Supporting online material for:

The Land Characteristics of Cropping Frequency, Expansion, and Abandonment in Mato Grosso, Brazil from 2001 to 2011

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Complete Methodology: Land Cover Classification

a. Data

All spatially-subsetted, georeferenced, 16-day, 250 m spatial resolution MODIS13Q1 data over Mato Grosso acquired between August 2000 and July 2011 were downloaded from the United States Geological Survey's Land Processes Distributed Active Archive Center. The data are composites of the highest quality observations of each pixel taken during a 16-day period. MODIS EVI, Day of Year (DOY) and VI Quality Assurance (QA) data were used in this crop classification. EVI was chosen over NDVI because NDVI saturates at lower leaf area indices than does EVI (Huete et al., 2002).

The EVI, DOY, and QA data were stacked sequentially, creating three image cubes consisting of 253 individual scenes resulting in an eleven-year-long time series for each pixel in the scene. Once these image cubes were created, pixels with EVI values below -2.0 and those whose QA data was less than or equal to "lowest quality" were replaced with temporally linearly interpolated values.

A crop year in Mato Grosso was defined to begin at Day 225 of the previous year and to end at Day 209 of the growing year itself. Thus the 2001crop year consists of 23 MODIS EVI scenes composited every 16 days beginning August 12, 2000 and ending July 27, 2001.

b. Decision Tree Classification Algorithm

Each pixel's resulting 2000-2011 time series was analyzed with a decision-tree algorithm written in Interactive Data Language (IDL) to determine both the area of cropland per growing season and the specific rotation of that cropland: a soy or cotton single-commercial-crop rotation or a soy-corn or soy-cotton double-commercial-crop rotation.

The decision tree uses crop-specific growing season lengths and maximum EVI thresholds to classify mechanized agriculture areas into one of four crop rotation classes: soy, cotton, soy-corn, and soy-cotton. The parameters of this classification are outlined in SOM Table 1. All thresholds and parameters were determined using basic statistics and trial-and-error on training data collected in Mato Grosso in March 2011 for the 2010-2011 crop year (99 total points: 10 non-mechanized agriculture, 89 in annual agriculture rotations), general phenological patterns and thresholds described in Galford et al. (2008), Arvor et al. (2011), and published crop calendars (United States Department of Agriculture Foreign Agricultural Service, 2012).

c. Characteristics of Mechanized Agriculture

The phenology of cropland has a distinctive rising and falling shape associated with the sowing and harvesting of crops. We classified a pixel as mechanized agriculture if its time series had a standard deviation greater than 0.21, or if it had a standard deviation greater than 0.16 and the time series had a distinct EVI peak between 50 and 150 days long (SOM Table 1). This second condition avoids false positive classifications of pasture or cerrado as cropland. To calculate these peaks, the algorithm finds the temporally closest observations to the maximum EVI observation that are lower than the average of the maximum and minimum EVI observations. The lengths of time—in days—between these observations are calculated using the corresponding pixel-specific DOY values. If the width of this derived peak is not between 50 and 150 days, the pixel is not classified as mechanized agriculture.

d. Specific Crop Rotations

Annual cropping systems are the predominant form of mechanized agriculture in Mato Grosso. Single cropping is the conventional system, in which only one commercial crop (soy or cotton) is cultivated during the crop year. Double cropping typically involves the cultivation of a short-cycle soy variety during the first half of the crop year and followed by the cultivation of a second commercial crop (often corn or cotton and occasionally soy). Because nearly all the mechanized agriculture in Mato Grosso is rainfed, the short-cycle soy varieties are essential for the planting of a second commercial crop during the wet season. Soy is typically sown between late September and November (United States Department of Agriculture Foreign Agricultural Service, 2012). Mato Grosso's farmers can only begin to plant soy on September 15 – the official end of the 90-day "Free Host Period" which is employed to deter the spread of Asian soybean rust. If soy is the only commercial crop being sown, the growing season typically spans October to March (United States Department of Agriculture Foreign Agricultural Service, 2012). If corn is planted as a second crop, it is often sown in late January-February (immediately following soy harvesting) and harvested in late May and June (United States Department of Agriculture Foreign Agricultural Service, 2012). Second crop cotton is typically sown in January (United States Department of Agriculture Foreign Agricultural Service, 2012). If cotton is the only commercial crop planted, it is sown in late December-January, and is harvested in late June or early July (United States Department of Agriculture Foreign Agricultural Service, 2012). Because corn is an erectophile and cotton and soy are planophiles, the latter crop's canopies often reach higher maximum EVI values during the growing season at full crop development (Dorigo et al., 2007).

For pixels classified as cropland, a second stage of the classification algorithm is employed to classify crop rotation based on the growing season length and maximum EVI. To determine the dates of green up and harvest, the time series is divided into two overlapping sections—EVI values that were compiled between DOY 225 (mid-August) and DOY 81 (late March of the following calendar year but same crop year) and those between DOY 353 (late December) and DOY 209 (late July of the following year). The algorithm identifies rapid increases and decreases in the EVI time series, specifically a ΔEVI greater than 0.4, corresponding to times of green up and harvest. The dates of these events for each pixel are then recorded. These pixel-specific dates are then used to calculate the lengths of the crop cycles for that growing season. If a green up date or a harvest date is not located for the first crop, the green up date of the second crop is used as the date of harvest for the first crop. Conversely if no green up date is identified in the second half of the time series, the date of the first crop's harvesting would be used as the second crop's green up date.

Because no smoothing algorithm is applied to the MODIS data, using maximum EVI values sometimes confused our training data classifications of a cover crop as corn, or corn as cotton. Thus, rather than use the maximum EVI value in each time segment, we chose to calculate the average of the second- and third-highest EVI values in each time series and use this as a corrected maximum.

The lowest 'corrected maximum' EVI value needed for classification as a soy or cotton crop is 0.6, while the lowest 'corrected maximum' EVI value for corn is 0.45. The growing season length for classification as soy and corn ranges from 78 days to 155 days. The growing season length for classification as cotton ranges from 116 to 240 days, but only appears during the second half of the growing season. While these growing season durations seem longer than appropriate, these extended lengths are necessary due to the methods by which MODIS derives its EVI data. The MOD13Q1 EVI product is a composite of the highest quality observations of each pixel taken during every 16-day compositing period. If a soy crop is harvested on January 1, the highest quality observation taken over that soy field may have been taken on January 16, seemingly adding 15 days to its growing season. Thus, we added a temporal buffer before and after the growing season to address this possibility when calculating crop cycle lengths. The algorithm, then, works pixel by pixel through a series of conditions to determine if the land cover of a given pixel's time series shows a soy, soy-non-commercial crop, cotton, non-commercial crop-cotton, soy-corn or soy-cotton pattern, and classifies the pixel as such.

Lastly, the algorithm also highlights irrigated cropland. To determine if a pixel represents irrigated agriculture, the pixel's time series must have a standard deviation that qualifies it as mechanize agriculture. Because irrigated land allows for the cultivation of crops through the dry season, unlike other annual crop rotations with characteristic low EVI values throughout the dry season, irrigated land shows high EVI values during these times. To be classified as such, a pixel must have the standard deviation characteristic of mechanized agriculture and a first or last growing season EVI pixel value greater than 0.5. Cotton, corn, and beans are the crops most commonly grown with central pivot-irrigation Mato Grosso. The algorithm, however, does not differentiate between irrigated crop types.

	Soy	Cotton	Soy/Corn	Soy/Cotton	Irrigated
σof EVI Time Series > 0.21	x	x	x	x	x

First/Last EVI Time Series Value < 0.5					x
Occurs First During Firs Half of Crop Year	x		x	x	
Occurs During Second Half of Crop Year		x	x	x	
Minimum EVI “Maximum” ≥0.6	x	x	x	x	
Minimum EVI “Maximum” 0.45 < x < 0.6			x		
Growing Season Length 78-155 days	x		x	x	
Growing Season Length 116-240 days		x		x	

Table S1. *Characteristics used to classify crop rotations. All other pixels were aggregated to ‘other’ class containing forest, cerrado, pasture, sugarcane and rice.*

If algorithm cannot determine when the start or end of a growing season occurs from the EVI time series, it cannot perform the rest of the crop classification analysis. In these instances, the crop type determination is dependent on the EVI-corrected maxima thresholds discussed above and outlined in SOM Table 1.

e. Post-classification noise filter

A conservative noise reduction mode filter is applied to minimize any ‘salt and pepper’ effect, e.g. one cotton pixel in the middle of a soy-corn field. A 3-pixel-by-3-pixel moving kernel window filters through the resulting crop year classifications and modifies the middle kernel cell if all of its surrounding cells are classified as the same land cover. This conservative mode filter amounted to a correction of approximately 0.5% of all pixels within the Mato Grosso scene over the eleven crop years.

In summary, the algorithm analyzes each pixel independently to determine if the land cover present as non-mechanized agriculture or mechanized agriculture. Each pixel classified as mechanized agriculture is further refined based on the phenology dynamics as a single- or double-crop rotation, and which principal crops (soy, corn, cotton, cover) comprise that crop rotation.

f. Verification and Validation

The results were validated with a web-tool developed at the National Institute of Space Research in Brazil (INPE) (Freitas, 2011). More details about applications of this web-tool can be found outlined in Adami et al. (2012), at http://www.dsr.inpe.br/laf/series/en/about.html and below.

Because mechanized agriculture is known to occur in close proximity to roads, we used ArcGIS 10.0 software to create randomly located validation points within a 1 km buffer shapefile of the road network shapefile downloaded from Mato Grosso's Secretary of State Planning and General Coordination (Mato Grosso State Secretary of Planning, 2013). The proximity of the validation points to roads was also important in facilitating ground truth validation activities. At least one false color composite of Landsat bands 4 (0.84 µm as red), 5 (1.65 µm as green), and 3 (0.66 µm as blue) was compiled for each of the 600 points for each growing season between 2001 and 2011. False color Landsat images highlight the unique shades of orange-red characteristic of forest, cerrado, pasture, soy, corn, cotton and cover crops with the aforementioned 4(red)-5(green)-3(blue) band combination (Figure 1). The 30 m resolution data are ideal for recognizing the different crop covers identified with MODIS, thus allowing for validation of the land-cover class at each point for each crop year. The tool's Landsat images were analyzed for each point for each crop year to determine that pixel's specific land-cover. The utility of having a spatial and temporal spread of validation points is integral to ensuring the robustness of the algorithm's processes.

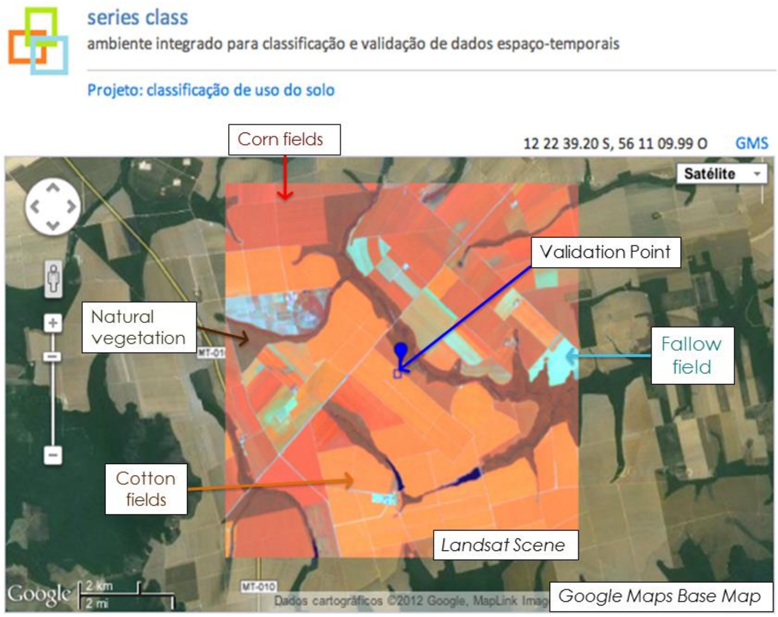


Figure S1. A screenshot of the validation webtool interface to demonstrate the ability to use Landsat imagery when field sizes are large.

Ideally the validation method would apply to all 600 points throughout all eleven crop years for a total of 6600 potential validation points. However, obtaining cloud free images over Mato Grosso during the season is extremely difficult. As a result, the only Landsat image associated with a particular point and growing season may not have been taken during the best crop identification window, making it impossible to accurately determine the land cover for some validation points. A point was only considered for validation if a Landsat image was if crop-type, and thus growing season rotation, could be distinguished. Furthermore, we excluded mixed pixels (MODIS validation points that covered two different land cover classes at Landsat resolution) from the validation analysis, but address their classifications below. Of the potential 6600 validation points, 2945 met our criteria as points to validate the algorithm's output.

As shown in Table 2, of the excluded validation points, 38% had no usable Landsat data due to missing data, cloud cover, or the date the image was taken; 52% were mixed pixels in which a MODIS pixel encompassed two land cover types; 3% were pixels that represented rice or sugarcane crops, both of which were classified as other in our analysis; and 7% were left unclassifiable. Of the pixels with no usable Landsat images, 53% were classified through the MODIS analysis as soy-corn land cover rotation; 46% as a soy-cover crop rotation; and 1% were as a soy-cotton rotation. Of the 7% of pixels in which the land cover could not be determined from the Landsat data; 60% were classified as other; 21% as a soy-cover crop rotation; 11% as soy-corn rotation; and 8% as a cotton rotation. These 235 unclassifiable pixels represent less than 4% of the total number of web-tool points and require fieldwork for verification and validation.

No usable Landsat	1387
Mixed pixels	1888
Rice or sugarcane	127
Unknown	253
Total	***3655***

Table S2. *Pixels not used in validation*

Every excluded mixed-pixel validation point was reanalyzed to estimate the aggregate effect on total area calculated. Of the 1901 mixed pixels, 97% were correctly classified as one of the two land covers contained within the pixel. Of the 97%, 25% were forest- or cerrado-crop boundaries that were classified as other; and the last 3% were randomly classified. The area attributed to may exhibit a slight positive bias. The classification of some mixed pixels at forest/crop edges would be troublesome if Mato Grosso were home to myriad patches of smallholder agriculture and thus create an abundance of non-crop/crop edges. However, because more than 85% of Mato Grosso's mechanized agricultural farms range are larger than 500 ha (Brazilian Institute of Geography and Statistics, 2013a), and the land-cover land-use change occurs at such a large scale, these pixels should not significantly affect aggregate area estimates.

g. Accuracy

We classified 11 years of MODIS data with a high degree of accuracy. Mechanized agricultural land was separated from pasture, cerrado, and forest with an overall accuracy of 98%

(Table 3). The algorithm successfully separated unique crop rotations with an overall accuracy of 93% and a k_{hat} of 0.90 (Table 3).

Classification	*Ground Cover Validation Data*			
	Mechanized Ag.	*Other*	*Row Total*	***User's Accuracy***
Mechanized Ag.	1608	16	1624	0.99
Other	49	1272	1321	0.96
Column Total	1657	1288	2945	
Producer's Accuracy	0.97	0.99		

Overall Accuracy = 98%

Classification	*Ground Cover Validation Data*							
	Soy	*Cotton*	*Soy/Corn*	*Soy/Cotton*	*Other*	*Irrigated*	Row Total	***User's Accuracy***
Soy	752	10	34	1	12	1	810	0.93
Cotton	10	165	4	1	0	0	180	0.92
Soy/Corn	41	3	502	4	4	3	557	0.90
Soy/Cotton	3	2	11	40	0	3	59	0.68
Pasture/Cerrado/Forest	38	3	2	0	1272	6	1321	0.96
Irrigated	0	0	0	0	0	18	18	1.00
Column Total	844	183	553	46	1288	31	2945	
Producer's Accuracy	0.89	0.90	0.91	0.87	0.99	0.58		

Overall Accuracy = 93% ***K_{hat} =.90***

Table S3. *Confusion matrices. Other contains forest, pasture, and cerrado.*

The land covers and uses associated with a relatively high error were ‘irrigated land’ and the soy-cotton rotation. The irrigated land class spanned a range of classifications, due to the irregular growing year phenology. Error associated with the soy-cotton rotation is related to the small number of validation points and conflation with soy-corn areas in the southeastern half of Mato Grosso.

We compared our classification of mechanized agriculture to statistics on the area of soy, corn, and cotton production statistics reported in the Municipality Agricultural Research (PAM) reports produced by the Brazilian Institute of Geography and Statistics (IBGE) (2013b). PAM agricultural production statistics are based on estimates by local experts. Averaged over the ten crop years, the soy algorithm results were in 86% of the area of the PAM, with a high of 96% of the area in the 2001 crop year and a low of 79% of the area in the 2004 crop year. Corn harvested area results were 32% higher than reported government statistics with a maximum of 70% higher than the area reported in the 2006 crop year. There was only one crop year, 2000/2001, where our corn harvested area estimate was lower than that reported by the IBGE. The average area of cotton estimated was never more than 9% higher than PAM statistics over the period 2000 to 2010.

Our approach has a number of limitations. There was decision tree confusion distinguishing between soy-cotton and soy-corn rotations in the southeastern half of Mato Grosso. There, the short and late wet season results in similar growing season phenologies for corn and cotton. We also obtained the fewest validation points for the soy-cotton class.

Although the algorithm can differentiate central-pivot irrigation areas, it cannot identify crops planted in these irrigation circles[i]. However, irrigated areas comprised less than 1% of the land in mechanized agriculture in Mato Grosso.

As Brown et al. (2013) highlight, other soy-commercial crop rotations, such as soy-sunflower, soy-sorghum, soy-soy, and soy-beans are present on the landscape. Because sunflower, sorghum and beans comprised less than 0.3%, 1.6%, and 0.93% of the total land in annual crops in Mato Grosso between 2000 and 2011 respectively (Brazilian Institute of Geography and Statistics, 2013b), they were not considered in our algorithm. Rice, which comprised almost 6% total land in annual agriculture over the eleven-year period (Brazilian Institute of Geography and Statistics, 2013c), was also not considered. Beans are often cultivated using pivot irrigation, which allows for the ability to plant three harvests per crop year, and our algorithm's irrigation results may be used as a proxy for bean-crop land cover.

Sugarcane was also not classified in our analysis. As of 2012, 290,000 hectares of sugarcane were cultivated in Mato Grosso, an increase of 83% over the 160,000 hectares cultivated in 2003, but no change has been observed since 2008 (Rudorff et al., 2010). Non-commercial cover crops such as millet, which often precede or succeed single crop soy or cotton rotations, were lumped into the single cropping class. Although not validated, using single cropped fields with commercial cover crops as a proxy for no-till management regimes, and single cropped fields with no cover crop as a proxy for till management regimes, in both 2001 and 2011, approximately 60% of single cropped field pixels presented an obvious cover crop.

Our algorithm was written to discriminate between crops that comprise 89% of the IBGE's reported total aggregated cultivated land area in Mato Grosso. The aforementioned crops of rice, sugarcane, beans, sorghum, and sunflower comprise much of the remaining 11%. Based on our validation points, both rice and sugarcane (7.75% of Mato Grosso's area in agriculture and less than 1% of Mato Grosso's total land cover) were consistently classified as 'other' due to the short growing season and low maximum EVI associated with rice and the similarity of sugarcane's phenology to pasture. While this misclassification causes us to slightly underestimate mechanized agricultural are, it does not affect our specific crop type accuracies.

Mixed pixels were classified as one land cover type. Pixels with a mixture of forests and crops were classified as other, biasing downward the area of mechanized agriculture. Pixels with a mixture of soy and corn were classified as soy/corn, biasing downward the area soy and the area of corn. However, the methodology succeeds in its goal if capturing majority of agricultural development in Mato Grosso.

Complete Methodology and Results: Logistic Regressions

a. Data

a1. Agri-climatic attribute maps

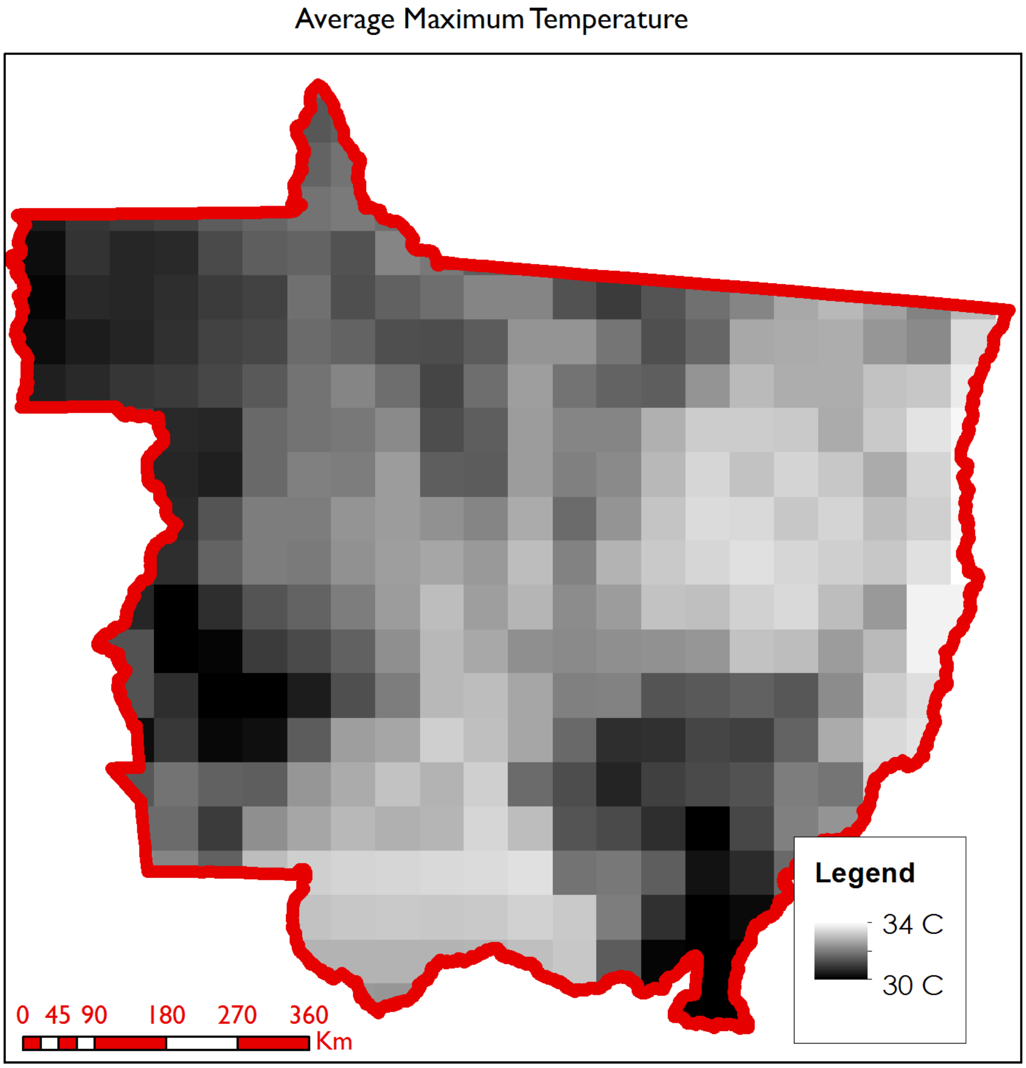
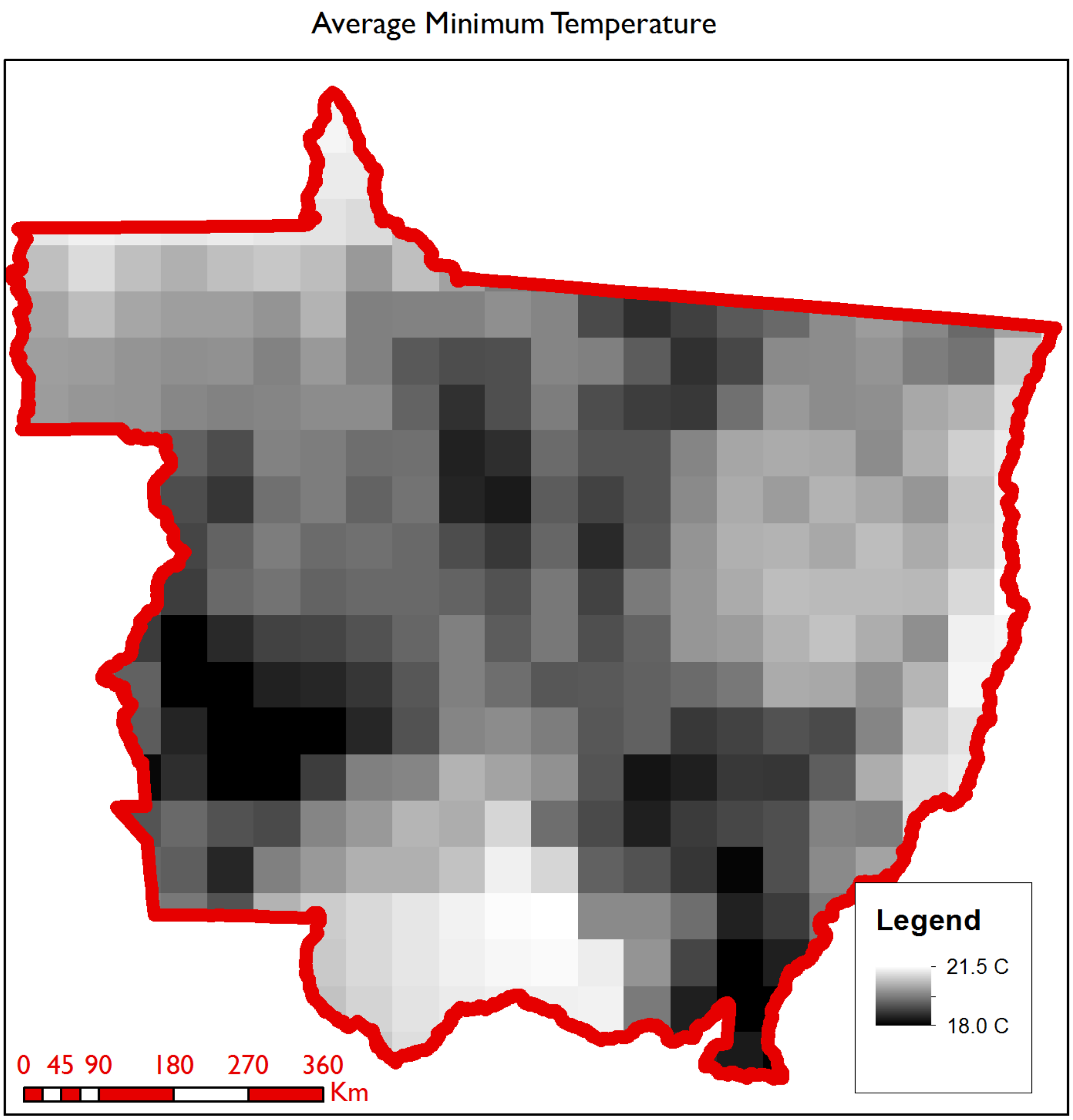


Figure S2. Climate Research Unit (CRU) Average Maximum Temperature across Mato Grosso from 1980 to 2000 (New, Lister, Hulme, & Makin, 2002).



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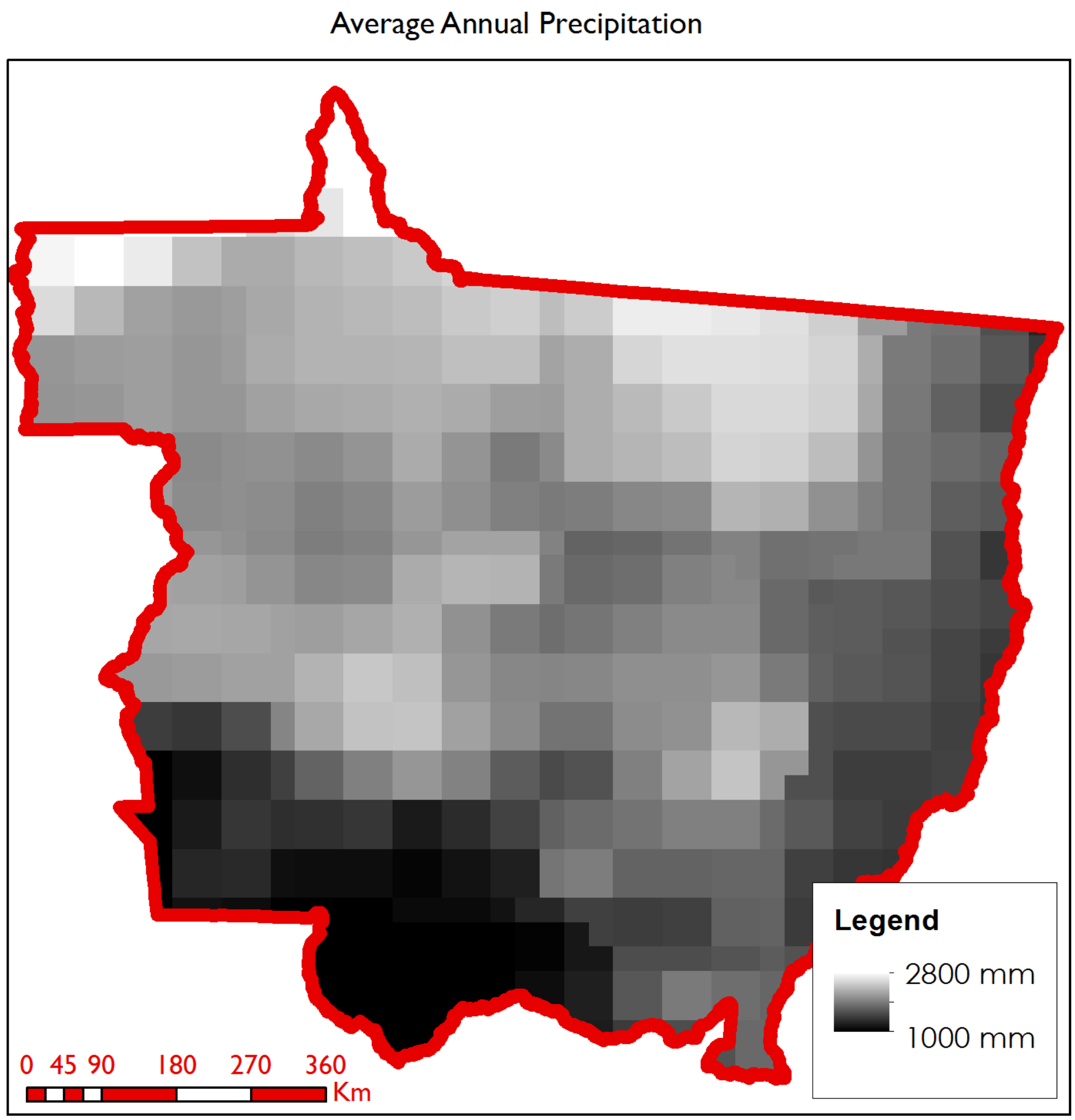

Figure S4: Climate Prediction Center (CPC) average annual precipitation across Mato Grosso from 1981 to 2010 (Fan & van den Dool, 2004).

Average Annual Soil Moisture

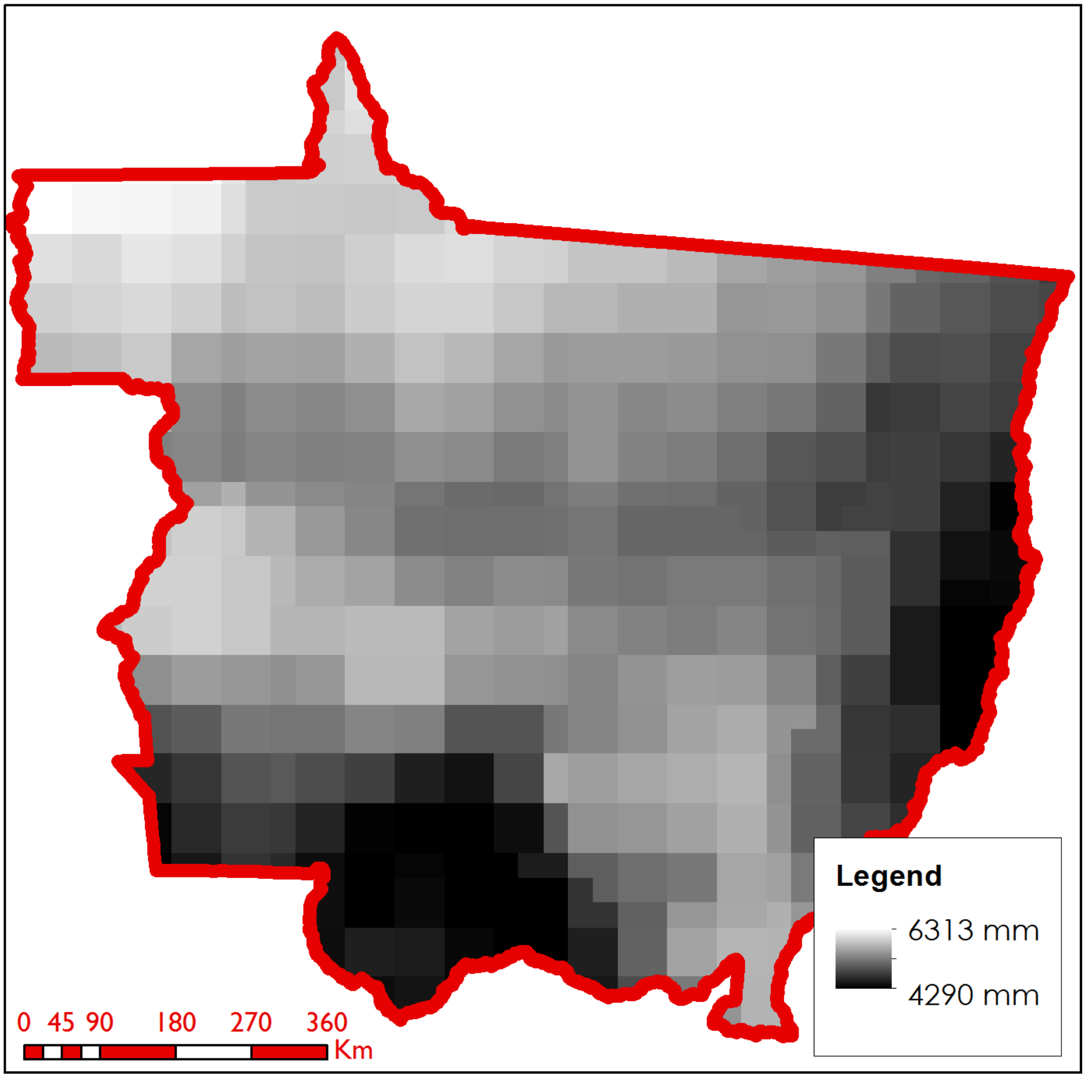

Figure S5. Climate Prediction Center (CPC) average annual soil moisture across Mato Grosso between 1981 and 2000 (Fan & van den Dool, 2004).

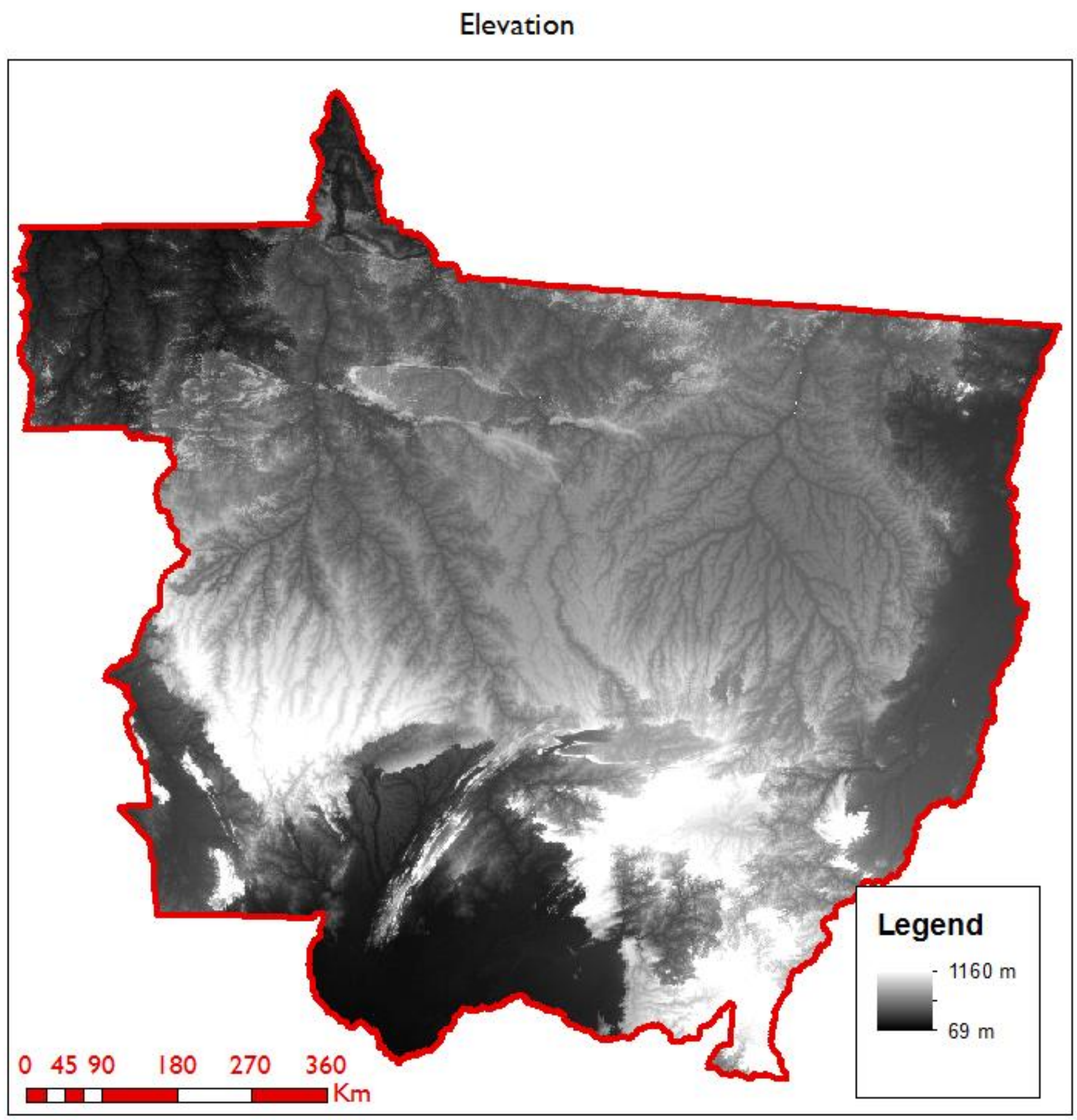

Figure S6. Shuttle Radar Topography Mission (SRTM) digital elevation map (Van Zyl, 2001).

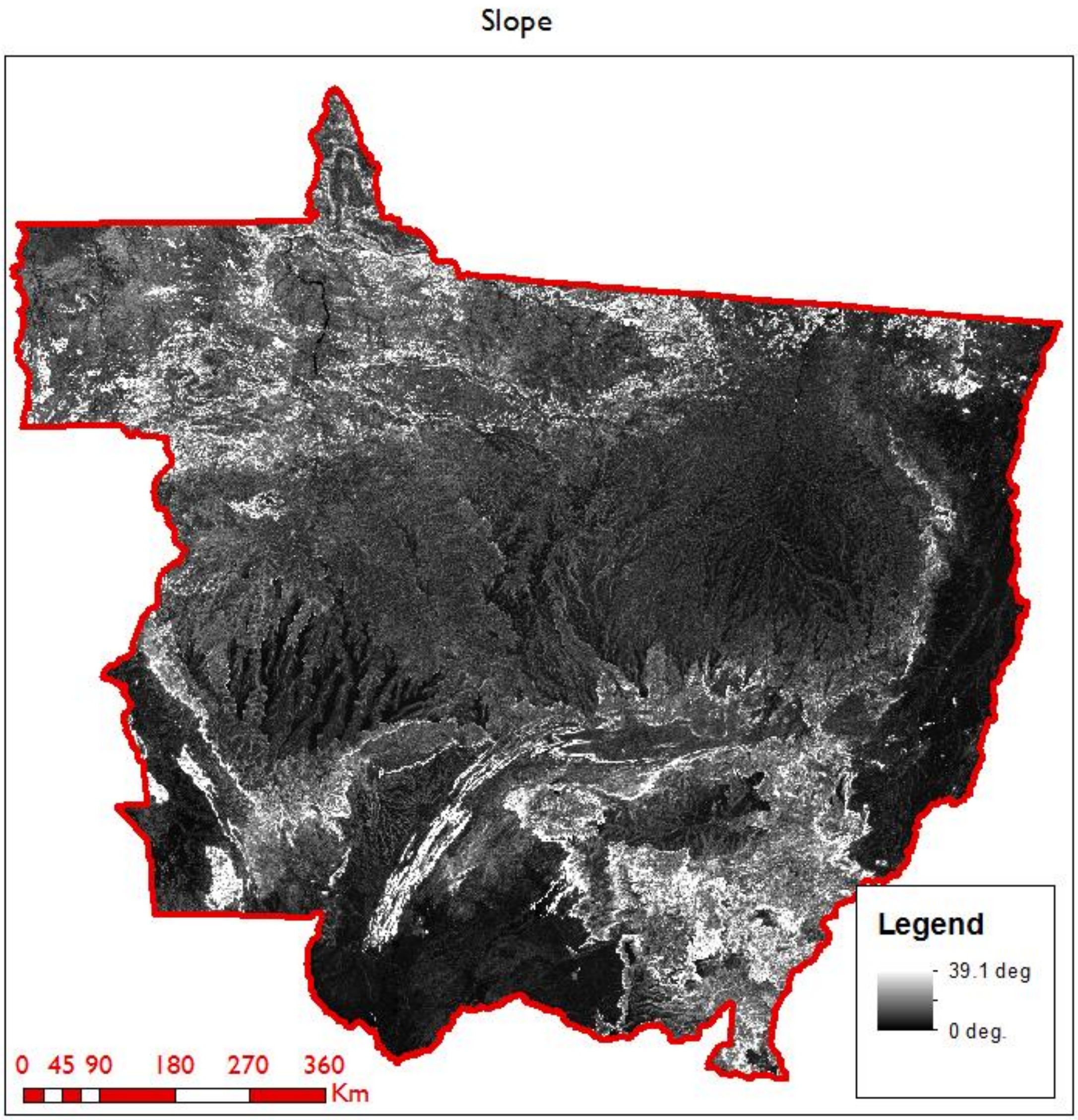

Figure S7. Shuttle Radar Topography Mission (SRTM) derived slope (Van Zyl, 2001).

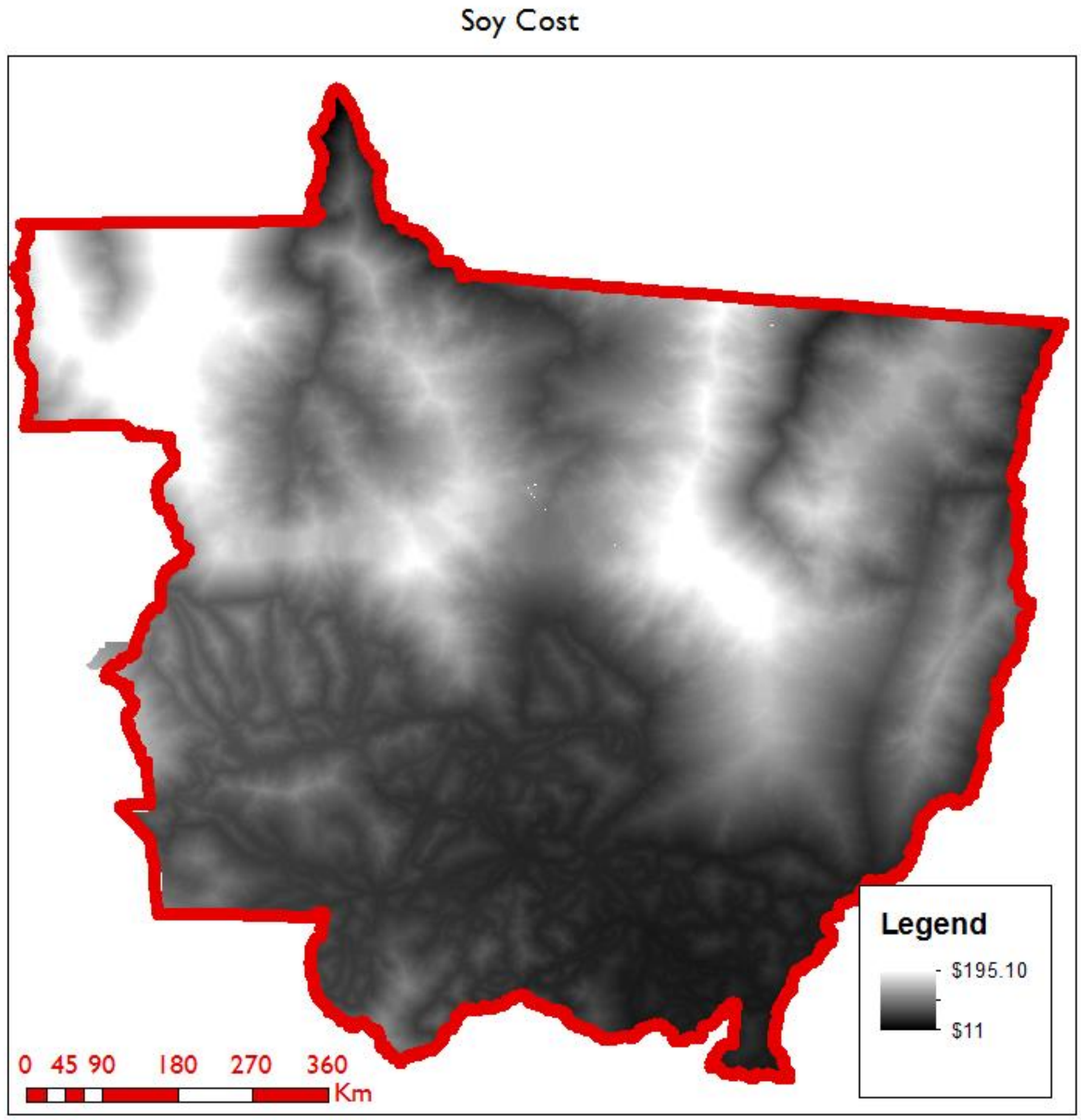

Figure S8. Soy logistics cost estimates map (in year 200 US Dollars).

a2. Agri-Climatic Attribute Correlation Matrix

	Precipitation	Soy Transport cost	Minimum temperature	Maximum temperature	Soil moisture	Slope	Elevation
Precipitation	1						
Soy Transport cost	0.422*	1					
Minimum temperature	-0.204*	0.00526*	1				
Maximum temperature	-0.311*	-0.142*	0.680*	1			
Soil moisture	0.804*	0.339*	-0.414*	-0.674*	1		
Slope	0.0720*	-0.0143*	-0.138*	-0.290*	0.215*	1	
Elevation	0.127*	-0.208*	-0.715*	-0.405*	0.254*	0.199*	1

* p<0.001

Table S4. *Correlation matrix of the seven agri-climatic variables investigated.*

a3. Agri-Climatic Attribute Histograms

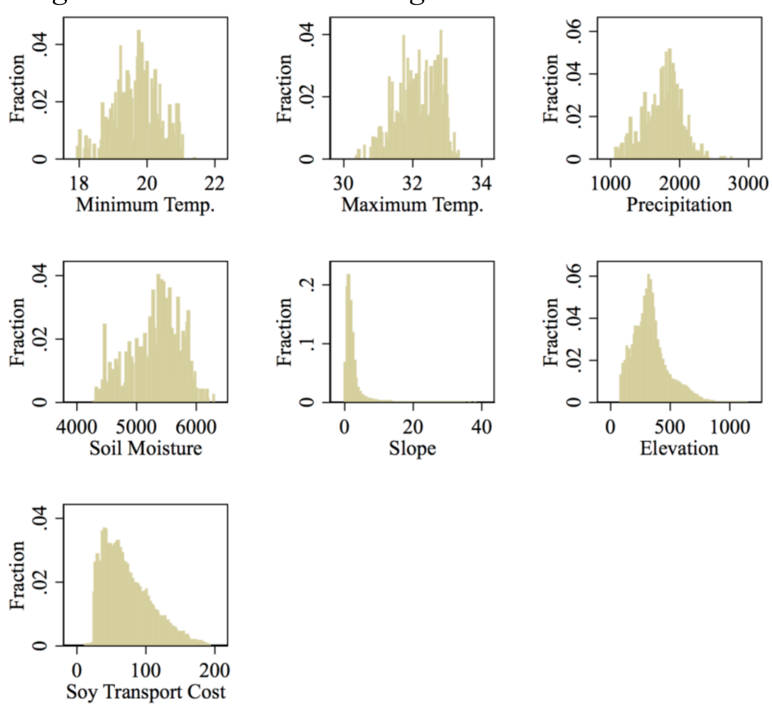

Figure S9: Histograms of land attributes investigated.

b. Protected areas and indigenous reserves

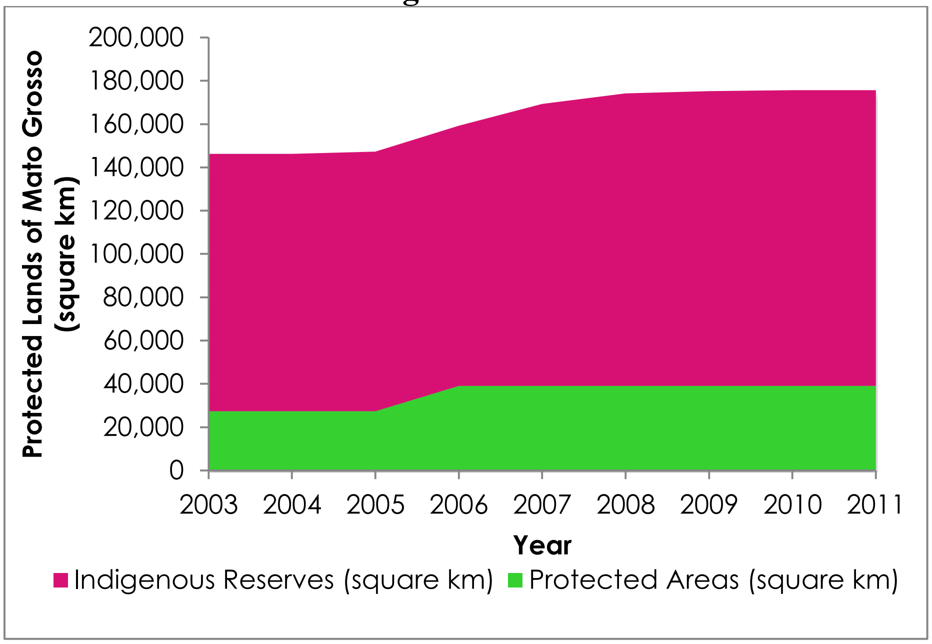

Figure S10: Cumulative area of protected areas and indigenous reserves over study period.

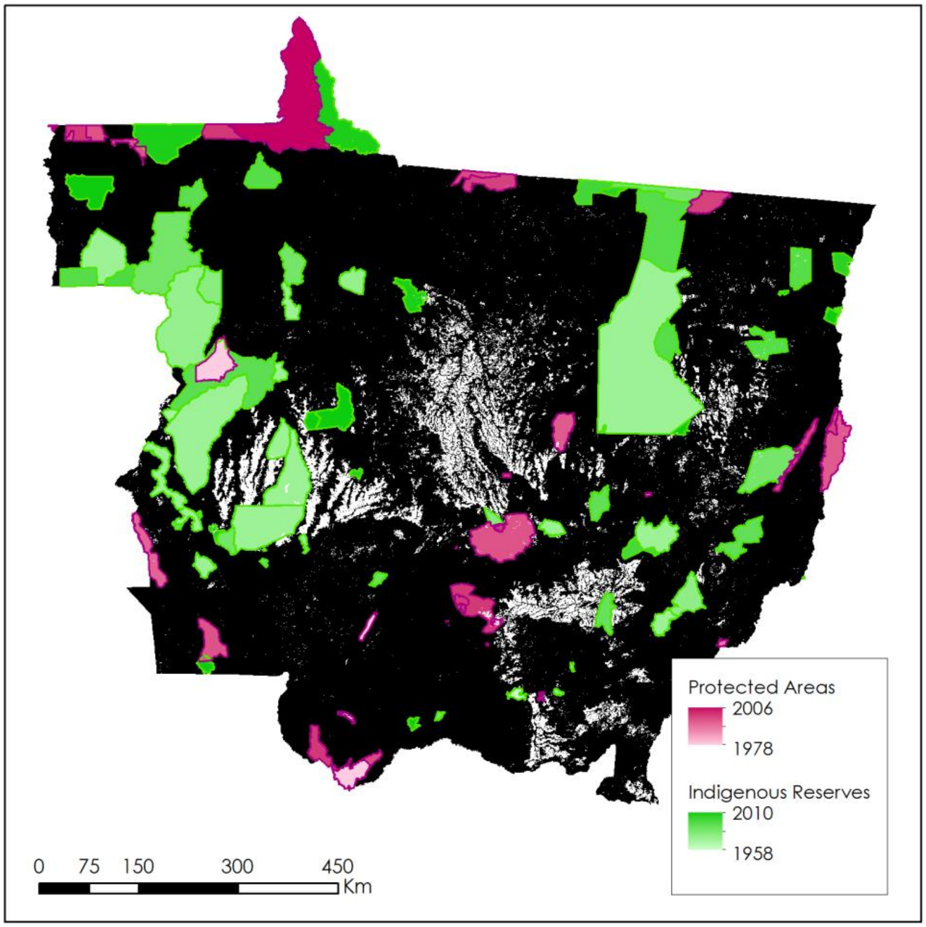

Figure S11. Map of protected areas and indigenous reserves by year of designation. (IUCN & UNEP 2014)

c. Soils

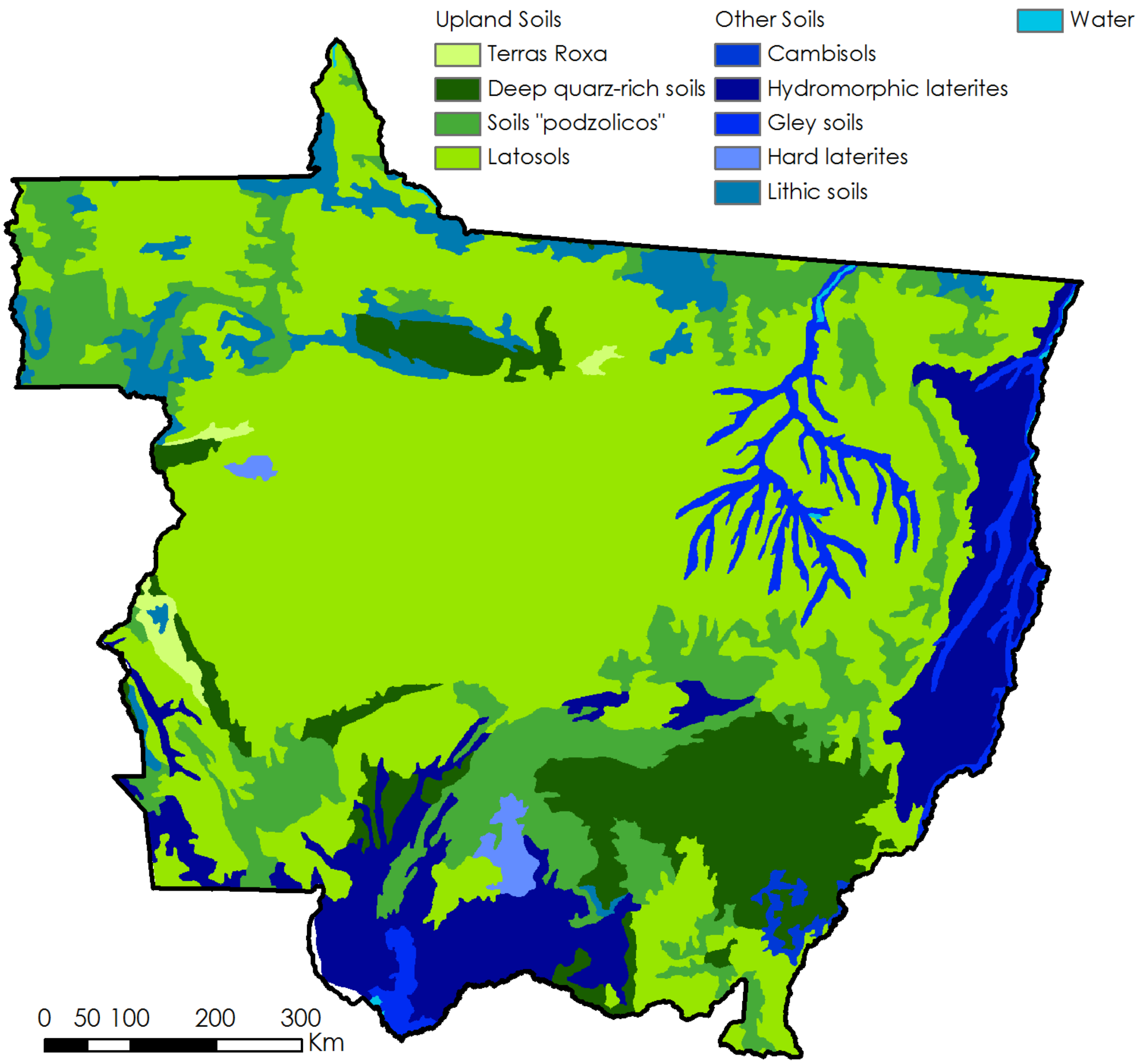

Figure S12. 1981 Embrapa soils map highlighting the Brazilian classification of soils and our categorization into 'upland soils' in green and all other soils, in blue.

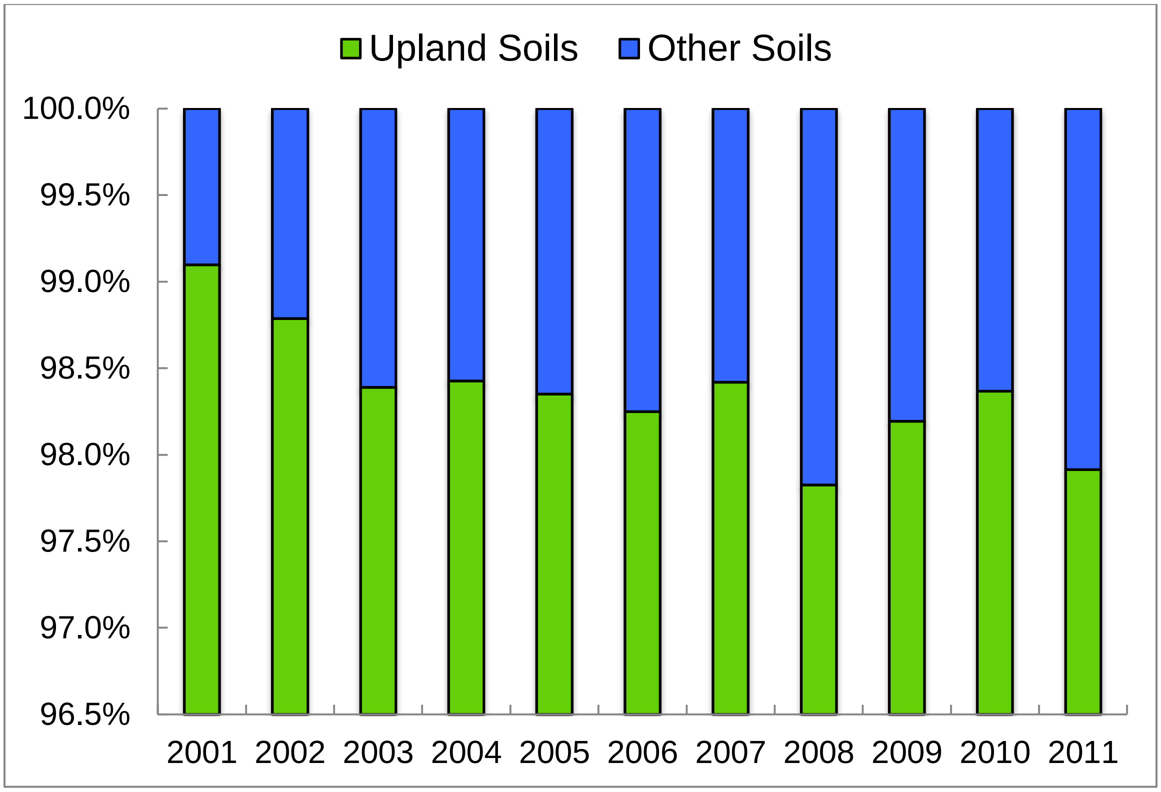

Figure S13. Breakdown of total agriculture on, preferred upland soils and other soil. 99% of agriculture was cultivated on preferred upland soil in 2001. In 2011, 98% of total agriculture was cultivated on upland soil.

d. Results Tables (Logistic Regressions and Transition Matrix)

Cropland Extent

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Minimum Temp.	0.0402*	0.163*	0.132*	0.107*	0.0900*	0.103*	0.0635*	0.0801*	0.0562*	0.0577*	0.0243*
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)
Maximum Temp.	53.63*	17.48*	19.37*	25.19*	29.75*	26.26*	46.76*	35.75*	57.24*	56.97*	94.22*
	(6.42)	(0.40)	(0.43)	(3.29)	(0.57)	(0.50)	(0.99)	(4.19)	(7.07)	(1.16)	(2.41)
Soil Moisture	0.997*	1.000*	1.000*	1.00	1.000*	0.999*	0.999*	0.999*	0.999*	0.999*	0.998*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Precipitation	1.006*	1.010*	1.010*	1.010*	1.010*	1.010*	1.010*	1.010*	1.010*	1.011*	1.008*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Elevation	1.001*	1.002*	1.001*	1.001*	1.001*	1.001*	1.001*	1.001*	1.001*	1.001*	1.001*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Slope	0.169*	0.0863*	0.0853*	0.100*	0.108*	0.113*	0.1000*	0.117*	0.0990*	0.0955*	0.136*
	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Soy Transport Cost	0.949*	0.964*	0.965*	0.969*	0.975*	0.977*	0.978*	0.980*	0.981*	0.983*	0.983*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Upland Soils	29.59*	7.398*	5.541*	5.611*	5.596*	6.010*	5.905*	5.634*	6.106*	6.122*	7.177*
	(11.45)	(0.27)	(0.17)	(0.98)	(0.14)	(0.15)	(0.17)	(0.82)	(0.98)	(0.16)	(0.30)
Indigenous Reserves	0.000878*	0.00138*	0.00106*	0.00167*	0.00199*	0.00407*	0.00202*	0.00493*	0.00457*	0.00560*	0.00710*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Protected Areas	0.0745*	0.0736*	0.0864*	0.116*	0.117*	0.157*	0.114*	0.127*	0.124*	0.125*	0.131*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Area (km^2)	36,015	38,120	42,222	48,505	57,387	55,090	48,722	61,240	60,086	56,341	61,954
Land Reserve (km^2)	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357
Pseudo R^2	0.538	0.515	0.511	0.490	0.475	0.457	0.475	0.452	0.476	0.476	0.462

* $p < 0.001$, Standard errors in parentheses

Table S4. Logistic Regression of Agricultural Extent: 2001 to 2011. Coefficients are reported as Odds Ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

Double Cropping Extent

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Minimum Temp.	0.0402*	0.0823*	0.0137*	0.0444*	0.0495*	0.0276*	0.0267*	0.0315*	0.0247*	0.0216*	0.0243*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Maximum Temp.	53.63*	26.39*	129.6*	38.64*	34.63*	74.49*	74.34*	64.84*	91.51*	107.6*	94.22*
	(6.42)	(1.09)	(18.17)	(1.21)	(1.12)	(2.16)	(2.12)	(9.98)	(14.39)	(18.19)	(2.41)
Soil Moisture	0.997*	0.997*	0.998*	0.999*	1.001*	0.998*	0.999*	0.999*	0.998*	0.998*	0.998*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Precipitatio n	1.006*	1.007*	1.006*	1.007*	0.999*	1.007*	1.008*	1.008*	1.008*	1.009*	1.008*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Elevation	1.001*	1.002*	1.001*	1.001*	1.007*	1.001*	1.001*	1.001*	1.001*	1.001*	1.001*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Slope	0.169*	0.155*	0.141*	0.154*	0.162*	0.154*	0.136*	0.152*	0.125*	0.114*	0.136*
	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)
Soy Transport Cost	0.949*	0.963*	0.966*	0.971*	0.970*	0.976*	0.975*	0.978*	0.982*	0.977*	0.983*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Upland Soils	29.59*	11.15*	6.901*	7.053*	6.769*	8.697*	11.83*	5.888*	11.18*	12.73*	7.177*
	(11.45)	(1.03)	(1.85)	(0.43)	(3.46)	(0.47)	(0.74)	(1.41)	(3.55)	(4.46)	(0.30)
Indigenous Reserves	0.00526 *	0.00398 *	0.00320 *	0.00174 *	0.00174 *	0.00237 *	0.00287 *	0.00523 *	0.00543 *	0.00493 *	0.00887 *
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Protected Areas	0.117*	0.201*	0.259*	0.263*	0.263*	0.334*	0.239*	0.211*	0.208*	0.233*	0.272*
	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)
Area (km^2)	4,911	8,560	11,898	17,022	14,901	20,965	23,342	31,409	32,038	28,759	30,559
Land Reserve (km^2)	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357	903,357
Pseudo R^2	0.369	0.396	0.396	0.393	0.424	0.415	0.342	0.400	0.410	0.431	0.455

* $p < 0.001$, Standard errors in parentheses

Table S5. Logistic Regression of Double Cropping Extent: 2001 to 2011. Coefficients are reported as odds ratios. The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

New Cropland

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Minimum Temp.	0.685***	0.683***	0.637***	0.755***	0.693***	0.724***	0.730***	0.760***	0.763***
	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Maximum Temp.	2.115***	2.234***	2.579***	1.892***	2.259***	2.066***	2.040***	1.985***	2.059***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)	(0.03)	(0.03)	(0.04)	(0.03)
Precipitation	0.997	1.002	0.997	0.965***	0.977***	0.988***	0.992***	0.981***	0.987***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Elevation	1.085***	1.082***	1.080***	1.064***	1.076***	1.072***	1.069***	1.080***	1.082***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soil Moisture	1.027***	1.037***	1.032***	1.076***	1.057***	1.037***	1.069***	1.051***	1.003
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)
Slope	0.814***	0.845***	0.841***	0.860***	0.849***	0.878***	0.854***	0.834***	0.879***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soy Transport Cost	0.960***	0.967***	0.977***	0.983***	0.990***	0.981***	0.989***	0.996***	0.992***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Upland Soils	2.603***	3.198***	3.712***	3.496***	2.945***	2.666***	3.110***	5.126***	3.559***
	(0.11)	(0.13)	(0.14)	(0.15)	(0.19)	(0.09)	(0.14)	(0.33)	(0.15)
Indigenous Reserves	0.00553***	0.0116***	0.0154***	0.0546***	0.0240***	0.0388***	0.0418***	0.0531***	0.0555***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Protected Areas	0.253***	0.248***	0.247***	0.332***	0.136***	0.192***	0.245***	0.269***	0.250***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)
Area (km^2)	6573	9391	10736	6327	2902	8882	6138	3612	6319
Land Reserve (km^2)	859083	854762	847922	839615	837134	841258	838193	834191	837023
Pseudo R^2	0.22	0.202	0.197	0.134	0.14	0.147	0.147	0.147	0.132

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S6. Logistic Regression of New Cropland: 2003 to 2011. Coefficients are reported as odds ratios. The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

New Double Cropping

	2003	2004	2005	2006	2007	2008	2009	2010	2011
Minimum Temp.	0.457^{***}	0.601^{***}	0.622^{***}	0.556^{***}	0.562^{***}	0.636^{***}	0.587^{***}	0.707^{***}	0.609^{***}
	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Maximum Temp.	4.106^{***}	2.610^{***}	2.531^{***}	3.139^{***}	3.102^{***}	2.622^{***}	3.196^{***}	2.468^{***}	2.851^{***}
	(0.07)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)	(0.05)
Precipitation	0.957^{***}	0.982^{***}	0.981^{***}	0.951^{***}	0.979^{***}	0.976^{***}	0.958^{***}	0.951^{***}	0.974^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Elevation	1.068^{***}	1.081^{***}	1.078^{***}	1.081^{***}	1.092^{***}	1.085^{***}	1.083^{***}	1.108^{***}	1.095^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soil Moisture	1.067^{***}	1.090^{***}	1.101^{***}	1.070^{***}	1.061^{***}	1.097^{***}	1.115^{***}	1.130^{***}	1.045^{***}
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Slope	0.790^{***}	0.802^{***}	0.801^{***}	0.807^{***}	0.791^{***}	0.811^{***}	0.797^{***}	0.772^{***}	0.804^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soy Transport Cost	0.943^{***}	0.957^{***}	0.969^{***}	0.965^{***}	0.962^{***}	0.968^{***}	0.981^{***}	0.966^{***}	0.980^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Upland Soils	10.64^{***}	4.600^{***}	5.159^{***}	6.618^{***}	8.729^{***}	3.387^{***}	5.511^{***}	8.374^{***}	4.621^{***}
	(1.13)	(0.31)	(0.44)	(0.42)	(0.70)	(0.15)	(0.32)	(0.76)	(0.27)
Indigenous Reserves	0.00242^{***}	0.00235^{***}	0.00581^{***}	0.00383^{***}	0.00541^{***}	0.0109^{***}	0.0127^{***}	0.0145^{***}	0.0257^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Protected Areas	0.195^{***}	0.232^{***}	0.334^{***}	0.264^{***}	0.145^{***}	0.197^{***}	0.122^{***}	0.162^{***}	0.266^{***}
	(0.03)	(0.03)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Area (km^2)	6172	7758	4312	6054	5092	6987	5009	2143	2809
Land Reserve (km^2)	889240	884532	878649	876838	874298	869570	863406	858788	860841
Pseudo R^2	0.338	0.331	0.287	0.285	0.33	0.283	0.27	0.325	0.249

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S7. Logistic Regression of New Double Cropping: 2003 to 2011. Coefficients are reported as odds ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

Abandoned Cropland

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Minimum Temp.	1.386***	1.450***	1.526***	1.468***	1.387***	1.491***	1.610***	1.557***	1.428***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)
Maximum Temp.	0.548***	0.453***	0.363***	0.405***	0.501***	0.371***	0.329***	0.373***	0.424***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Precipitation	1.044***	1.035***	0.99	1.037***	1.065***	1.050***	1.053***	1.044***	1.037***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Elevation	0.891***	0.905***	0.903***	0.922***	0.942***	0.915***	0.918***	0.919***	0.905***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soil Moisture	1.01	0.978***	0.961***	0.956***	0.962***	0.958***	0.952***	0.955***	1.016***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Slope	1.196***	1.213***	1.179***	1.220***	1.203***	1.195***	1.206***	1.237***	1.207***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Soy Transport Cost	1.013***	1.038***	1.036***	1.024***	1.014***	1.006***	1.016***	1.005***	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Upland Soils	0.218***	0.288***	0.288***	0.414***	0.532***	0.694***	0.752***	0.457***	0.486***
	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.04)	(0.06)	(0.02)	(0.03)
Indigenous Reserves	4.126***	9.368***	7.751***	5.992***	5.072***	20.90***	5.232***	3.756***	4.300***
	(1.54)	(2.91)	(2.33)	(1.36)	(0.86)	(2.73)	(1.03)	(0.50)	(0.59)
Protected Areas	22.49***	7.170***	7.163***	3.417***	2.112***	4.426***	2.270***	2.728***	3.498***
	(4.68)	(1.73)	(1.56)	(0.55)	(0.27)	(0.49)	(0.50)	(0.33)	(0.49)
Area (km^2)	2,420	2,528	2,383	3,820	7,016	5,785	2,101	6,417	4,932
Land Reserve (km^2)	36,015	38,120	42,222	48,505	57,387	55,090	48,722	61,240	60,086
Pseudo R^2	0.198	0.222	0.24	0.202	0.14	0.187	0.171	0.225	0.173

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S8. Logistic Regression of Abandoned Cropland: 2002 to 2010. Coefficients are reported as odds ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

Abandoned Double Cropping

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Minimum Temp.	1.831***	1.781***	1.552***	1.589***	1.587***	1.656***	1.547***	1.564***	1.551***
	(0.04)	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Maximum Temp.	0.363***	0.420***	0.523***	0.453***	0.470***	0.435***	0.465***	0.459***	0.510***
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Precipitation	1.055***	1.049***	1.020***	1.059***	1.048***	1.012***	1.048***	1.047***	1.049***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Elevation	0.974***	0.988***	0.980***	0.961***	0.966***	0.965***	0.983***	0.969***	0.960***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soil Moisture	1.00	1.02	1.00	1.019***	1.046***	1.032***	0.971***	0.973***	1.029***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
Slope	1.084***	1.101***	1.080***	1.108***	1.134***	1.096***	1.094***	1.136***	1.128***
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soy Transport Cost	1.046***	1.033***	1.022***	1.010***	1.023***	1.027***	1.016***	1.008***	1.021***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Upland Soils	0.280*	0.70	0.235***	0.326***	0.382***	0.579***	0.375***	0.294***	0.365***
	(0.14)	(0.13)	(0.05)	(0.05)	(0.06)	(0.07)	(0.05)	(0.02)	(0.03)
Indigenous Reserves	0.79	1	3.163*	4.293*	3.649**	7.517***	1.624	**3.425***	3.047***
	(0.49)	(0.75)	(1.66)	(2.70)	(1.62)	(2.89)	(0.52)	(0.71)	(0.59)
Protected Areas	0.78	0.267***	0.455**	0.389***	0.725	1.431*	1	0.92	0.520***
	(0.34)	(0.09)	(0.11)	(0.08)	(0.14)	(0.20)	(0.22)	(0.13)	(0.10)
Area (km^2)	1,461	2,382	3,287	5,472	3,289	4,231	3,527	6,756	4,932
Land Reserve (km^2)	4,911	8,560	11,898	17,022	14,901	20,965	23,342	31,409	60,086
Pseudo R^2	0.10	0.09	0.05	0.07	0.09	0.09	0.06	0.10	0.09

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S9. Logistic Regression of Abandoned Double Cropping: 2002 to 2010. Coefficients are reported as odds ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

Abandoned Agriculture Cropping: 5-Year Rule

	2002	2003	2004	2005	2006
Minimum Temp.	1.257***	1.106**	1.121***	1.395***	1.03
	(0.05)	(0.04)	(0.03)	(0.10)	(0.02)
Maximum Temp.	0.736***	0.737***	0.788***	0.664***	0.895***
	(0.04)	(0.04)	(0.04)	(0.08)	(0.03)
Precipitation	1.01	1.028**	0.972***	1.04	1.027***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Elevation	0.941***	0.933***	0.938***	0.99	0.967***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Soil Moisture	1.00	0.957**	1.00	1.00	0.973***
	(0.02)	(0.01)	(0.01)	(0.03)	(0.01)
Slope	1.038***	1.089***	1.083***	1.071***	1.077***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Soy Transport Cost	1.014**	1.018***	1.018***	1.02	1.006**
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Upland Soils	0.77	0.90	0.553***	0.234**	0.536***
	(0.18)	(0.14)	(0.07)	(0.12)	(0.06)
Indigenous Reserves	4.62	22.59**	8.202**	.	4.169***
	(3.82)	(23.15)	(6.60)	.	(1.51)
Protected Areas	50.09***	8.335***	3.274***	.	1.770*
	(48.14)	(5.23)	(1.13)	.	(0.45)
Pseudo R^2	0.160	0.153	0.176	0.044	0.050

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S10. Logistic Regression of Abandoned Agriculture using a five-year abandonment rule: 2002 to 2006. Coefficients are reported as odds ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

Abandoned Double Cropping: 5-Year Rule

	2002	2003	2004	2005	2006
Minimum Temp.	1.473***	1.419***	1.379***	1.808***	1.400***
	(0.08)	(0.07)	(0.06)	(0.25)	(0.05)
Maximum Temp.	0.509***	0.526***	0.643***	0.298***	0.600***
	(0.05)	(0.04)	(0.04)	(0.07)	(0.04)
Precipitation	1.093***	1.058***	1.01	1.00	1.024*
	(0.02)	(0.02)	(0.01)	(0.04)	(0.01)
Elevation	0.956***	0.974***	0.986*	0.944**	0.966***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.00)
Soil Moisture	0.915**	0.922***	0.96	1.10	1.00
	(0.03)	(0.02)	(0.02)	(0.06)	(0.02)
Slope	1.095***	1.081***	1.066***	1.04	1.132***
	(0.01)	(0.01)	(0.01)	(0.04)	(0.01)
Soy Transport Cost	1.022*	1.01	1.016*	1.04	1.019***
	(0.01)	(0.01)	(0.01)	(0.03)	(0.00)
Upland Soils	0.25	0.81	0.182***	1.40	0.492*
	(0.27)	(0.35)	(0.09)	(2.06)	(0.17)
Indigenous Reserves	0.40	.	.	.	3.63
	(0.46)	.	.	.	(3.78)
Protected Areas	1.68	0.492	0.332**	.	0.93
	(1.29)	(0.29)	(0.13)	.	(0.44)
Area (km^2)					
Land Reserve (km^2)					
Pseudo R^2	0.113	0.069	0.068	0.099	0.126

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S11. Logistic Regression of Abandoned Double Cropping using a five-year abandonment rule: 2002 to 2006. Coefficients are reported as odds ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

Abandoned Cropland and Double Cropping: 9-Year Rule

	AC_{2002}	ADC_{2002}
Minimum Temp.	1.193**	1.930***
	(0.07)	(0.28)
Maximum Temp.	0.780**	0.350***
	(0.07)	(0.08)
Precipitation	1.01	1.155*
	(0.03)	(0.08)
Elevation	0.98	1.04
	(0.02)	(0.04)
Soil Moisture	0.937***	0.905***
	(0.01)	(0.02)
Slope	1.061***	1.05
	(0.01)	(0.03)
Soy Transport Cost	1.030***	1.061*
	(0.01)	(0.02)
Upland Soils	1.41	0.57
	(0.40)	(0.65)
Indigenous Reserves	.	.
	.	.
Protected Areas	.	.
	.	.
Area (km^2)		
Land Reserve (km^2)		
Pseudo R^2	0.179	0.209

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, Standard errors in parentheses

Table S12. Logistic Regression of Abandoned Agriculture (*AC*) and Abandoned Double Cropping (*ADC*) using a nine-year abandonment rule: 2002. Coefficients are reported as odds ratios (ORs). The ORs presented were normalized to their maximum value (Table S15) to allow for a more reasonable and intuitive comparison across variables. The ORs measure how much more likely the outcome land cover is to be found given a one unit increase in a predictor where all other predictors are at their means. Units for Minimum and Maximum Temperature are degrees Celsius. Units for Soil moisture and precipitation are millimeters, units for soy transportation cost is U.S.D. per ton soybeans, units for elevation are meters, and units for slope are degrees. All 15 soil classes in the state are represented as dummy variable controls. The presence of protected areas and indigenous reserves is indicates with binary variables.

	2-year AC_t	5-year AC_t	9-year AC_t	2-year ADC_t	5-year ADC_t	9-year ADC_t
Maximum Temp.	-*	-*	-*	-*	-*	-*
Minimum Temp.	+*	+*	+	+*	+*	+*
Precipitation	m	m	ns	+*	+	+
Soil Moisture	m	m	-*	m	m	-*
Soy Transport Cost	+	+	+*	+*	+	+
Elevation	-*	-	ns	-*	-*	ns
Slope	+*	+*	+*	+*	+	ns
Upland soils	-*	-*	ns	-	-	-*
Protected areas	+*		+	m	ns	
Indigenous reserves	+*		+*	m	ns	

Table 13. *Correlations and inverse correlations of land attributes and land use with different abandonment rules.* Pluses with asterisks indicate positive correlations ($p < 0.001$) across all years investigated. Pluses without asterisks indicate positive correlations across all years, but with some years statistically insignificant. Minuses indicate negative correlations ($p < 0.001$) across all years. Minuses without asterisks indicate negative correlations across all years, but with some years statistically insignificant. “M”s indicate cases where both negative and positive correlations were observed across the study period. Full results of all of the regressions performed are reported in the SOM.

		2002			2003			2004		
		O	**S**	**D**	**O**	**S**	**D**	**O**	**S**	**D**
2001	**O**	99	1	0	96	3	1	95	4	1
	S	50	39	11	42	44	14	20	57	23
	D	87	8	4	59	20	20	26	32	42
2002	**O**				99	1	0	96	3	1
	S				68	28	4	47	42	11
	D				85	13	3	83	9	8
2003	**O**							98	2	0
	S							41	46	12
	D							80	13	6

		2005			2006			2007			2008			2009			2010			2011		
	D	**O**	**S**	**D**	**O**	**S**	**D**	**O**	**S**	**D**	**O**	**S**	**D**	**O**	**S**	**D**	**O**	**S**	**D**	**O**	**S**	**D**
2001	**O**	96	3	1	98	1	1	98	1	1	96	2	2	98	1	1	99	1	0	97	1	1
	S	15	70	15	21	48	31	22	49	28	9	43	48	22	36	43	22	43	35	14	42	44
	D	19	48	32	20	22	57	14	33	53	5	22	73	10	23	67	15	27	58	7	23	71
2002	**O**	95	5	0	97	2	1	98	1	0	96	3	1	98	1	1	98	1	0	97	2	1
	S	18	74	8	22	54	24	26	52	22	11	54	36	19	41	40	24	56	20	13	51	36
	D	48	37	15	36	26	38	21	35	44	7	32	61	12	21	67	13	40	47	8	24	67
2003	**O**	94	5	0	94	5	1	97	2	0	95	4	2	97	2	1	97	2	0	95	3	1
	S	39	55	6	24	60	17	28	55	17	10	62	29	21	43	37	24	56	20	12	55	33
	D	62	25	13	39	25	36	24	36	40	8	31	61	15	27	58	16	37	47	8	31	61
2004	**O**	97	3	0	97	3	0	98	2	0	95	4	1	96	3	1	97	3	0	96	3	1
	S	28	62	9	40	46	14	33	50	17	14	56	30	21	46	33	26	60	14	16	57	26
	D	67	25	8	49	18	33	27	36	37	11	31	57	18	25	57	20	40	40	11	27	62
2005	**O**				99	1	0	99	1	0	97	2	1	98	2	1	97	2	0	97	2	1
	S				59	31	11	76	18	6	31	52	16	37	42	21	31	58	11	17	60	23
	D				76	9	16	74	14	13	49	20	30	51	16	33	34	37	29	16	28	56
2006	**O**							99	0	0	98	2	0	98	1	0	98	2	0	98	2	1
	S							66	24	10	58	31	11	39	48	14	30	61	9	15	57	28
	D							68	16	16	57	15	28	58	19	22	45	32	23	22	32	46
2007	**O**										99	1	0	99	1	0	99	1	0	99	1	0
	S										52	36	12	72	21	8	42	50	8	33	52	15
	D										66	9	25	80	5	15	60	15	24	29	24	47
2008	**O**													99	0	0	100	0	0	99	1	0
	S													52	28	20	48	35	17	28	55	17
	D													42	20	38	41	25	34	22	27	51
2009	**O**																100	0	0	100	0	0
	S																52	24	24	52	24	24
	D																66	17	17	66	17	17
2010	**O**																			99	1	0
	S																			33	46	21
	D																			49	13	37

Table S14. Transition matrix of Mato Grosso single cropping, double cropping, and other (forest/pasture/savannah) 2001 to 2011. O=other, S=single cropping, and D=double cropping. Rows are source years and columns are destination years. Numbers are percentages. Thus, the cell D,D in row 2010, column 2011 contains the percentage of double cropped land in 2010 that remained in double cropping in 2011.

Variable	Maximum Value
Precipitation (mm)	2767.1

Minimum Temp. (°C)	21.4
Maximum Temp. (°C)	33.4
Slope (Degrees)	12.9
Elevation (m)	1158
Soy Cost (2000 $USD)	195.1
Soil Moisture (mm)	6312

Table S15. Maximum value of each variable used in logistic regression.

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[i] it is common to cultivate cotton, beans, or corn for seed in irrigated areas.