


LETTER**Soy expansion in Brazil's Cerrado**

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Funding information

Direktoratet for Utviklingssamarbeid; Gordon and Betty Moore Foundation; Norwegian Climate and Forest Initiative

Abstract

The Cerrado biome is Brazil's breadbasket and a major provider of ecosystem services, though these dual roles are increasingly at odds, in part because there are few mechanisms to protect remaining vegetation from large-scale agricultural expansion. We assessed Cerrado conversion to soy using over 580,000 property boundaries, covering 77% of the biome that is eligible for commercial land use, and using microwatersheds, to cover 100% of eligible areas. Soy expansion accounted for 22% of conversion during 2003–14. Only 15% of clearing exceeded restrictions on private properties under the Forest Code (FC). However, 51% of soy farms have violated the FC, five times the rate of other farms. As a leading cause of both Cerrado conversion and FC violations, the soy sector has environmental and economic incentives to shift production to already cleared land. We used suitability maps to identify potential pathways for soy expansion across both old and new cropland frontiers.

KEYWORDS

Brazil, commodity agriculture, deforestation, land use change, policy analysis, property-level analysis, soy, supply-chain policies

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1 | INTRODUCTION

The Brazilian Cerrado is a vast neotropical savanna and Brazil's most productive agricultural region (Lambin et al., 2013; Rada, 2013; Cardoso da Silva & Bates 2002). By 2015, 41% of native Cerrado vegetation (86 Mha) had been cleared for agricultural use. One-fifth (17 Mha) of this cleared area was planted with soy and most of the rest (60 Mha) was used as pasture (INPE, 2015).

Though conversion of the Cerrado began in the 1960s (Klink & Machado 2005; Sano, Rosa, Brito, & Ferreira, 2010), the pace of clearing has increased over the last two decades (Strassburg et al., 2017). Continued clearing is expected because the Cerrado has relatively little legal protection, especially compared with the Amazon biome. Brazil's Forest Code (FC) permits agricultural use on 65–80% of a property with Cerrado vegetation, compared with only 20% on most Amazon properties. Protected areas cover 8% of the Cerrado compared with 46% of the Amazon. Further, private sector zero-deforestation agreements for soy (2006) and cattle (2009) in the Amazon do not apply in the Cerrado (Gibbs et al., 2015a, b; Macedo et al., 2012).

Cerrado conversion affects a range of ecosystem services. The loss of deep-rooted shrubs and trees alters carbon storage and evapotranspiration, which may contribute to a climate transition to hotter temperatures and lower rainfall that will ultimately reduce agricultural productivity (Spera, Galford, Coe, Macedo, & Mustard, 2016). The loss of remaining biomass carbon stocks could also hinder Brazil's ability to meet climate treaty targets for greenhouse gas emissions (Aguiar et al., 2016; Coe et al., 2017). Continued clearing also threatens endemic flora and fauna and water supplies for more than 29 million Cerrado residents (Strassburg et al., 2017; Vieira et al., 2017).

Many companies have now made public commitments to eliminate conversion of natural vegetation from their supply chains (UN, 2014; CGF, 2017), which further raises the stakes for clearing in the Cerrado. Here we used maps of private properties and of microwatersheds, as proxies for properties, to assess the role of soy expansion on recent land use trends and the potential effects of zero-conversion production. Our study focuses specifically on soy- and Cerrado-specific trends and context, building upon previous work that analyzed expansion of croplands and FC compliance more generally (de Freitas et al., 2017; Gibbs et al., 2015a; Noojipady et al., 2017; Soares-Filho et al., 2014; Sparovek, Berndes, Barretto, & Kulg, 2012). These results are particularly relevant for stakeholders there, which include soy trading companies, retailers, and environmental groups, who are actively considering how to implement zero-deforestation commitments in the Cerrado (FAIRR, 2018).

2 | METHODS

We evaluated changes in land cover across the entire Cerrado biome from 2003 to 2015 and we also summarize results for three subregions with unique characteristics. The Cerrado biome portion of Mato Grosso (hereafter MT-Ce) is part of the Legal Amazon administrative region, which means it is subject to different policy pressures such as a more restrictive FC. Matopiba comprises the Cerrado portions of Maranhão, Tocantins, Piauí, and Bahia states and has been the epicenter of soy expansion over the last decade. The Southern Cerrado is an older frontier with the most area planted in soy.

2.1 | Biome-wide assessment

We combined satellite-based deforestation and land cover data to assess clearing for any purpose. We overlaid the MODIS-based Systematic Monitoring of Deforestation in the Cerrado Biome dataset (henceforth SIAD-Cerrado, following the Portuguese acronym) that tracks native Cerrado conversion (annual 2003–2015; LAPIG, 2016) with the 2002 land cover map from the PROBIO project (2002; MMA, 2014) to map the extent of historic conversion as well as annual clearing between 2003 and 2015. We chose SIAD-Cerrado over PRODES-Cerrado, Brazil's official clearing maps, because SIAD-Cerrado provides complete coverage of our study area, with annual estimates. PRODES-Cerrado would have limited our analyses because the data are biannual and because the year of clearing is ambiguous in portions of certain key soy-producing regions in MT-Ce and Matopiba (Brito, Valeriano, Ferri, Scolastrici, & Sestini, 2018). Clearing identified by SIAD-Cerrado for 2003–2015 agreed well with PROBIO's 2002 vegetation class (95.4% of the total area identified as cleared by SIAD-Cerrado from 2003 to 2015). When SIAD-Cerrado disagreed with PROBIO, we considered PROBIO to be correct; likewise, for the small degree of overlap within SIAD-Cerrado deforestation detections (0.43%) we used the earlier year.

To assess conversion for soy, we created an annual dataset of soy expansion for 2003–2014 by combining annual soy maps from NASA for 2001–2013 (Gibbs et al., 2015a; Noojipady et al., 2017) and from Agrosatélite for 2014 (Rudorff, Risso, & Aguiar, 2015) (we excluded 2015 for lack of data). To determine how much clearing was caused by soy expansion each year, we combined the annual SIAD-Cerrado conversion maps with our dataset of annual soy expansion, then tracked land use for the three years following deforestation (following Gibbs et al., 2015a; see SI §4). Our estimates should be regarded as the minimum area cleared for soy because we did not consider indirect impacts such as displacement of cattle pasture.

2.2 | Assessment of land use on properties

We characterized land use on farms, including FC compliance, to evaluate the role that soy has played in clearing and to assess pathways for future expansion. These analyses were based primarily on a map of private properties created by combining 573,638 boundaries from Brazil's recently available Rural Environmental Registry (Portuguese acronym: CAR; SFB, 2016), with an additional 140,311 private property boundaries from the National Institute of Colonization and Agrarian Reform (INCRA, 2016). We removed overlaps within and between the two databases to avoid double counting (SI §5). Our final property map contained 584,161 private properties. It covered 62% of the area eligible for private property ownership and 77% of the 2014 soy area. We then overlaid our map of 2014 soy (Rudorff et al., 2015) with the property map and classified those properties with more than 25 ha of soy as "soy farms," and classified all others as "non-soy farms."

We assessed the legality of annual clearing at the property level by comparing the vegetation remaining each year with the area of on-property set-asides called Legal Reserves (hereafter LR), required by the FC. Any conversion beyond these reserves is illegal.

The property boundaries exclude 38% of the area eligible for crops, because some is not yet registered, and some was excluded during the process of removing overlaps. Thus, we used microwatersheds, following Soares-Filho et al. (2014) and Gibbs et al. (2015a), to provide an additional, comprehensive estimate to compare with the property level data (Table 2). We also conducted the same analysis using microwatersheds and the PRODES-Cerrado maps to allow for comparison between official data and the results based on SIAD-Cerrado; we present a summary of these results in the SI (§5.1).

We identified the properties that could still be cleared under the FC. For this assessment, we created a more comprehensive natural vegetation map, by combining the extent of natural vegetation from the combination of noncleared areas in SIAD-Cerrado and remaining vegetation in PROBIO with additional native vegetation areas identified by INPE's TerraClass 2013 (INPE, 2015; SI §5.2), to avoid exaggerating the number of properties with insufficient LR. This map classifies areas of disagreement between the two datasets as vegetation, which accounts for potential regrowth of secondary vegetation on areas previously classified by SIAD-Cerrado or PROBIO as cleared. We then compared this remaining vegetation to LR requirements to determine the potential for additional legal clearing (a "surplus" of vegetation) on each property and to identify properties that had reached or exceeded legal limits on clearing as of 2015. For comparison, we also conducted this analysis a second time using PRODES-Cerrado and provide a summary of these results in the SI (§5.2).

2.3 | Assessment of land available for soy expansion

To assess the maximum area that soy could occupy under certain policy scenarios, we estimated suitability for three categories of land in the Cerrado: land under native vegetation and protected by the FC; land with surplus native vegetation; and cleared areas not used for soy production. We used microwatersheds rather than property boundaries because this analysis required complete coverage of the study area.

To determine the extent of surplus vegetation, we summed remaining native vegetation in each microwatershed according to our SIAD-Cerrado + TerraClass map. We compared these amounts with LR requirements and considered any area of remaining native vegetation that exceeded the required amount to be available for legal clearing.

We relied on two suitability maps to assess areas suitable for soy. We identified "highly suitable" areas using a 30 m resolution map developed specifically for soy (Rudorff et al., 2015; SI §6.1), and "potentially suitable" areas based on a more general cropland suitability map from Soares-Filho et al. (2014), also used in Gibbs et al. (2015a). We superimposed our native vegetation map on these suitability maps and allocated different categories of land up to the maximum legally clearable area for each microwatershed by first counting the highly suitable areas; next, potentially suitable areas; and finally, the remaining (unsuitable) areas. To assess the suitability of land already cleared, we overlaid the suitability maps with cleared areas and removed the 2014 soy extent.

2.4 | Market access to cleared and suitable areas

To assess the accessibility of cleared and suitable land, we estimated their proximity to transportation corridors and to commercial soy storage and processing infrastructure. We applied 10 km buffers around federal and state highways and 100 km buffers around silos and crushing facilities owned by major soy traders (CONAB, 2016, DNIT, 2017). We considered cleared and suitable land inside both buffers to be accessible.

We used surveys to supplement our accessibility estimates and to learn more about soy supply chains in the Cerrado. Between July and December 2016, we conducted phone interviews with 907 grain storage facilities to determine how common soy storage and purchases are among smaller companies with lower profiles in agricultural supply chains (SI §7). We also conducted interviews with farmers and soy silo managers, or personnel, during three trips to MT-Ce and Matopiba between 2014 and 2016, to learn more about how soy is produced and marketed in these regions.

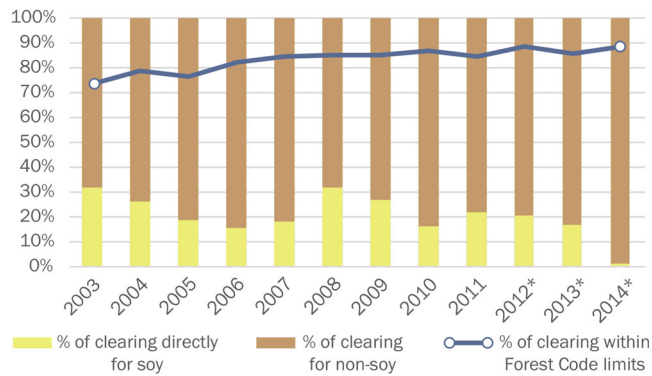


FIGURE 1 The role of soy in annual Cerrado clearing. Soy expansion contributed at least 22% of recent clearing in the Cerrado, 2003–2014, and was largely within the legal clearing limits prescribed by the FC (blue line). The bars show the percent of annual clearing for soy (based on soy expansion within three years ($year_i - year_{i+3}$) onto areas deforested in the year indicated), and for other purposes (the remainder of deforestation in that year). For years with an asterisk (2012, 2013, and 2014), annual clearing for soy is underestimated because they represent fewer than three years following clearing due to data limitations

3 | RESULTS

3.1 | Soy expansion led to significant conversion in the Cerrado

Soy expansion was a major driver of recent clearing in the Cerrado. Direct conversion for soy accounted for 16–32% of annual clearing between 2003 and 2014 (Figure 1; Table 1). In total, soy replaced at least 1.3 Mha of native vegetation during this period, averaging over 108,000 ha per year (max. 243,855 ha in 2003; min. 53,653 ha in 2006, during years for which we had complete data). Conversion was highest in MT-Ce and in Matopiba; between 6% and 33% of annual clearing in the Cerrado biome portion of MT-Ce and between 24% and 46% in Matopiba was planted directly to soy. Soy expansion accounted for only 2–11% of the conversion of remaining natural vegetation each year in the Southern Cerrado.

3.2 | Illegal clearing was concentrated on soy properties

Most conversion was within the legal limits established by the FC. On our mapped properties, only 15% exceeded FC limits, though this totaled nearly 700,000 ha across the entire Cerrado biome (Table 2). MT-Ce had the highest annual rates of clearing beyond legal limits (35% of total clearing), in part due to higher LR requirements in the Legal Amazon; there, only 24% of the 15.3 Mha of remaining natural vegetation was eligible for legal clearing by 2015 (Table 3). The lowest rates of illegal clearing were in the older frontier areas of the Southern Cerrado (9%), where 34.1 Mha of native vegetation

TABLE 1 Annual clearing for soy

Year of deforestation from LAPIG	Entire Cerrado		Matopiba		MT-Ce		Southern Cerrado	
	Total clearing, ha	% of total annual clearing for soy	Total clearing, ha	% of total annual clearing for soy	Total clearing, ha	% of total annual clearing for soy	Total clearing, ha	% of total annual clearing for soy
2003	762,047	32%	239,303	46%	342,802	33%	179,941	11%
2004	853,027	26%	383,066	37%	289,303	22%	180,658	10%
2005	460,922	19%	183,108	36%	165,226	9%	112,588	7%
2006	335,333	16%	134,084	34%	76,642	6%	124,607	3%
2007	422,114	19%	209,280	33%	63,636	10%	149,197	3%
2008	362,662	32%	240,935	45%	48,667	13%	73,061	3%
2009	274,828	27%	136,425	45%	59,017	17%	79,386	4%
2010	358,806	17%	253,469	22%	26,682	11%	78,655	2%
2011	697,426	22%	376,344	34%	107,362	17%	213,720	4%
2012*	735,094	21%	523,317	26%	60,450	21%	151,328	2%
2013*	407,424	17%	241,897	24%	77,858	13%	87,669	4%
2014*	439,183	2%	279,242	2%	71,131	1%	88,810	1%
TOTAL	6,108,866	22%	3,200,471	31%	1,388,775	19%	1,519,620	5%

* Clearing for soy is underestimated in the years 2012, 2013, and 2014. Estimates in 2003–2011 include the area planted to soy within three years of conversion.

TABLE 2 Legality of Cerrado clearing through time. We assumed that areas not identified as cleared were covered with native vegetation. Legality estimates for all years were based on the percent of the property or the microwatershed that could be cleared under the rules established by the FC and did not consider whether a license was obtained or if areas of permanent preservation were intact. Property boundaries covered 77% of soy area. Microwatersheds cover 100% of soy area

	2003*	2004*	2005*	2006*	2007*	2008*	2009	2010	2011	2012	2013	2014	2015	TOTAL
Entire Cerrado														
Property Boundaries	Area of clearing (ha)	555,962	607,607	308,337	229,667	286,090	189,023	233,112	463,168	489,203	288,928	309,591	226,198	4,449,505
	% legal	78%	82%	80%	88%	87%	87%	88%	86%	88%	87%	87%	86%	85%
	% illegal	22%	18%	20%	12%	13%	13%	12%	14%	12%	13%	13%	14%	15%
Microwatersheds	Area of clearing (ha)	719,407	786,647	410,555	311,949	388,724	250,769	324,117	644,562	677,258	373,827	401,424	284,843	5,914,681
	% legal	74%	80%	77%	83%	86%	86%	88%	86%	90%	87%	90%	89%	84%
	% illegal	26%	21%	23%	17%	14%	14%	12%	14%	10%	13%	10%	11%	16%
Matopiba														
Property Boundaries	Area of clearing (ha)	151,370	238,265	115,630	76,987	118,491	84,263	121,767	200,084	262,757	155,625	189,868	172,241	2,040,600
	% legal	90%	90%	92%	91%	89%	90%	92%	85%	86%	88%	86%	87%	88%
	% illegal	10%	10%	8%	9%	11%	10%	8%	16%	14%	12%	14%	13%	12%
Microwatersheds	Area of clearing (ha)	220,913	339,606	165,412	121,596	183,772	224,381	123,310	221,581	344,267	480,867	216,901	253,528	219,746
	% legal	93%	96%	94%	95%	92%	93%	94%	90%	92%	92%	93%	92%	93%
	% illegal	7%	4%	6%	5%	8%	7%	6%	10%	8%	8%	7%	8%	7%
MT-Ce														
Property Boundaries	Area of clearing (ha)	250,923	208,149	104,489	39,429	31,818	22,477	29,783	15,757	50,012	27,850	44,256	38,719	19,637
	% legal	62%	63%	56%	74%	66%	62%	66%	73%	67%	74%	77%	77%	69%
	% illegal	38%	37%	44%	26%	34%	34%	27%	32%	33%	26%	23%	23%	31%
Microwatersheds	Area of clearing (ha)	322,944	271,984	139,945	69,867	59,691	46,112	53,491	26,022	95,050	55,107	74,227	63,746	1,313,751
	% legal	73%	56%	56%	53%	69%	64%	57%	67%	63%	66%	70%	75%	68%
	% illegal	27%	44%	44%	47%	31%	36%	43%	33%	38%	34%	30%	25%	32%
Southern Cerrado														
Property Boundaries	Area of clearing (ha)	133,449	127,762	74,769	87,540	106,807	54,399	52,812	47,527	141,934	93,728	60,689	54,659	21,272
	% legal	89%	92%	92%	90%	91%	92%	91%	93%	91%	92%	92%	92%	91%
	% illegal	11%	8%	8%	10%	9%	8%	9%	7%	10%	9%	8%	8%	9%
Microwatersheds	Area of clearing (ha)	175,551	175,057	105,198	120,486	145,261	70,106	73,968	76,514	205,245	141,284	82,698	84,149	29,533
	% legal	81%	84%	81%	78%	86%	86%	86%	90%	87%	92%	88%	90%	86%
	% illegal	19%	16%	19%	22%	14%	14%	14%	10%	13%	8%	12%	10%	14%

*Excess clearing prior to 2008 on properties <4 fiscal modules (a fiscal module is an administrative unit that varies in size by municipality, based on how much land is required to support a family, as defined by the federal government) was forgiven under the 2012 update to the FC Estimates presented here, however, consider this deforestation on small properties to be illegal clearing, because it was illegal at the time it occurred.

TABLE 3 Area and location of land suitable for soy that was previously cleared, surplus vegetation, and vegetation protected by the FC. Only land that is privately owned or eligible for private ownership is included

		Entire Cerrado	Matopiba	MT-Ce	Southern Cerrado
Cleared area (ha)	Land highly suitable for soy	22,975,496	1,954,731	2,547,852	18,472,913
	Land potentially suitable for soy	15,220,975	513,330	2,237,221	12,470,425
	<i>All land suitable for soy</i>	<i>38,196,471</i>	<i>2,468,060</i>	<i>4,785,073</i>	<i>30,943,338</i>
Surplus natural vegetation (ha)	Land highly suitable for soy	8,002,563	3,840,642	1,110,328	3,051,593
	Land potentially suitable for soy	6,563,552	1,522,445	1,177,537	3,863,570
	<i>All land suitable for soy</i>	<i>14,566,115</i>	<i>5,363,087</i>	<i>2,287,865</i>	<i>6,915,163</i>
Vegetation protected by the FC (ha)	Land not suitable for soy	18,014,922	12,318,386	1,263,254	4,433,282
	Land highly suitable for soy	9,540,411	2,464,349	2,965,747	4,110,315
	Land potentially suitable for soy	11,275,201	865,312	4,234,671	6,175,218
	Land not suitable for soy	37,181,289	20,203,375	4,509,427	12,468,487

remained in 2015, 33% of which was eligible for legal clearing. Matopiba, where 12% of clearing surpassed legal limits, had the total highest amount of remaining native vegetation of the three regions (41.3 Mha in 2015) and the highest portion of vegetation that was surplus under the FC (43%).

Clearing by soy farms disproportionately exceeded FC allowances. Although soy farms represented only 7% of properties (42,256 of 584,161) and 23% of the mapped area eligible for agricultural production, they accounted for 44% of the 7,080 properties that cleared beyond legal limits between 2003 and 2015 and represented 59% of the area so affected. Soy farms with excess clearing were concentrated in MT-Ce between 2003 and 2008 (59%, or 1,247 of 2,120 farms) but this shifted to Matopiba after 2008 (52%, or 725 of 1,389 farms). At least 51% of soy farms across the Cerrado cleared beyond FC limits, a figure nearly five times that of nonsoy properties (11%).

3.3 | Millions of hectares can be cleared under the FC

Over one-third of the Cerrado's remaining vegetation outside of protected areas could be legally cleared under the FC (38 Mha; Table 3), of which over one-fifth (8 Mha) was on land highly suitable for soy, while another 7 Mha was on potentially suitable land. Nearly half of surplus vegetation on highly suitable land was in the agricultural hotspot of Matopiba (3.8 Mha, 48%), where recent rapid soy expansion puts vegetation particularly at risk (Figure 2, Table 3). A similar amount fell within official priority areas for conservation (3.3 Mha, 42%; MMA, 2017). Surplus vegetation on highly suitable land covered nearly five times the area cleared for soy since 2003. This suggests that conversion could continue legally at current rates for decades. Most of the highly suitable surplus vegetation was located on nonsoy properties (83%; 4.7 Mha). Only 12% of soy farms (4,865) had over 25 ha of these highly suitable areas, and only 4% (1,829) had more than 100 ha (Table 4).

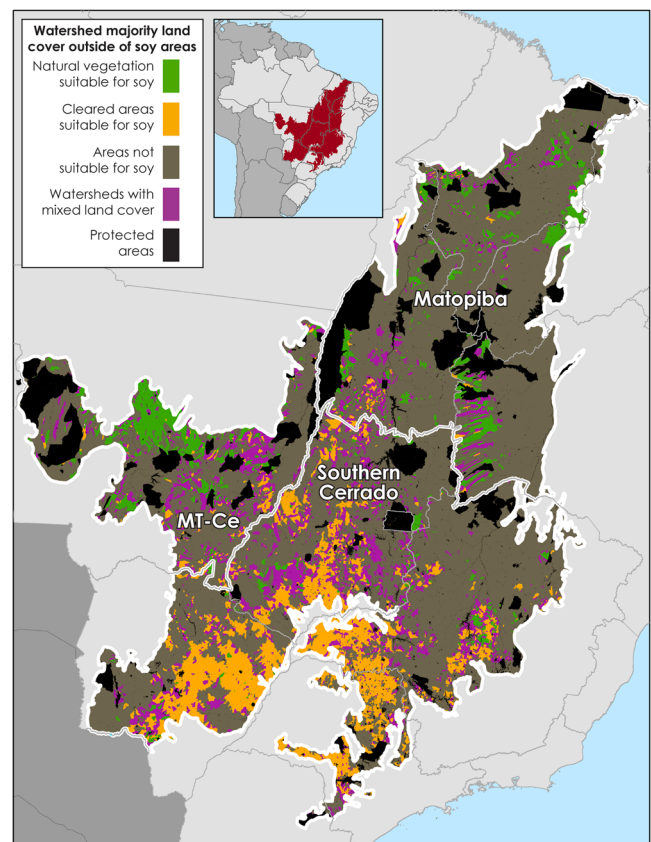


FIGURE 2 Vegetated and cleared land highly suitable for soy in the Cerrado. For each microwatershed, we mapped the dominant land cover types that are highly suitable for soy. Cleared areas suitable for soy are concentrated in the Southern Cerrado. Native vegetation suitable for soy is concentrated in MT-Ce and in Matopiba; the FC limits conversion of some of this vegetation

The highest concentration of remaining highly suitable land on soy farms was in Matopiba, where nearly 19% of soy farms can legally expand into 312,342 ha of area highly suitable for soy and with native vegetation cover.

TABLE 4 Properties with land highly suitable for soy that could be legally cleared under FC requirements. Surplus vegetation includes TerraClass 2013 vegetation in areas considered to have been cleared in previous years by SIAD-Cerrado or PROBIO

Region	Total soy properties			Number of soy properties with surplus vegetation on suitable land			% soy properties with surplus vegetation on suitable land			Total nonsoy properties			Number of nonsoy properties with surplus vegetation on suitable land			% of nonsoy properties with surplus vegetation on suitable land		
	>10 ha	>25 ha	>100 ha	>10 ha	>25 ha	>100 ha	>10 ha	>25 ha	>100 ha	>10 ha	>25 ha	>100 ha	>10 ha	>25 ha	>100 ha	>10 ha	>25 ha	>100 ha
MT-Ce	10,170	1,168	413	886	1,113	569	11.48%	8.71%	4.06%	28,754	3,790	2,808	1,350	13.18%	9.77%	4.69%		
MATOPIBA	5,902	1,458	569	1,113	2,866	847	24.70%	18.86%	9.64%	105,043	11,149	7,786	3,523	10.61%	7.41%	3.35%		
Southern Cerrado	25,806	4,531	847	2,866	847		17.56%	11.11%	3.28%	408,486	26,054	13,757	3,882	6.38%	3.37%	0.95%		
State properties	Total soy >10 ha	Total soy >25 ha	Total soy >100 ha	Total soy >10 ha	Total soy >25 ha	Total soy >100 ha	Total nonsoy >10 ha	Total nonsoy >25 ha	Total nonsoy >100 ha	Total nonsoy properties	Total nonsoy >10 ha	Total nonsoy >25 ha	Total nonsoy >100 ha	Total nonsoy >10 ha	Total nonsoy >25 ha	Total nonsoy >100 ha		
Bahia	2,296	567	244	444	244		24.70%	19.34%	10.63%	21,964	1,010	906	703	4.60%	4.12%	3.20%		
Distrito Federal	-	-	-	-	-		0.00%	0.00%	0.00%	120	-	-	-	0.00%	0.00%	0.00%		
Goiás	12,721	2,561	481	1,608	481		20.13%	12.64%	3.78%	101,030	11,909	6,348	1,699	11.79%	6.28%	1.68%		
Maranhão	1,205	352	138	274	138		29.21%	22.74%	11.45%	36,459	4,037	2,588	1,014	11.07%	7.10%	2.78%		
MT-Ce	10,170	1,168	413	886	1,113	569	11.48%	8.71%	4.06%	28,754	3,790	2,808	1,350	13.18%	9.77%	4.69%		
Mato Grosso do Sul	2,185	538	164	408	164		24.62%	18.67%	7.51%	17,130	2,885	2,113	931	16.84%	12.34%	5.43%		
Minas Gerais	7,863	1,229	182	749	182		15.63%	9.53%	2.31%	208,765	9,616	4,685	1,151	4.61%	2.24%	0.55%		
Paraná	138	27	1	13	1		19.57%	9.42%	0.72%	1,063	24	5	-	2.26%	0.47%	0.00%		
Piauí	780	113	51	78	51		14.49%	10.00%	6.54%	12,928	508	354	203	3.93%	2.74%	1.57%		
São Paulo	2,899	176	19	88	19		6.07%	3.04%	0.66%	80,378	1,620	606	101	2.02%	0.75%	0.13%		
Tocantins	1,621	426	136	317	136		26.28%	19.56%	8.39%	33,692	5,594	3,938	1,603	16.60%	11.69%	4.76%		
Total	41,878	7,157	1,829	4,865	1,829		17.09%	11.62%	4.37%	542,283	40,993	24,351	8,755	7.56%	4.49%	1.61%		

3.4 | Soy farming could expand without additional clearing

The Cerrado's soy sector could grow without additional conversion of natural vegetation. In 2015, there was approximately 23 Mha of cleared land considered highly suitable for soy and another 15 Mha classified as potentially suitable (i.e., 38 Mha total beyond current areas). The highly suitable, cleared land would suffice to more than double the current production area. Soy area could triple if potentially suitable land were also cultivated.

Our analysis shows that most suitable cleared land is accessible to markets and to soy producers. Most cleared and highly suitable land is within 10 km of a major federal or state highway (19 Mha, 82%) and within 100 km of a silo or crushing facility owned by a major trading company (18 Mha, 79%). Our survey indicated that there are hundreds of additional commercial silos across the Cerrado that receive soy on behalf of major trading companies or that sell soy to these major traders; incorporating these silos would more than double the number of units receiving soy and reduce transport distances from cleared, suitable areas.

Despite the abundance and accessibility of cleared, suitable land, most is located on older frontiers and nonsoy farms. For example, over 80% (18 Mha) of highly suitable cleared land is in the Southern Cerrado (Figure 2, Table 3), where recent soy expansion has been slow compared to Matopiba and MT-Ce. Further, as little as 2.8 Mha (12%) of the highly suitable cleared area was found on current soy producing properties, though 8.7 Mha (37%) was within 20 km of 92% of current soy properties. Most is located on pasture (70% of the cleared, highly suitable land; 16 Mha) with another 12% occupied by sugarcane (2.8 Mha).

4 | DISCUSSION

Our results show that soy has played a significant role in recent conversion in the Cerrado. Indeed, conversion rates there were five times as high as deforestation rates in the Amazon prior to the Soy Moratorium ("ASM"; Gibbs et al., 2015a; SI §4). The Brazilian government had intensified its efforts to protect Cerrado vegetation by imposing fines on companies that bought soy from land embargoed for illegal deforestation and by launching a Cerrado monitoring system (INPE, 2018a), but more recent political developments under the Bolsonaro administration include substantial budget cuts to Brazil's environmental enforcement agencies that may threaten their efficacy. Regardless, improved legal enforcement will do little to eliminate clearing for soy because most takes place within legal limits.

Private sector policies that restrict clearing by soy producers could help protect the Cerrado's surplus vegetation

because nearly half of it is on land suitable for soy production. In fact, such policies are likely the only way for companies to meet their commitments to eliminate deforestation from their supply chains by 2020 (UN, 2014; CGF, 2017). Zero conversion policies would likely impose minimal constraints on current soy farms because most (83%) have no remaining suitable areas that could be legally cleared. These restrictions could limit speculative land acquisition and clearing of new properties for soy production and encourage the use of the ample, already-cleared land across the Cerrado.

Additional public or private policy measures may be needed to support exclusive use of previously cleared areas under zero conversion policies. Competition with ranching and other agricultural activities for already cleared areas may increase costs of land acquisition and expansion compared with use of previously undeveloped areas. However, pasture replacement is already the most common expansion pathway and was the land source for more than half of the soy expansion between 2001 and 2014 (Carneiro Filho & Costa, 2016). Even moderate intensification in the cattle sector could make room for a large amount of soy expansion given that Brazil's pasturelands are currently used at only about one-third of their potential productivity (Strassburg et al., 2017; Strassburg et al., 2014). Increased integration of soy production with cattle ranching could also support expansion of soy on cleared areas (Gil, Garrett, & Berger, 2016; Rausch & Gibbs, 2016). Similarly, policies that support improved efficiency in soy farming could increase production while reducing the need for expansion (Battisti et al., 2018; Rada, 2013). However, these types of "land-sparing" approaches must be accompanied by a policy mix that limits clearing in other sectors to avoid perverse outcomes such as rebound effects (Arima, Richards, Walker, & Caldas, 2011).

Private sector efforts to eliminate conversion for soy in the Cerrado will face challenges that were not present when the ASM was implemented. Our surveys of soy farmers and buyers indicate that the influence of large companies on producer land management decisions is more limited in the Cerrado where as much as 40% of the soy produced is consumed domestically. When the ASM was implemented, the 28 signatory trading companies purchased 90% of Amazon soy directly from farmers, largely for export (Brannstrom, Rausch, Brown, Andrade, & Miccolis, 2012; Gibbs et al., 2015a; Godar, Persson, Tizado, & Meyfroidt, 2015). The same companies are active in the Cerrado, but their combined market share is lower than it was in the Amazon a decade ago. Our surveys also revealed that traders commonly purchase from smaller, local firms that act as intermediaries not subject to the same consumer pressure as traders due to their lack of global presence (SI §7). To avoid leakage, strategies that involve local buyers and smaller traders may be necessary, as has been observed in the Amazon under the zero deforestation cattle agreements (Gibbs et al., 2015b).

5 | CONCLUSION

The expansion of soy into native vegetation is transforming the Cerrado. However, the attention that has long been focused on the environmental consequences of agricultural production in the Amazon is now widening to include this important biome. Stakeholders in the agricultural sector are realizing that conversion of native vegetation may put future production at risk by reducing precipitation and increasing temperatures in important soy producing regions (Costa & Pires, 2009). Government statistics suggest that Cerrado clearing has slowed since 2015 (INPE, 2018b), which could mean conditions are ripe to end clearing for soy there. As with the ASM a decade ago, declining trends in conversion may signal an opportune moment for the soy sector to contribute to solutions that protect remaining Cerrado vegetation. A high-profile policy change for zero deforestation in the soy sector could lead the way for cattle as it did in the Amazon, and ultimately help generate even more protection for the Cerrado's natural habitats.

ACKNOWLEDGMENTS

We thank T. Passos for helping collect survey data and G. Allez for editing the manuscript. Funding provided by the Gordon and Betty Moore Foundation and Norwegian Agency for Development Cooperation's Department for Civil Society under the Norwegian Climate and Forest Initiative. This article was significantly improved by comments from three anonymous reviewers.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Rausch LL, Gibbs HK, Schelly I, et al. Soy expansion in Brazil's Cerrado. *Conservation Letters*. 2019;12:e12671. <https://doi.org/10.1111/conl.12671>