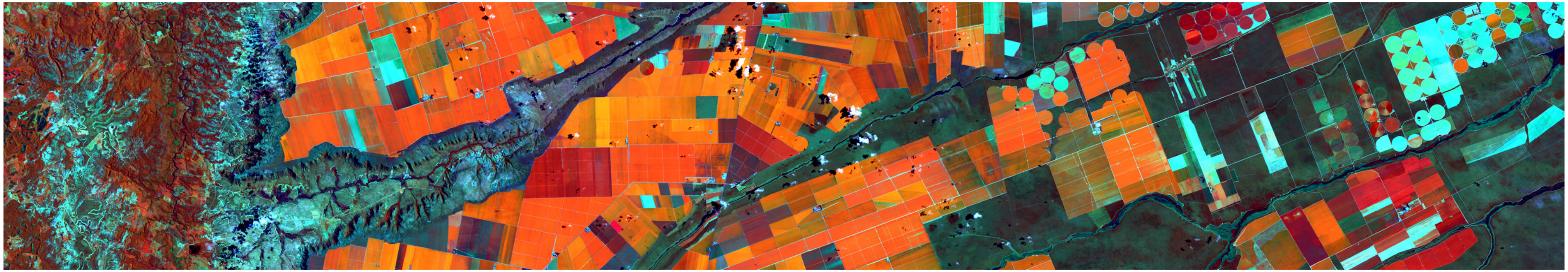
The study presents a detailed analysis of the annual crops expansion dynamic in the Brazilian Cerrado between 2000 and 2014, with strong emphasis on soy. Nonetheless, there is an established process of land-use intensification with double cropping of corn and cotton, which certainly has diminished the pressure on the opening of new areas and, consequently, saving millions of hectares of native vegetation. In this sense, this study creates an opportunity for a complementary analysis that describes the intensification dynamic of agricultural land use in the Cerrado biome.

The study revealed that from 2000 to 2014 more than 5.6 Mha of pasture were converted to soybean. The hypothesis that most of this pasture is degraded should be tested and validated based on historical satellite images.

As the pasture area in the Cerrado biome has been decreasing in recent years, while cattle herd increased by around 15% between 2000 and 2014, there is also evidence of an intensification process in cattle ranching. The understanding of how this intensification process occurs in different parts of the Cerrado biome, with a focus on the assessment of the quality of the pastures and the adoption of practices such as crop-livestock integration or crop-livestock-forest integration also demands further study.

As a result of this broad analysis of the agricultural expansion in the Cerrado biome, it was possible to evaluate the degree of activity in the agricultural frontier, as well as to identify the most suitable areas for future agricultural expansion without deforestation. However, the crop expansion process is also related to aspects such as the land cost, proximity to agricultural clusters, logistical infrastructure, among others that should be considered in future studies to better understand and model the crop expansion in the agricultural frontier in this biome.

The study revealed that the Cerrado biome possesses approximately 103.1 Mha (50.5%) of native vegetation remnants, of which 15.5 Mha have high agricultural capacity for soybean production. However, this area needs to be better understood in terms of biodiversity, land-ownership structure and conformity with the Forest Code, among others.



Grantee:

GORDON AND BETTY MOORE FOUNDATION

agrosatélite
applied geotechnology

4850, Km 5, SC 401 Highway - Store E-23/30 | Zip Code 88032-005
Florianópolis | Santa Catarina | Brazil
Telephone: +55 (48) 3209-1650