MONITORING THE PIONEER FRONTIER AND AGRICULTURAL INTENSIFICATION IN MATO GROSSO USING SPOT VEGETATION IMAGES

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Résumé

La production de soja a augmenté de manière considérable les dix dernières années au Mato Grosso, atteignant 17,9millions de tonnes en 2009 (contre 7,2 en 1998). Une telle expansion a eu de graves conséquences environnementales et socio-économiques, telles que la déforestation et l'urbanisation. L'objectif de cet article est de mettre en avant l'efficacité des techniques de télédétection et des indices qui en découlent, tels que le NDVI, pour analyser l'avancée des champs de soja au Mato Grosso ainsi que la transformation de l'agriculture dans cet État. L'indice NDVI a été calculé à partir de séries mensuelles du capteur SPOT-Vegetation. Il a permis de trouver les zones cultivées et de surveiller la croissance des cultures. Il a aussi permis la détection des pratiques de gestion de double culture, qui se sont drastiquement accrues depuis quelques années. Les résultats ont montré une corrélation de 0,98 entre notre estimation des zones cultivées et les statistiques agricoles officielles de l'IBGE pour l'intégralité du Mato Grosso. Les séries temporelles de NDVI ont également confirmé l'augmentation des systèmes de double culture, représentant 30% des zones cultivées en 1999, 57% en 2006 et 67% en 2009. Cette évolution est un indicateur de la diversification de l'agriculture et de l'intensification des traitements dans cette région. En outre, la surveillance des grandes clairières récentes au niveau local (comté de Vera) a montré une réduction de l'écart entre trois états consécutifs conduisant à l'intensification des pratiques agricoles. En se fondant sur notre méthodologie, nous avons finalement proposé une classification des municipalités selon leurs modes d'usages du sol dominants.

Mots clés : Télédétection, NDVI, agro-business, Déforestation, Amazonie, front pionnier.

Abstract

Mato Grosso's soybean production has considerably increased in the last ten years reaching 17.9 millions of tons in 2009 (7.2 in 1998). This expansion has led to severe environmental and socio-economical consequences such as deforestation and urbanization. The objective of this study is to assess the efficiency of remote sensing techniques such as NDVI for analyzing the extent of soybean fields in Mato Grosso and the transformation of agriculture in this State. The NDVI was computed from the SPOT-Vegetation sensor on monthly time series (maximum value composition at a 1 km spatial resolution). It enabled locating cultivated areas and monitoring crop growth. It also allowed the detection of the double cropping management practices, which increased drastically in this area for a few years. The results showed a correlation of 0.98 between our estimation of crop areas and IBGE official agricultural statistics for the whole of Mato Grosso. The NDVI time series also confirmed the increase of double cropping systems representing 30% of the cultivated areas in 1999, 57% in 2006 and 67% in 2009. This evolution is an indicator of the agricultural diversification and intensification processes occurring in this region. Moreover, the monitoring of recent large clearings at a local scale (county of Vera) showed a gap reduction between the three successive stages leading to intensified agricultural practices, i.e. forest clearing, first crop plantation and first adoption of double cropping practices. Based on our methodology, we finally proposed a classification of municipalities according to their dominant modes of land use.

Keywords : *Remote Sensing, NDVI, agro-business, Deforestation, Amazonia, pioneer frontier.*

1. Introduction

The Southern Amazon has experienced a tremendous pioneer surge since the 1970s (Dubreuil, 2002; Le Tourneau, 2004). This spatial dynamic was can be explained by a large migration process by settlers mainly coming from southern Brazil (Rivière d'Arc, 1977; Nédélec, 2005): the population of the Brazilian Amazon increased from 2 to 20 million inhabitants from

1900 to 2000. Since the 1990s, soybean has been a predominant driver of colonization, especially in the states of Central Western Brazil. The state of Mato Grosso is now the leading producer in Brazil: in 2009, 5.8 million hectares were planted accounting for 31% (i.e. 17.9 million tons) of Brazilian soybean production (IBGE, 2011). Whereas most of the production is concentrated in two main production centers located in the Chapada dos Parecis and along the BR 163 highway linking Santarem to Cuiaba, soybean areas are still expanding currently reaching northern areas historically dedicated to timber production (Dubreuil et al., 2008). Therefore the objective of this study is to assess the potential of NDVI images from SPOT Vegetation instrument for monitoring soybean areas as well as secondary crops (including corn) that are cultivated after the main harvest.

In order to analyze the land-use/land-cover evolution related to agricultural practices in a vast study area such as the State of Mato Grosso (907,000 square kilometers), remote sensing appears to be the most appropriate tool. Many vegetation indices combining the red and near infrared channels such as NDVI (Normalized Difference Vegetation Index) have shown to be useful tools for the study of vegetation and crops such as soybeans (Motta et al., 2003). The NDVI time series allow temporal monitoring of plant growth, which is both an indicator of crop yield and of climatic conditions (Lupo et al., 2001; Gurgel and Ferreira, 2003). Thus, we determined how the monthly NDVI time series derived from SPOT-Vegetation (1 km spatial resolution) can be used for mapping the spatio-temporal dynamics of agricultural practices (Carreiras et al., 2003). After a comprehensive approach for the entire state of Mato Grosso, we proposed a classification of municipalities according to the type of dominant land use and crop intensification.

2. Overview of the study area and methodology

2.1. Crops and Deforestation in Mato Grosso

Mato Grosso has become a "breadbasket" of the world thanks to a tremendous growth in cultivated areas during the last 20 years. Data provided by IBGE (2011) clearly shows the increasing importance of soybean cultivation since 1990 (Bertrand, 2004). Production increased from 3 million of tons in 1990 to 17.7 million tons in 2005. This 600% increase can be explained by a sharp increase in soybean demand but also by increasing agricultural productivity, fostered by the efforts of Brazilian research. All major crops in the State have increased significantly ($\times$ 2 for rice, $\times$ 3 for sugarcane, $\times$ 4 for corn, $\times$ 11 for cotton), illustrating the dynamism of mechanized agriculture in the region.

This situation has led to some regionalization of different crops. The mechanized cultivation of soy RP is located mainly on the flat areas of north-central Mato Grosso, along the BR163 (around Sorriso, the main county producing soybeans in Brazil), and plateau of Chapada dos Parecis to the west. The corn crop, sown as a second harvest (safrinha) after soybean (safra), has developed logically in the same municipalities as soybeans. This is also the case of cotton, which is most often grown as a main crop and sometimes as the second crop after soybeans. The difference, however, is that cotton has emerged in regions (Campo Novo dos Parecis and Primavera do Leste) where farms are larger, because of newer and less organized colonization processes compared to that to be found along the BR163, and thus having more capital to invest in this activity. Sugar cane is also mostly located in the Chapada dos Parecis.

The expansion of these crops has mainly taken place upon cerrados (Brazilian savannah) and transition forest (Cardille and Foley, 2003). Thus, data from PRODES (INPE, 2011) shows that Mato Grosso has been regularly pointed out as the main Brazilian state for deforestation: in recent years, the cleared areas ranged from 4,333 km^2 in 2006 to 11,814 km^2 in 2004, the record year. A sharp decline in cleared areas has been be observed for three years, probably related to lower soybean prices and the impact of conservation policies (Arvor et al., 2012).

Monitoring the expansion of deforestation is now well known thanks to the PRODES and DETER programs from INPE. Meanwhile, some States such as Mato Grosso have developed their own deforestation monitoring program (SEMA): work is generally carried out using images with high spatial resolution (Landsat, CBERS), most recently with medium-resolution MODIS data (Brow et al., 2007; Lima et al., 2007). Global studies are also carried out using low-resolution imagery (NOAA, SPOT-Vegetation) within the frame of planetary land use changes programs (LUCC, (Lambin et al., 2003)). Our purpose in this paper is to test a simple tool for monitoring the development of land under cultivation using the low spatial resolution SPOT-Vegetation data.

2.2. Contribution of SPOT-Vegetation data

SPOT is a satellite designed by the French CNES (Centre National d'Etudes Spatiales) as part of the SPOT program (System for Earth Observation). In 1998, a Vegetation instrument was installed onboard SPOT-4 under the Vegetation program led by France, the European Union, Sweden, Belgium and Italy: the objective was to provide specific measure characteristics of canopies from regional to global scale in order to promote research on agriculture, deforestation and the monitoring of natural resources (Gallego, 1999; Eerens et al., 2000; Bartalev et al., 2003; Han et al., 2004). To meet these objectives, the resolution of the instrument vegetation was set at one kilometer (1,165 m) to cover a width of 2,000 km

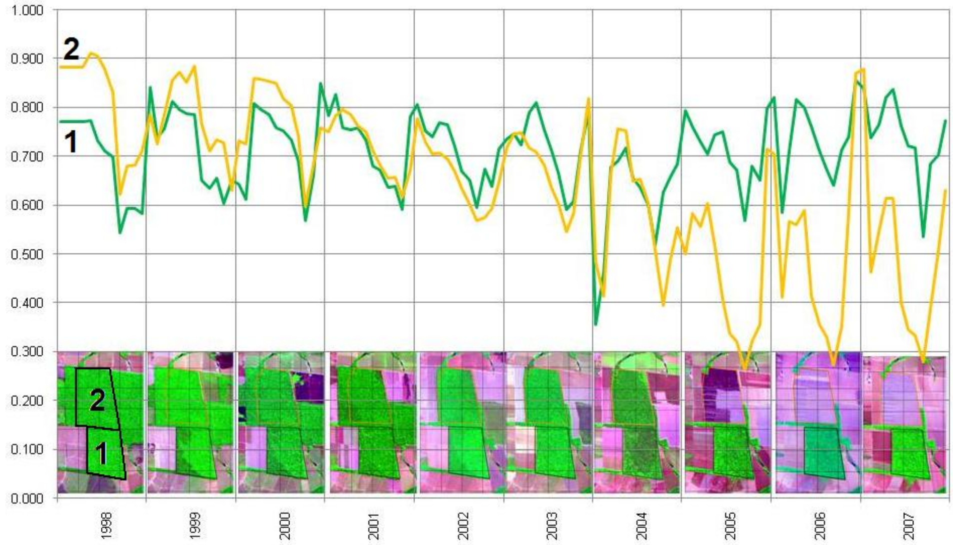


Figure 1 : Above: Profiles of SPOT-Vegetation NDVI for two parcels located south of Vera MT. **(1)** Plot in forest (300 hectares); **(2)** Plot cleared in 2004-2005 (500 hectares). **Below:** Images from Landsat scenes (5x7 km) for each dry season showing the evolution of land use (colored compositions 3,4,5).

every day. This tool produces images in four spectral bands:

- blue (0.43 - 0.47 μm)
- red (0.61 - 0.68 μm)
- near infrared (0.78 - 0.89 μm)
- mid-infrared (1.58 - 1.75 μm)

This satellite is a low sun-synchronous polar orbital satellite at 820 km altitude and its orbital inclination is 98.7^o (SPOT, 2011). The spatial resolution is consistent with the average size of fields and farms in the soybean-growing regions of Mato Grosso, the former often having an area ranging from 100 to 300 hectares and over a few thousand hectares for the latter.

The data used for this study was the corresponding decadal synthesis S10 which is computed through the "Maximum Value Composite" method on 10-day periods of NDVI (Vancutsem et al., 2007). However, due to the abundance of cloud cover during the rainy season in Mato Grosso (November-March), decadal syntheses were noisy so therefore we processed monthly synthesis. The period covered by this study thus extends from April 1998 to September 2009, i.e. eleven complete crop cycles.

Figure 1 compares the NDVI time series of a forest plot and a plot cleared and converted into an arable plot. In the first plot (300 hectares) NDVI values remain high (usually between 0.6 and 0.8) with a low seasonal contrast. The second plot (approximately 500 hectares) shows that we are dealing with a forest cover with a profile very similar to that of the NDVI of Plot1 from 1998 to early 2004; during the 2004 dry season, the NDVI is far lower revealing a clearing process confirmed by the profile in 2005 and the Landsat image of the following year. After 2006, Plot 2 moved to an agricultural parcel with a marked peak in January (probably rice), a secondary regrowth in April-May and bare soil during the dry season (NDVI amplitude between the earlier peak and minimum dry season more than 0.4). It is noteworthy that the second peak is slightly marked which means that we are not in the presence of a true second culture but simply a post-harvest spontaneous regrowth. Also note that in January and February 2004, the NDVI values are abnormally low due to heavy cloud coverage impeding the detection of crops during this season.

2.3. Methodology

The method used in this study can be summarized by the following three steps:

1. Production of monthly synthesis of NDVI over the entire period 1998-2009 from decadal syntheses S10.
2. Discrimination of cultivated surfaces when the NDVI values observed the following conditions: the difference between the maximum value observed from December to February and the value of July is greater than twice the average spread over the entire season. The choice of the maximum value from December to February is due to the fact that the peak of NDVI can be observed more or less early in the season depending from years and regions; this also helps to smooth the residual presence of clouds on monthly synthesis. The choice of July rather than August for the minimum value is

to better discriminate the real bare soil after pasture crops, whose NDVI remains somewhat higher, in the first part of the dry season.

3. The double-cropping regions are, among those who have been discriminated in the previous step, those with maximum NDVI over the period of April-May above the threshold of 0.7. Again, the choice of a period of two months is to better reflect the regional variability of NDVI profiles associated with the second crop: the threshold of 0.7 is high enough to discriminate between secondary regrowth, which does not correspond to real cultures. However, it is not possible in this case to distinguish a true second commercial crop (corn, cotton) from a non-commercial crop cover (such as millet, for example) used to protect soil during the dry season.

The choice of these thresholds was validated using two methods on different scales:. Firstly, farm scale for which data of land use types were available for several years. Figure 2 shows, for two farms, the crossing of the data derived from SPOT-VGT and the real data and shows a satisfactory adaptation of the method (over 80% of well classified plots). A second test was performed at municipality level by comparing the surface data provided by IBGE and those estimated by our method. On this scale, connections are excellent with a correlation up to 0.98 (Figure 3).

3. Results and discussion

3.1. Expansion of croplands in Mato Grosso

Figure 4 illustrates the evolution of cultivated lands in Mato Grosso from 1999 to 2009. The sharp expansion of these areas until 2003 from the "historical" counties of the three main regions is noticeable: Campo Verde, Primavera do Leste in the south, Lucas do Rio Verde, Sorriso, in the center of the State, and Campo Novo dos Parecis, Sapezal to the west. From 2006, a fourth pole appears around Querencia, in the east; its development also seems to continue until 2009 whereas some stagnation appears in the other regions. Although it was initially restricted to the cerrados, the expansion of soybeans is nowadays obviously located in forested counties: Tapurah, Vera, Nova Ubirata or Querencia.

The comparison between IBGE and SPOT-Vegetation data shows the relevant contribution of low resolution remote sensing images for monitoring agricultural dynamics on a regional scale. Indeed, the annual curve of surfaces estimated by SPOT-Vegetation is very close to that of the IBGE (Figure 5): the correlation reaches 0.98 for the 11 annual values if we take all crops grown in soy and cotton (the latter crop is usually grown as main crop and its area is less than 10% of the soybeans in Mato Grosso during the entire period). The difference between the SPOT-Vegetation data and

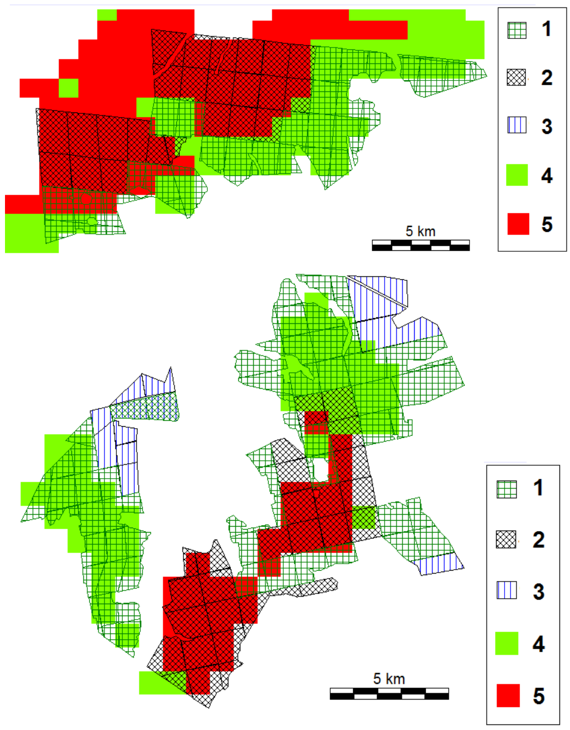


Figure 2 : Comparison of land uses for two farms of Mato Grosso and classification SPOT-VGT in 2006. **1:** One single crop of soybeans per plot; **2:** Double cropping (soybean + maize or soybean + millet) per plot; **3:** Other cultures (pasture or rice); **4:** One single crop based on SPOT-VGT data; **5:** Double cropping based on SPOT-VGT data.

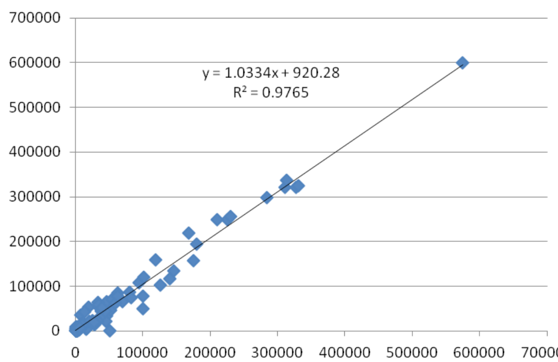
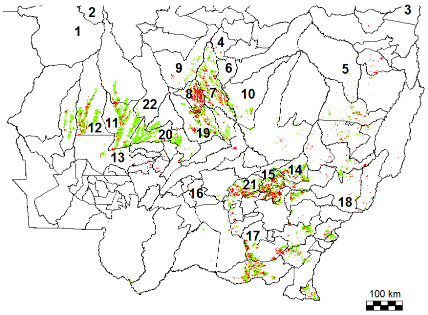
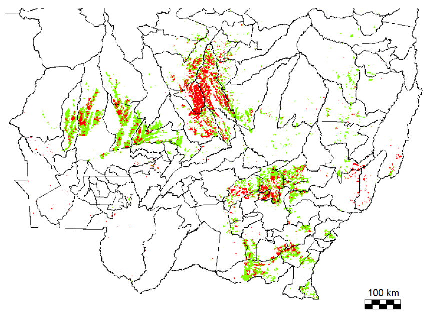


Figure 3 : Correlation between the actual cultivated area (in hectares x-axis), and the estimates by municipality by SPOT-VGT (in hectares y-axis).



(1) 1999



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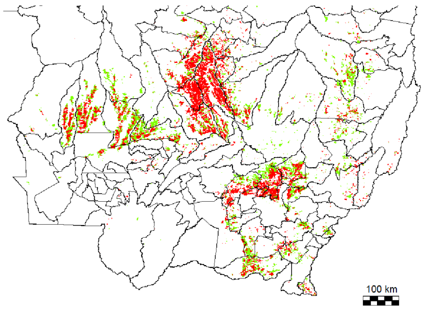

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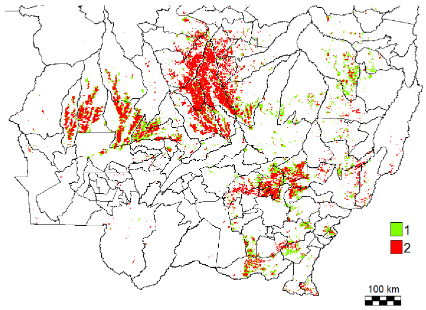


(4) 2009

Figure 4 : Evolution of croplands in Mato Grosso from 1999 to 2009 according to SPOT-Vegetation data. ■ **1**: One single culture; ■ **2**: Two cultures (communal boundaries in black). Names of localities cited in the text: 1, Juina; 2, Juruena; 3, Vila-Rica; 4, Sinop; 5, Querencia; 6, Vera; 7, Sorriso; 8, Lucas do Rio Verde; 9, Tapurah; 10, Nova Ubirata; 11, Campo Novo do Parecis; 12, Sapezal; 13, Tangara da Serra; 14, Novo Sao Joachim; 15, Primavera do Leste; 16, Cuiaba; 17, Rondonopolis; 18, Barra do Garças; 19, Nova Mutum; 20, Diamantino; 21, Campo Verde; 22, Nova Maringa.

those of the IBGE is very low for most years except 2002 (8.9% overestimation), 2005 and 2006 (underestimates by 12.5 and 9.8%). This gap tends to minimize the peak observed in Mato Grosso crops in 2005 and the following decline in 2006 and 2007. However, the extension or reduction or stagnation of agricultural land is only one aspect of the evolution of land use and we must also take into account another significant trend, intensification.

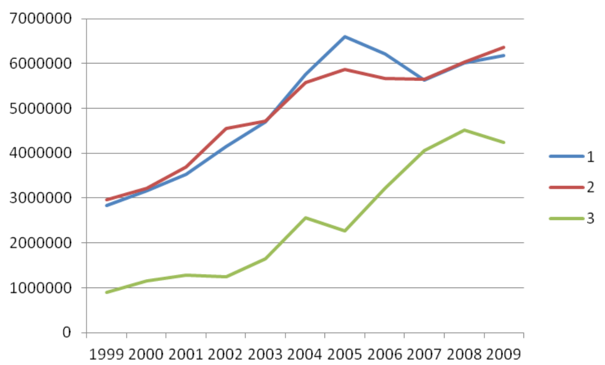


Figure 5 : Evolution of cultivated land in Mato Grosso (hectares). **1:** IBGE data (soy + cotton); **2:** SPOT-VGT estimates; **3:** Estimates of crop areas in double crops system by SPOT-VGT.

3.2. The expansion of secondary crops (safrinha) and the intensification of agriculture

Figures 4 and 5 also show the intensification of land use that has occurred in the recent years and is the result of a generalization of the second crop (safrinha) in most regions of soybean production. Thus, while it covered only 30% of the area (mainly around Lucas do Rio Verde and the south-east) in 1999, this proportion rose to 39% in 2005, 57% in 2006 to 72% in 2007. Over the past years, only the regions of recent clearings (Querencia, Nova Maringa) still remain with dominant single cropping systems; elsewhere double cropping has become a set practice, even if a small decline could be observed in 2009 (67%).

Another significant change concerns the increasing speed with which the plots are being cleared and crops planted in this system of dual culture. The monitoring of two control plots near the town of Vera is used to illustrate this phenomenon (Figure 6). In both cases these parcels that have been deforested, the first (No. 3) in 1998-1999, and the second (No. 4) in 2001-2002. The profiles of NDVI SPOT-VGT and Landsat images show that plot No. 3 was cleared and burnt in 2000 and then for five years was sown with a single crop of rice and/or soy. From 2006, a double cropping regime was clearly established (the secondary low peaks of

2004 and 2005, probably corresponding to a marked spontaneous regrowth). In the case of Plot No. 4, the phase of site preparation for agriculture was completed in 2004, the first culture crop was detected in early 2005 and the second crop appeared as early as 2007 or even 2006. In these examples, while the duration of land preparation is short (about two years), the plot cleared in 2001-2002 became a part of the intensive system of two crops more rapidly. The question is whether this is an isolated phenomenon or a more general trend.

In an attempt to quantify this phenomenon we have chosen to work only on the county of Vera, representative of municipalities where the expansion of soy has been massive and recent. Only cleared plots whose size was greater than 300 hectares were chosen to keep compatible surfaces monitored by SPOT Vegetation data. For each of these plots, the NDVI profiles were used to determine the year of the first cultivation and the year of the first observation of double cropping (repeating the same criteria as outlined in the methodology). Calculations show that the average time between the year of clearing and detected by the first crop NDVI profile varies slightly (between 2 and 3 years). However, the time period between the first cropping year and the first year of intensive double cropping safra-safrinha decreased continuously, from 3.1 years in 1999 to 2.3 in 2001 and 2002 to 1.5 in 2003 and 2004. This means that for nearly one of two cleared plots in 2003-2004, the cycle of dual cultures began to be practiced from the year following the first real harvest, reflecting the willingness of farmers to optimize the use of their land quickly. It is to be noted that this rate remains the same for plots cleared in 2005 being difficult calculating an average because for that year, a significant proportion of open land (about a half) in the county of Vera showed NDVI profiles corresponding to a type of capoeira, i.e. forest regrowth after a clearing phase. It could be an illustration of the recently observed slowdown of deforestation in the region: farmers chose to intensify production on land rather than creating new areas of production.

4. Synthesis and typology of counties land use trajectories in 10 years

4.1. Construction of a reference multi-sources map

SPOT-VGT data is only one part of the data available to characterize landscape changes. In order to have an overview of these processes and provide a wide synthesis for the State of Mato Grosso, this study proposes to combine multiple data sets: data from deforestation and vegetation cover provided by federal (INPE) and national (SEMA) agencies; SPOT-VGT data presented above is used to detect and locate areas yielding one or two annual crops. Deforestation maps provided by INPE are produced annually based on Landsat images for the Brazilian Amazonian biome as part of the PRODES project (INPE, 2011). In the case of our study that is focused on the state of Mato Grosso, this product has a major limitation, which is that the areas cleared in the Cerrado and Pantanal biomes are not taken into consideration. The SEMA-MT (State Secretary of Environment in Mato Grosso) also produces deforestation maps based on visual interpretation of Landsat and CBERS images. This almost annual data has the advantage to map deforestation in the cerrado and the Pantanal but they are not produced automatically. In summary, both data are complementary and we merged them in order to produce a finer dataset. Deforested areas were considered as deforested if at least one data source (PRODES or SEMA) labeled it as deforested in the forest area, and if the SEMA data source labeled it as deforested in the Cerrado biome.

The maps in Figure 7 show the syntheses of the major types of landscapes and dynamics between 1999 and 2009. They show that deforestation in Mato Grosso is focused primarily in the center of the State as both sides of the federal highway BR-163 (Cuiaba-Santarem) and to a lesser extent along secondary roads that also cross from south to north: the Barra do Garças-Vila Rica road in the east, the road from Tangara da Serra to Campo Novo and Juruena in the west. The role of communication infrastructures is evident here. The Cuiaba-Santarem axis, the main transit road between the upstate and the southern region, also known as "the settler road" (estrada dos colonos), has a decisive impact on the structuring of this new region and the transformation of the environment: it is in this region that the main production center of soybeans is located, in particular around the town of Sorriso. Deforestation moved forward up to the north and the forested part of the State suffered the higher pressure with a loss of 28% of its forested area between 1999 and 2009 (against 12% for the Cerrado, already more deforested (Jepson, 2005)). In total, over this period, more than 73,000 square kilometers have been cleared in Mato Grosso. Forested lands therefore represent today less than 31% of the area of the State, a smaller surface than the land cleared and cultivated (38%) but more than the cerrados (25%). Croplands are proportionately those who experienced the most spectacular growth (+300%) although they represent just under 15% of the cleared spaces, emphasizing the dominant role of livestock in deforestation (Fearnside, 2001; Morton et al., 2006). The variety of observations recorded at this local scale leads us to attempt to offer a summary of these transformations at the municipal level.

4.2. Typology of municipalities according to their land use dynamics

In a given region, land-use potentially follows a series of steps, which are intricately related to both economic development and the ecological characteristics of the landscape (DeFries et al 2004; Hirsch, 2009). In this study, the stages were identified based on thresholds

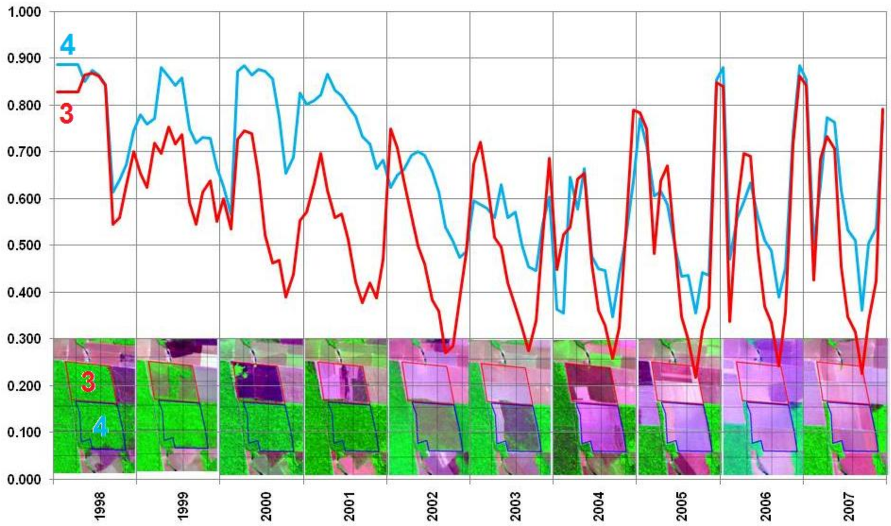


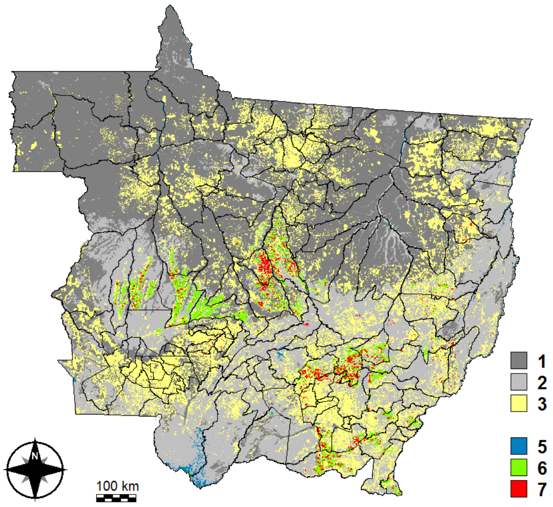
Figure 6 : Above: Profiles of SPOT-Vegetation NDVI for two parcels located south of Vera MT. **3:** Plot cleared in 1998-1999 (300 hectares); **4:** Plot cleared in 2001-2002 (400 hectares). **Below:** Landsat images (5 × 7 km) for each dry season showing the evolution of land use (colored compositions 3,4,5).

of proportion of landscape applied to land-use areas adopted from Clairay (2005); Dubreuil et al. (2008) and Arvor et al. (2011b). The initial stage corresponds to the arrival of migrants (Coy, 1996) while the consolidation stage aims at pursuing the territorial occupation in order to make it productive (Albaladejo et al., 1996). Intensification stages take into account the number of crops per year as identified in the previous pages using SPOT-VGT data. All the data is gathered at a municipality level (i.e. the 145 counties or "municipios", ref. IBGE, 2001), remembering that their areas can be very different (from 135 to 26,500 km^2, with a mean of 6,400 km^2). It is noteworthy that our method only takes into account remote sensing data, but it could be possible to add other data such as socio-economic data available at municipal level.

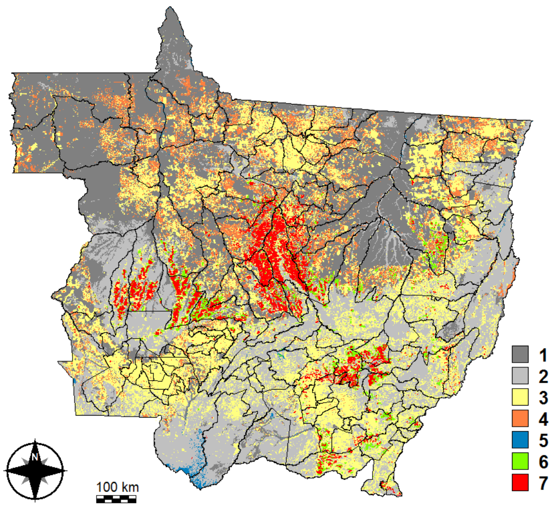
The eight stages of evolution of our typology are defined as follows:

- Pre-settlement (1): wildland areas are dominant in the municipality, i.e. wildland areas (SEMA and PRODES data) represent more than 90% of the county.
- Non-cropland (2) and cropland (3) occupation: wildland areas have decreased but are still major in the municipality, i.e. wildland areas represent between 50 and 90% of the land-use (SEMA and PRODES data). In the cleared areas, if the area dedicated to extensive croplands (SPOT-VGT data) is greater than the area occupied by non-croplands, the stage is called cropland occupation (2). Otherwise it is called non-cropland agricultural occupation (3).
- Non-cropland (4) and cropland (5) consolidation: wildland areas continue decreasing so that they now represent between 25% and 50% of the municipality (SEMA and PRODES data). If the area dedicated to croplands is greater than the area non-dedicated to croplands (SPOT-VGT data), the stage is called cropland consolidation (5). Otherwise it is called non-cropland consolidation (4). If more than 80% of the croplands are cultivated using single cropping system (SPOT-VGT data), it was considered as cropland intensifying stage (7).
- Non-cropland (6) and cropland (7) intensifying: this stage is reached when wildland cover less than 25% of the municipality (SEMA and PRODES data). If cropland areas are greater than the non-cropland areas and if more than 50% of the croplands are cultivated with a single cropping system (SPOT-VGT data), we considered it as cropland intensifying stage (7), otherwise it was called it non-cropland intensifying stage (6).
- Intensive (8): the intensive stage is achieved when wildland have nearly disappeared (less than 25% of the municipality), the areas dedicated to croplands represent more than 50% of the cleared area and double cropped areas represent more than 50% of the cropped area (SPOT-VGT data).

Figure 8 shows the overall regression of stages 1 and 2 and, on the contrary, the progression of stages 4 to 8. In 2009, there are only three municipalities in stage 1 compared to 11 in 1999. Several municipalities have also passed from stage 2 to stage 4 or 6, especially in the north-central and eastern regions where the cattle farming and pastures have increased significantly in recent years. The region dominated by agriculture, which concerned only six counties in 1999, now reaches fourteen. We clearly see the three soybeans producing re-

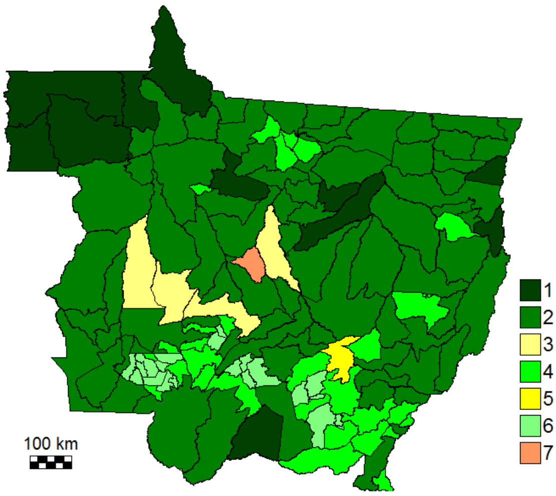


(1) 1999.

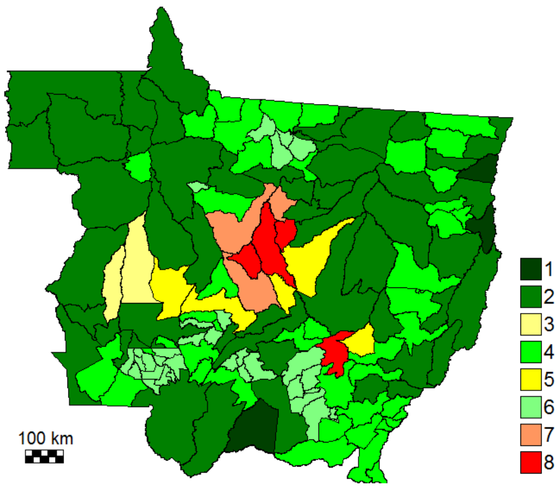


(2) 2009.

Figure 7 : Evolution of the land types in Mato Grosso in 1999 (above) to 2009 (below) from different sources. **1:** Forest (PRODES); **2:** Cerrado (PRODES); **3:** Cleared before 1999 (SEMA + PRODES); **4:** Cleared between 1999 and 2009 (SEMA + PRODES); **5:** Water (SEMA); **6:** Cultivated area with one culture (SPOT-VGT); **7:** Cultivated area with two cultures (SPOT-VGT).



(1) 1999.



(2) 2009.

Figure 8 : Typology of Mato Grosso municipalities in 1999 (above) and 2009 (below) according to their types of land use (see details in text). **1:** Pre-settlement stage; **2:** Non-croplands occupation; **3:** Croplands occupation; **4:** Non-croplands consolidation; **5:** Croplands consolidation; **6:** Non-croplands intensifying; **7:** Croplands intensifying; **8:** Intensive.

gions with a more intensive model around Sorriso-Lucas and Primavera do Leste, and a less intensive one around Campo Novo. The emergent pole of Querencia is not listed here because forest areas still dominate across the county although crop expansion has been strong for 10 years. Finally, the counties where agricultural expansion has been spectacular (Vera passes from stage 2 to stage 8!) are evident in the central region.

5. Conclusion

SPOT-Vegetation data enables satisfactory monitoring of cultivated soybean areas and those subject to a dual-culture safra safrinha. The size of the plots (hundreds of hectares) and farms (often several thousand hectares) can offset the disadvantages of low spatial resolution. The results show the continuous expansion of cultivated areas and the double-cropping system until 2005. From that date, the cultivated area has stagnated (while the cleared surfaces have decreased) but the dual culture continues to spread over more than 70% of cultivated land in Mato Grosso in 2007 and 2008. The study of NDVI profiles provided by SPOT-Vegetation can therefore show that the crisis faced by soybean producers during 2006-2007 led them, on the one hand, to limit the clearing of new lands but, on the other hand, led them to try to improve profits from the land already in use by diversifying and intensifying their farming practices.

The combination of different types of satellite data is especially valuable for monitoring territorial dynamics by quantifying and qualifying the changes of land use. In this region where the changes are very spectacular, deforestation reached record highs before declining in recent years. However, within the frontier, the continuing transformation and, in particular, agricultural intensification with the generalization of the double cropping system is the most notable. The methodology and typology of municipalities proposed here can therefore clearly highlight the dynamism of these regions. However, some limitations should be noted: the spatial resolution of SPOT-VGT, well suited to large parcels, is less adapted in the regions of more diffuse transformations (small family farms, for example). In addition, the discrimination of growing cycles from the NDVI is convenient for intensive crops such as soybeans, but the types of land use in lower-contrast index profile (i.e. grasslands) or finer discrimination between ground-covers (millet) or commercial (corn, cotton) subcultures are not possible. Further works can therefore be considered with higher spatial resolution sensors such as MODIS (Arvor et al., 2011a).

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