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Remote observations with images from landsat satellites to determine the environmental impact of agrarian reform in the Brazilian Midwest between 2004 and 2014

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Abstract: The Midwest region of Brazil has a high concentration of land and is the primary producer of grains and livestock in the country, activities with a negative impact on environment. Agrarian reform allows redistribution of land and reinforces family agriculture, which is considered to be favorable to environmental protection. The aim of this study was to use field and remote observations to verify the evolution of environmental preservation and land use in rural settlements in the Midwest region of Brazil. 54 settlements distributed in the region were analyzed. We used images from Landsat 5 satellite obtained by the Thematic Mapper sensor in 2004 and images from Landsat 8 satellite from 2014. The NDVI and NDWI vegetation indexes were used to classify urban, agricultural, pasture, savannah and forest areas. Forests declined in all states, however Mato Grosso, the only one with Amazonian forest, where settlements presented lowest compliance with environmental legislation. The evolution indicates the transformation of forest areas into savannah. Settlers predominantly engage in dairy farming, which requires large areas of land and thus exerts significant pressure on the environment. Productive areas are poorly exploited, and better technical assistance could have a significant impact on environmental protection.

Key words: Brazilian Midwest, environmental preservation, geotechnologies, landsat images, rural settlements.

INTRODUCTION

The Midwest region of Brazil is known for its large areas of agricultural production, focused on the production of commodities. According to Hogan et al. (2002), agricultural activities require elimination of areas of native vegetation and introduction of monocultures for commercial use, which causes severe environmental imbalances, especially a reduction of biodiversity; contamination of the natural environment; compaction, erosion and fertility loss of soils; and a reduction of water quality and quantity.

Currently, the Brazilian Midwest is a major producer of commodities and is characterized by farms for large-scale production and extensive livestock farming. Egler (2012) states that this region features the greatest extent of cultivated area and the largest production of agricultural commodities in Brazil.

According to Castro (2014), the expansion of agricultural activities in the region caused damage to the environment, which suggests that these activities could have some difficulties to be sustainable in the future.

In addition to these factors, it is important to remember that the concentration of land

in Brazil is one of the greatest problems from the colonial period in which the *latifundio* predominated over all other production structures. According to Souza & Silva (2012), the 2006 Census of Agriculture shows the aggravation of land concentration in the country, with a Gini Index of 0.872. The Gini index of the Midwest region, 0.91, is higher than the national average (Alves et al. 2012).

By analyzing the land structure in the region, it is possible to observe that 65% of the area of rural properties corresponds to properties of great extension (MDA/ DIEESE 2011). Among the predominant farming activities in the region, soybean production stands out, accounting for 56.5% of the total area harvested in the Midwest, followed by corn and sugarcane production, which account for 27.3 and 7.8% of the total area harvested in the region (IBGE 2013).

By comparing IBGE data from 2006 and 2013, it is possible to observe the substantial growth of areas planted with agricultural commodities, in particular sugarcane, corn, soybeans and cotton, to the detriment of traditional crops such as rice and cassava. In this scenario, the agrarian reform process is highlighted as a method to ensure the redistribution of land and the reproduction of family farming.

According to INCRA (2016), the state with the highest number of settlements in the Midwest is Mato Grosso, with 551 settlements, followed by Goias, with 439, Mato Grosso do Sul, with 204, and the Federal District, with 22.

In terms of area devoted to agrarian reform in the region, the state of Mato Grosso leads, with approximately 6.1 million hectares and 82,952 families settled. Next comes the state of Goias, with 1,124,709 hectares of land for agrarian reform incorporated in 439 settlements, totaling 22,755 settled families (INCRA 2016). The state of Mato Grosso do Sul has approximately 716,000 hectares for agrarian reform, with 27,868 families settled. Finally, the Federal District contains 9,658 hectares for agrarian reform and 957 settled families (INCRA 2016).

According to Alfatin (2007), the role of environmental preservation has been assigned to family farming, although this is still a controversial issue. For this author, the relationship between family agriculture and natural resources is considered positive in terms of its potential to promote ecological sustainability, especially its ability to coexist in harmony with natural ecosystems. On the other hand, when in situations of risk, the need for survival causes small farmers to consume the available resources, which damages the environment (Alfatin 2007, Soares 2001). Vilpoux & Cereda (2014) affirm that many doubts remain about the role of settlers in environmental sustainability. In the settlements of Mato Grosso do Sul, preservation areas continue to be exploited for raising animals or illegal logging, resulting in their degradation over time.

Doubts about the role of agrarian reform in maintaining the environment are becoming increasingly important in the context of land redistribution and the management of environmental resources. Studies that can address these doubts are thus essential. In this sense, the need to collect information about land use and environmental preservation in agrarian reform in the Midwest region is highlighted, since there are little data available. In parallel, the dimensions of the Brazilian Midwest, which is the size of Germany, France and England together, make it difficult to obtain field data.

In this context, Sistemas de Informação Geográfica (SIG) becomes of fundamental importance once it facilitates the understanding and spatialization of quantitative and qualitative data. For decades, the integration of social and territorial information through GIS was exclusively quantitative, and the qualitative

data were neglected, reducing the possibilities of applications in the most diverse areas (Verd & Porcel 2012). The GIS presents an integrated collection of software and data used to visualize and manage information from specific locations (ESRI 2011). It covers all forms of spatial data collection, especially satellite images, which are widely used for monitoring and mapping of areas of interest. The data obtained by remote sensors have been used in several study areas, such as evaluating vegetation cover, studying urban areas and monitoring agricultural and forest areas (Fonji & Taff 2014).

Lillesand & Kiefer (1994) define remote sensing as the science and art of obtaining information about an object, area or phenomenon by analyzing data acquired by a device that is not in direct contact with the object, area or phenomenon that is under investigation.

Remote sensing has become widely used because it enables rapid monitoring and evaluation of important environmental variables and several other factors related to human activities. Through satellite images, it is possible to have a broad view of a region, allowing the analysis of landscape dynamics at different spatial and temporal scales (Shimabukuro et al. 2009, Albuquerque et al. 2014).

According to Paranhos Filho et al. (2003), GIS are ideal for integrating data, information and charts of different natures and scales. Remote sensing and GIS play an important role in the understanding of natural resources. Remote sensing yields a great range of data about the Earth's surface, detecting and recording the image and/or object without direct contact with it. The GIS allows researchers to verify the changes that occurred in the study area through a multitemporal analysis, in other words, through overlaying maps from different periods for the same region of study. These changes may suggest guidelines for the use and occupation of the area (Gillanders et al. 2008, Kindu et al. 2013).

Riva et al. (2017) developed a methodology to map and analyze land degradation in areas of Spain, Greece and Cyprus. Using NDVI in conjunction with Landsat 8 images and digital elevation and terrain models (DEMs / DTMs), they assessed forest and pasture status in the three countries. They identified how forest fires and overgrazing influence the degradation of the land, with recommendations for the development of public policies for the rational use of land.

In view of these considerations, it is natural to question whether remote observation techniques allow for obtaining the necessary information about the use of land and environmental preservation in the settlements of the region, which are composed of small producers and dispersed over a large area. Based on this question, the aim of the present research is to use remote observation to verify the evolution of land occupation and environmental preservation in rural settlements in the states of the Brazilian Midwest.

MATERIALS AND METHODS

This section is subdivided between the methodology used in the field research and the description of the geotechnologies used.

Field research

The research used direct and *in situ* observation. The selection of the settlements was performed through a convenience sample, which seeks to obtain a suitable sample of elements, leaving the selection of the sample units to be executed by the researcher (Malhotra 2001). The adoption of this technique is due to the distances and

isolation of the settlements, in addition to the difficulties of access.

In spite of these difficulties, settlements were selected from different parts of the Midwest, covering the geographic range of each state as much as possible, as shown in Figure 1.

Twenty settlements were visited in the state of Mato Grosso do Sul, 15 in the state of Goias, 17 in the state of Mato Grosso and 2 in the Federal District.

The field research allowed for observing the conservation of forest areas, degraded pastures, the main production and the average size of the plots.

Pasture areas were considered as degraded if there was the presence of invasive plants, exposed soils and small shrubs. The percentage of degraded pasture was calculated by dividing the pasture area with these characteristics by the total pasture area observed in the visited plots.

Conservation of the agricultural area has also been the subject of research. The criterion used was the existence of crop rotation and the presence of level curves in the plots.

Geotechnologies used

The images used to identify the soil cover were from the Landsat Program (Land Remote Sensing Satellite). To perform the multitemporal analysis in a period of 10 years, we chose to obtain images from the Landsat 5 satellite obtained using the TM sensor (Thematic Mapper) in 2004 and images from the Landsat 8 satellite obtained using the OLI (Operational Land Imager) in 2014.

In the field data collection phase, the coordinates of field control points were collected using the application Mobile Topographer V. 7.2.0 (STGRDEV Android Developer 2014), which employs a Sistema Global de Navegação por Satélite (GNSS) on a mobile phone.

Based on the geodetic coordinates of each settlement, it was possible to identify the orbit/point of the image to be used. The Landsat 8 (OLI) satellite images were obtained from the Pesquisa Geológica dos Estados Unidos (USGS) website, totaling 27 scenes. The images from the Landsat 5 (TM) satellite were obtained from the INPE website (Instituto Brasileiro de Pesquisa Espacial), for a total of 27 scenes.

To download the images, the period between June and October was established, due to the

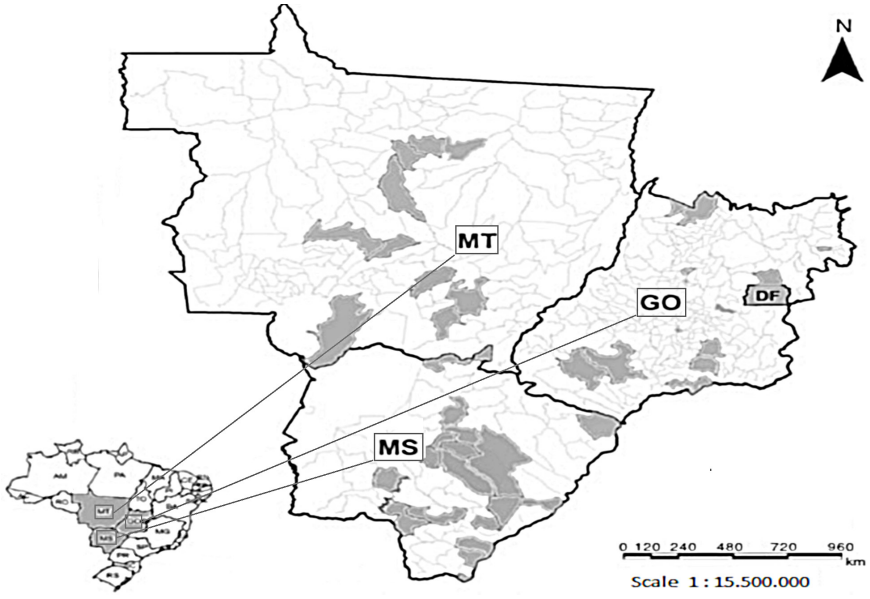

Figure 1. Municipalities of settlements surveyed in the Brazilian Midwest.

low influence of clouds during this period (dry season), which is the period of greatest contrast between the phytophysiognomies that exist in the biomes of the region.

After this step, the composition of the images was performed using the free and open-source software QGis 2.8 Wien (QGIS Development Team 2015). Through the union of bands 1 through 7, the image was saved in a single file in .GEOTIFF format, thus making it possible to visualize the image using the colors characteristic of each spectral band.

Landsat 8 satellite images are available for georeferenced download. It was necessary to perform the atmospheric correction using the Geosud Toa Reflectance plug-in available in the QGis 2.8 Wien software package. For the Landsat 5 satellite images, the atmospheric correction was performed using the Atmospheric Correction plug-in of the Geomatics Focus software package (PCI 2003). The images were sequentially georeferenced using the OrthoEngine module of the Geomatics Focus software (PCI 2003). A total of 100 homogeneously distributed control points were collected in each image using a Landsat 8 image of the same orbit/point, with correction error always below one pixel (equivalent to 30 meters).

Then, the areas of each of selected settlement were identified and delimited. This step was performed with the help of Google Earth software (GOOGLE 2015) and with the maps provided by the official rural technical assistance agencies (INCRA, EMPAER, AGRAER, EMATER).

After the stage of identification and delimitation of the settlements, the Índice de Vegetação por Diferença Normalizada (NDVI), which was developed by Rouse et al. (1974), and the Índice de Água por Diferença Normalizada (NDWI), which was proposed by Hardisky et al. (1983) and Gao (1996) to measure areas for agriculture, livestock and environmental preservation, were applied.

The NDVI is the ratio of the difference between the near-infrared band and the visible red band to the sum of the near-infrared and visible red bands, according to Equation (1).

$$\text{NDVI} = \frac{\rho NIB - \rho V}{\rho NIB + \rho V} \quad [1]$$

$\rho\, NIB$ = Near Infrared Band

ρV = Visible Red Band

NDWI is the ratio of the difference between the near infrared band and the medium infrared band, and the near infrared sum to the medium infrared bands, according to Equation (2).

$$\text{NDWI} = \frac{\rho NIB - \rho MIB}{\rho NIB + \rho MIB} \quad [2]$$

$\rho\, NIB$= Near Infrared Band

$\rho\, MIB$= Medium Infrared Band

For the NDVI, the classes of interest were reclassified according to the values obtained from the vegetation cover samples in each study area.

Previous studies (Jackson et al. 2004, Chen et al. 2005, Sahu 2014) proved to be of great importance for correlating the results obtained by the two indices (NDVI and NDWI) in agricultural and forest areas, where there is a possibility of quantifying chlorophyll and moisture in the vegetation cover. Therefore, the NDVI and NDWI indexes were correlated using the Pearson correlation coefficient (Johnson & Bhattacharyya 2000) in the areas corresponding to each settlement to identify and estimate the agricultural areas, the areas dedicated to pastures and the areas of environmental preservation.

Figure 2 illustrates the type of results obtained through the NDWI and NDVI calculations for the years 2004 (a and c) and 2014 (b and d), respectively, for the area of a settlement.

Based on the results obtained by reclassifying the NDVI, it was possible to measure

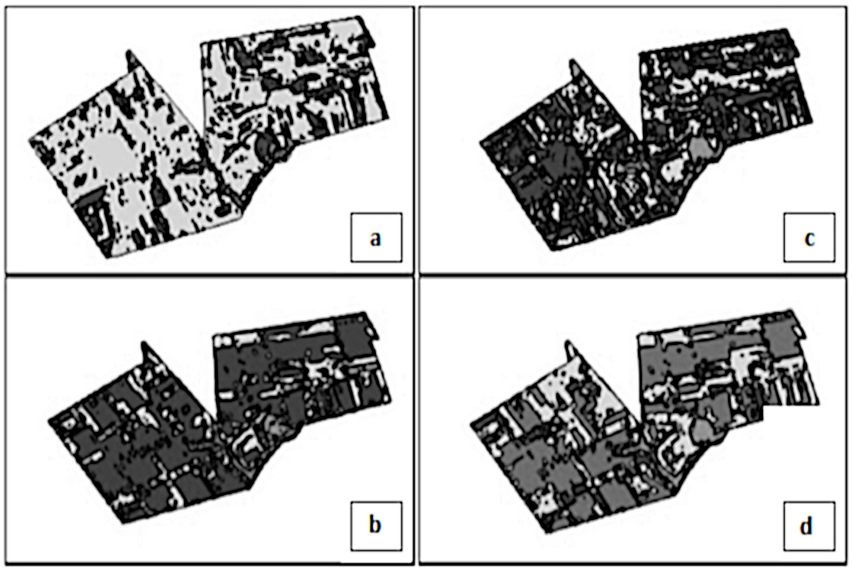

Figure 2. NDWI/NDVI spatial distribution for the years 2004 (a and c) and 2014 (b and d) in a settlement in the state of Mato Grosso do Sul.

the percentage corresponding to each interest class. The results of the NDWI calculation were used to evaluate the environmental quality to complement the results obtained based on the NDVI.

Four classes of interest were established: agricultural (referring to cultivated and cultivable areas), pasture, savannah (where there is a predominance of shrub vegetation typical of the Cerrado biome) and forest (corresponding to areas covered with higher vegetation). Forest and savannah correspond to the areas of environmental preservation. Savannah may also represent areas of poorly tended pasture, with a high presence of small trees.

RESULTS AND DISCUSSION

To facilitate the analysis, the results were divided between evolution of the areas of environmental preservation and areas for use in agriculture and livestock.

Evolution of environmental preservation areas

Table I presents the results for the environmental preservation areas obtained for the years 2004 and 2014 in the 54 settlements surveyed. The table presents the average percentage and the standard error of the classes savannah and forest, according to the ANOVA.

When comparing the average percentage value of the savannah and forest classes, it is possible to verify that no significant differences were found between the states. This means that the profiles of the savannah and forest areas in the settlements visited are similar in all of the Midwest states.

Even if the differences were not significant, it is possible to observe that the settlements in the State of Mato Grosso have a higher average percentage of areas destined to forests. This because the state has 54% of its territory located in the Amazon biome, where the areas of environmental preservation must be at least 80% of the rural property area, against 20% in the other biomes.

When considering the evolution in the period, it is possible to observe a reduction of 46% in the forest areas of the state of Goias, significantly more than the 3% reduction in the savannah areas. This means that a lot of forest areas have been suppressed in the settlements of this state and that new production areas such

Table I. Mean percentages of savannah and forest areas for the settlements of the states in the Midwest region in 2004 and 2014, with the standard error for each class.

States	2004		2014	
	Savannah	Forest	Savannah	Forest
Mato Grosso do Sul	24.09 [a] ± 6.26	23.73 [a] ± 8.02	26.86 [a] ± 6.90	17.24 [a] ± 7.32
Mato Grosso	23.66 [a] ± 7.30	41.32 [a] ±11.99	31.79 [a] ± 7.86	27.58 [a] ± 9.51
Goias	34.40 [a] ± 5.36	32.67 [a] ±11.80	33.31 [a] ± 5.18	17.62 [a] ± 5.64

The same lowercase letters within a column do not differ statistically at the 5% level of significance according to Tukey's test.

as agricultural and pasture areas have been opened.

On the other hand, the reduction in forest areas was 33%, which is a very high number. In contrast, the savannah areas in this state increased by 34%, which indicates the replacement of forest areas with savannah areas but not with producing areas.

The state of Mato Grosso do Sul also exhibits a large reduction in forest areas, registering a loss of 27%. In parallel, the savannah area exhibited a small oscillation in the period, with an increase of 11%, a positive variation but lower than the decrease in forest areas. This indicates the transformation of forest areas into both savannah and agricultural or pasture areas.

In most of the settlements visited, it was possible to observe the presence of degraded and dirty pastures, which had small shrubs that may have been confused with savannah, thus influencing the percentage obtained for this class. Forest areas can be classified as always being part of the environmental reserve, whereas savannah areas may include environmental reserve areas and unclean pastures, with no possibility of differentiation via remote observation. Thus, the evolution of environmental preservation in the settlements was performed considering only the forest areas and joining the forest and savannah areas. The real preservation area can be considered as being between these two results.

Figure 3 shows the percentage of settlements by state that meet the minimum preservation area required by law, considering only the forest areas or the forest and savannah areas, for the years 2004 and 2014. The percentage considered was 80% in the Amazonian biome, which in the Brazilian Midwest is encountered only in the state of Mato Grosso, while it is 20% in the other biomes.

When only the forest areas are considered, Figure 3 shows that Mato Grosso do Sul and Goias are the states with the highest percentage of settlements that comply with environmental legislation in the periods analyzed. However, it is possible to identify a reduction of over 20% of settlements that comply with the legislation in these states. Mato Grosso exhibits a lower percentage of reduction in the number of settlements that comply with the legislation only considering the forest areas, but with initial and final percentages that are lower than the other states, which confirms the damage to the forest areas in this state.

When considering the areas of forest and savannah, 100% of the settlements of the state of Goias comply the legislation in the two periods analyzed. The state of Mato Grosso do Sul exhibits a reduction of 5% in the period, but with the permanence of most of the settlements within the limits of the law.

Mato Grosso is the state in which settlements least comply with legislation. Between 2004 and

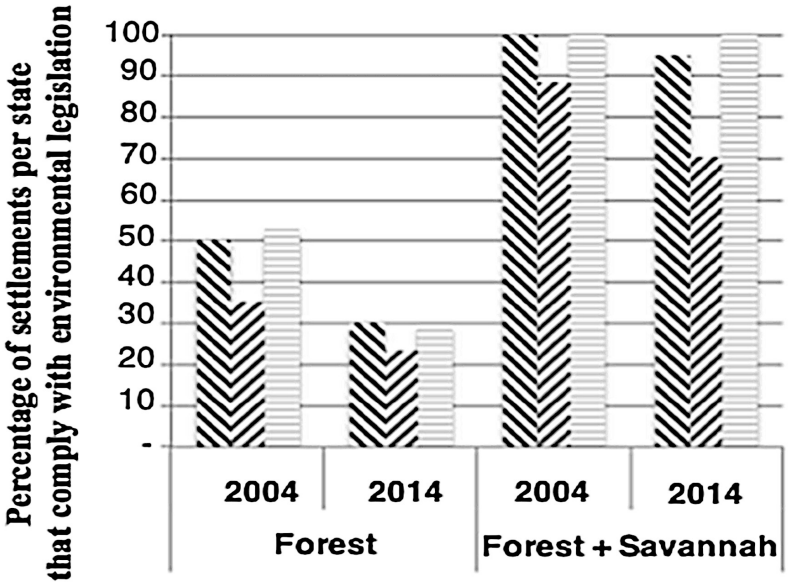

Figure 3. Percentage of settlements per state that comply with environmental legislation, in 2004 and 2014, considering only the forest area or the forest and savannah areas.

2014, the state exhibited a 20% reduction in settlements that comply with the legislation. Part of the forest areas of these settlements suffered from deforestation and was transformed into a savannah area, as indicated in Table I.

With the field observations, it was possible to verify the state and format of the existing reserves in the settlements in 2014. In 23.5% of the collective reserves in Goias, 30% in Mato Grosso do Sul and 41% in Mato Grosso, there were traces of grazing livestock management inside the reserves. The fact that the state of Goias exhibits a higher percentage of reserves with little presence of animals reinforces that it is the state with the largest amount of settlements within the limits of the law.

The reduction in the areas of environmental protection has a direct impact on the agricultural and pasture areas and is analyzed in the following section.

Evolution of agricultural and pasture areas by state

Table II presents the results regarding the evolution of agricultural and pasture areas for the period between 2004 and 2014. The analysis includes the average percentage and the standard error of the classes.

When analyzing the agricultural and pasture areas for the year 2004, it is possible to verify the existence of significant differences in the agricultural class. The average percentage value obtained for the state of Mato Grosso do Sul is statistically different from that of the state of Goias. When observing the average percentages for the year 2014, there are no more significant differences, with greater homogeneity among the settlements of the different states.

When comparing the 2004 and 2014 results, it is possible to observe the expansion of pasture areas to the detriment of the agricultural areas, both in Mato Grosso and Mato Grosso do Sul. The main activity of the settlers in the Midwest is based on livestock, essentially for milk production.

The settlements of Goias were the only ones with growth in the agricultural area. However, in 2004, the settlements of this state had much less agricultural area, and in 2014, they only eliminated that difference with the settlements of the other states. The strong growth of agricultural and pasture areas in the

settlements of the state of Goias originated from deforestation, with a strong reduction in the forest areas, as identified in Table I.

The data in Table II also indicate growth of livestock in all of the states, with transformation in pastures of areas originating from agricultural areas but primarily from forests.

To complement the evolution of the producers' activities in the settlements, Table III presents the average size of the area used in the individual plots, in hectares, for the years 2004 and 2014, in addition to the evolution percentage during the period.

To obtain the average size of the plots, the total of agricultural and pasture areas evaluated in the image analysis divided by the number of families inhabiting the settlements was computed.

The state of Goias is the one with the highest gain of production area per settler in the period. The evolution of the production areas in this state is close to the proportion of reduction of forest areas, as highlighted in Table I, which confirms the occurrence of deforestation. Despite the reduction obtained in the environmental preservation areas, Goias presents the highest percentage of settlements that meets environmental legislation when considering forest and savannah areas.

Mato Grosso exhibits the smallest area used by settlers. The evolution presented in the state indicates that the increase in production areas occurred through a reduction of forest areas, especially in the Amazonian biome, where areas of dense forests, characteristic of this biome, transitioned mainly into areas with savannah

Table II. Mean values in percentage of the agricultural and pasture areas for the settlements of the states in the Brazilian Midwest, in 2004 and 2014, with the standard error of each class.

States	2004		2014		Evolution (%)	
	Agriculture	Pasture	Agriculture	Pasture	Agriculture	Pasture
Mato Grosso do Sul	15.46 ^{a} ± 4.30	38.88^{a} ± 9.10	14.48 ^{a} ± 5.54	42.30 ^{a} ± 5.49	- 6.33	8.8
Mato Grosso	12.23 ^{ab} ± 4.36	24.54^{a} ± 7.48	10.61 ^{a} ± 7.09	32.82 ^{a} ± 8.16	-13.3	33.7
Goias	5.89^{b} ± 2.59	26.25^{a} ± 7.87	10.71 ^{a} ± 4.77	38.01 ^{a} ± 5.16	81.8	44.8

The same lowercase letters within a column do not differ statistically at the 5% level of significance according to Tukey's test.

Table III. Average size used for agricultural and livestock production in the plots of settlements in the Midwest region, in 2004 and 2014 by state.

States	Plots (ha)		Evolution 2004/2014 (%)
	2004	2014	
Mato Grosso do Sul	23.8	26.9	13.0
Mato Grosso	12	15.6	30.0
Goias	13.2	19.9	50.8

vegetation, although a smaller part have also been transformed in productive areas.

The settlements of Mato Grosso do Sul are those where there was lower growth in the productive area, which is explained by the greater size of the areas used in this state.

Figure 4 shows the average areas effectively used for agriculture and livestock in 2004 and 2014.

The savannah may include areas of environmental reserve and unclean pasture, with no possibility of differentiation, which influences the pasture areas presented in Figure 4. However, the areas of unclean pastures are little explored by settlers and can be disregarded in the analysis of the areas used for production.

The results confirm the homogeneity of the agricultural areas in 2014, with an average area of 4 to 5 hectares in the settlements of the 3 states of the region. In the case of pastures, despite the similar percentages, there is a large difference in the number of hectares used, a difference that has been maintained over the last 10 years. These results are worrying, since they mean that the settlements in the states of Goias and Mato Grosso, which have much smaller areas than the settlements of Mato Grosso do Sul, will be able to expand their pasture areas in the coming years, thus increasing deforestation.

From the field research, it was possible to observe the practice of polyculture, with the production of cassava, corn, beans, fruits and vegetables for subsistence and the local market. These agricultural activities differ from the activities of large producers who specialize in a few large crops, such as soybean, corn, cotton and sugarcane. In the case of pastures, dairy farming stands out as the main activity in most of the settlements, in contrast to the large producers, for which beef cattle dominate.

The conservation of the agricultural area (crop rotation and contour lines) and the percentage of degraded pastures were also objects of observation in the field research. Mato Grosso do Sul and Goias exhibited larger conserved agricultural areas, with 47% and 40%, respectively. The state of Mato Grosso presented the highest percentage of degraded pasture (42%), followed by the states of Goias and Mato Grosso do Sul with 22% and 11%, respectively. The high degradation of pastures and the lack of conservation of agricultural areas further increase the pressure on environmental reserves in Mato Grosso.

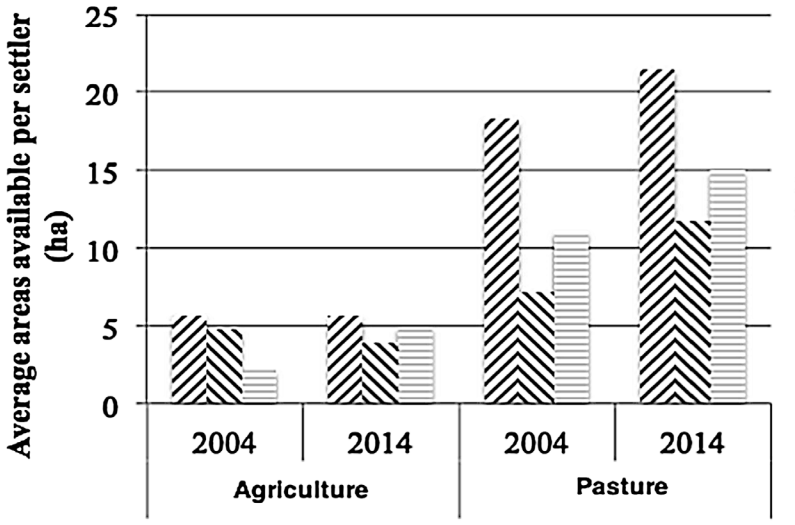

Figure 4. Average areas in hectares of agriculture and pasture available to settlers in 2004 and 2014 by state.

CONCLUSIONS

The research confirms the possibility of using remote observation to analyze environmental preservation and land use in settlements of agrarian reform in a very large territory that is difficult to access, such as the Brazilian Midwest.

The results indicated that the agrarian reform in the Brazilian Midwest region has a negative impact on environmental preservation, as evidenced by the reduction in these areas in all of the states of the region. However, the analysis revealed that most of the time, the settlements remain within the limits of environmental legislation. Mato Grosso, the only state in the Midwest with an Amazonian biome, is the state where settlements least comply with legislation. In this state, the increase in production areas occurred through the reduction of forest, which gave way to areas with vegetation similar to savannah and production areas.

The settlements of the state of Goias exhibited strong growth, both in agricultural areas and pastures, with great reductions in forest areas, which indicates the existence of deforestation in this state. Even with the opening of new areas, the settlements of this state continue to meet the minimum percentages established by law.

The state of Mato Grosso is the state with the smallest area that can be used by the settlers. However, it is also the state in which settlements have the highest percentage of degraded pastures and non-conserved agricultural areas, which indicates that increasing the size of the plots is not an efficient solution; rather, more efficient use of areas already in production should be considered first.

This study enabled us to identify that most settlements continue to use the same production practices over time, conducting their activities with small-scale production, with the predominant presence of dairy farming and polyculture.

Lack of supervision to prevent animal husbandry in environmental reserves and poor efficiency of producers, as characterized by the high percentage of depleted pastures and poorly conserved agricultural areas, are problems that can undermine the environmental sustainability of these settlements in the long term. Thus, providing quality technical assistance and an efficient monitoring system could prevent environmental degradation, not only in forest but also in pasture and agriculture areas.

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Alencar Garcia Bacarji conducted the study collecting the observations in the field, performing the image processing, generating the multitemporal analysis for the results and discussion of the study. Olivier François Vilpoux responsible for the settlement research project, funded by CNPq and which gave rise to the research. Specialist in settlements in Brazil and participated in the analysis of data on the evolution of the occupation of plots and forest reserves. Antonio Conceição Paranhos Filho, a specialist in geotechnologies applied to the environment, co-supervised the research, guiding the processing of images and the use of the adopted geotechnologies, in addition to contributing to the results and discussion of the study.