

# RATES AND DRIVERS OF LAND USE LAND COVER CHANGE IN THE AGRICULTURAL FRONTIER OF MATO GROSSO, BRAZIL

Progress Report for Year 1: April 2011-March 2012

## *Mapping of LULCC and Cropping in Mato Grosso*

The research we are funded to perform by this grant is directed to the important agricultural frontier of Mato Grosso Brazil. The research consists of two primary themes: **1) detection and characterization of land cover change with remotely sensed data, and 2) explaining and attributing the observed changes through socioeconomic analyses.** We have made excellent progress in the first phases of the first theme. Dan Mahr (undergraduate who graduated from Brown in spring 2011) has continued to work on this project and established a set of novel methodologies to characterize the nature of cropping in Mato Grosso from 2001-2010 that was presented in his senior thesis. Graduate student Stephanie Spera came to Brown in August, 2011 and has made good progress over the fall semester re-creating Mahr's thesis work and updating it to include the most recent years (2010-2011). The key results are shown in Figures 1 and 2 and essential activities are summarized below

The key result is that following the rapid expansion in land converted to mechanized agriculture in the early part of the decade, the pace of expansion slowed markedly. However the amount of land devoted to multi cropping (two or more crops per year) has expanded markedly. This represents a significant shift in land use and we are exploring the social and economic drivers behind this and are very excited by the initial results.

All MODIS data observed over the region since August 2000 have been acquired and processed. This procedure involved downloading spatially-subsetted and georeferenced MODIS09A1 and MODIS13Q1 data from NASA's Land Processes Distributed Active Archive Center (LPDAAC) website over the study region. After the data were downloaded, ten-year-long time series were created for each of the data products. Thus, time series image cubes of the Day of Year, Enhanced Vegetation Index, Vegetation Index Quality, etc., were produced by sequentially stacking the images. Once these time series were created, pixel with values that were below the valid data ranges or considered lowest quality (i.e. for the Enhanced Vegetation Index, pixels with values less than -2000 or those with a corresponding Vegetation Index Quality coded below 1000 as denoted by the Vegetation Index Quality data) were eliminated and replaced with values interpolated from the surrounding pixels.

The corrected Enhanced Vegetation Index time series over Mato Grosso, Brazil, was then analyzed, in a decision tree approach, to determine specific thresholds associated with the phenologies of various land-classes: forest, pasture, and cropland. A growing 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 2011 growing year consists of 23 images, beginning with the image compiled for Day 225 of 2010, and ending with that compiled for Day 209 of 2011. To determine if a pixel was forest, cropland, or pasture, only the observations in the growing year being processed were analyzed. If the pixel's EVI remained relatively constant throughout the growing year—the standard deviation of the EVI observations was less than .05—and the first and last observations in the time series had an EVI greater than .4, then the pixel was classified as forest. If the standard deviation of the pixel's EVI was

greater than .05, then other thresholds were utilized to determine whether the pixel was pasture or cropland. These thresholds incorporated both the width and the height of various peaks and valleys within the time series in order to differentiate pasture, where the EVI generally follows a crescent shape corresponding to the yearlong growth and senescence often never exceeding an EVI value of .6, from cropland, where the observed EVI can range from .1 when the fields are barren to .9 when the crops are in full bloom.

Moreover, if a pixel was characterized as cropland, it was further analyzed to determine, based on the number of peaks in EVI, whether the pixel showed single (one peak) or double (two peaks) cropping. This single versus double cropping issue is complicated by the fact that farmers may either grow millet as a cover crop at the beginning or end of a growing year or let natural growth appear on their land, thus creating peaks in the EVI time series leading to the misclassification of double cropping. However, this issue is currently being addressed, and robust land-classification maps of Mato Grosso have been created for each year between 2001-2011 outlining areas of forest, pasture, and single- and double-cropped land. To perform these routines, programs were written in IDL and run in ENVI/IDL.

The land-classification analysis is currently being taken one step further to identify specific crop types from the MODIS imagery. For each peak, the length of the crop cycle is calculated by subtracting the date of harvest from the date of green up. The dates used in these calculations are not the general DOY as given in the image file name, but the specific date at which each pixel's EVI observation was taken, as saved in the Day of Year MODIS product. The green up date and harvest date are determined by looking for jumps and in EVI greater than .4 both forward (green up) and backwards (harvest) through the growing year. Crop calendars and the calculated lengths of these crop cycles will assist in determining crop type. Although corn and soy have often been classified in previous studies simply as "summer crops" because their phenologies are so similar, Wardlow and Egbert (2008) and Arvor et al. (2011) show that corn, and soy differ in growing season length and peak EVI. (*Should I cite papers?*) Thus, both growing season length and the maxima of each EVI peak will be taken into account when differentiating crops type. Moreover, MODIS' 8-day surface reflectance data product may provide extra characteristic information.

In order to validate the initial results, they will be compared to data acquired during a ground-truthing campaign undertaken in March 2011 that focused on center of Mato Grosso where just over 100 validation points were collected. In monitoring the effects of Brazil's Soy Moratorium, ABIOVE (Brazilian Association of Vegetable Oils Industry) and INPE (Brazil's National Space Research Institute) have flown planes over various agricultural areas of Mato Grosso, during the 2008, 2009 and 2010 growing seasons, categorizing both the spatial extent and current land use. Bernardo Rudorff, Technical Coordinate of the INPE and collaborator on this grant, will (*hopefully*) provide this extensive set of validation data. Lastly, Stephanie Spera will also be traveling to Mato Grosso in the summer of 2012 to either collect hundred of validation points or conduct several in depth surveys of the agricultural practices as certain farms.

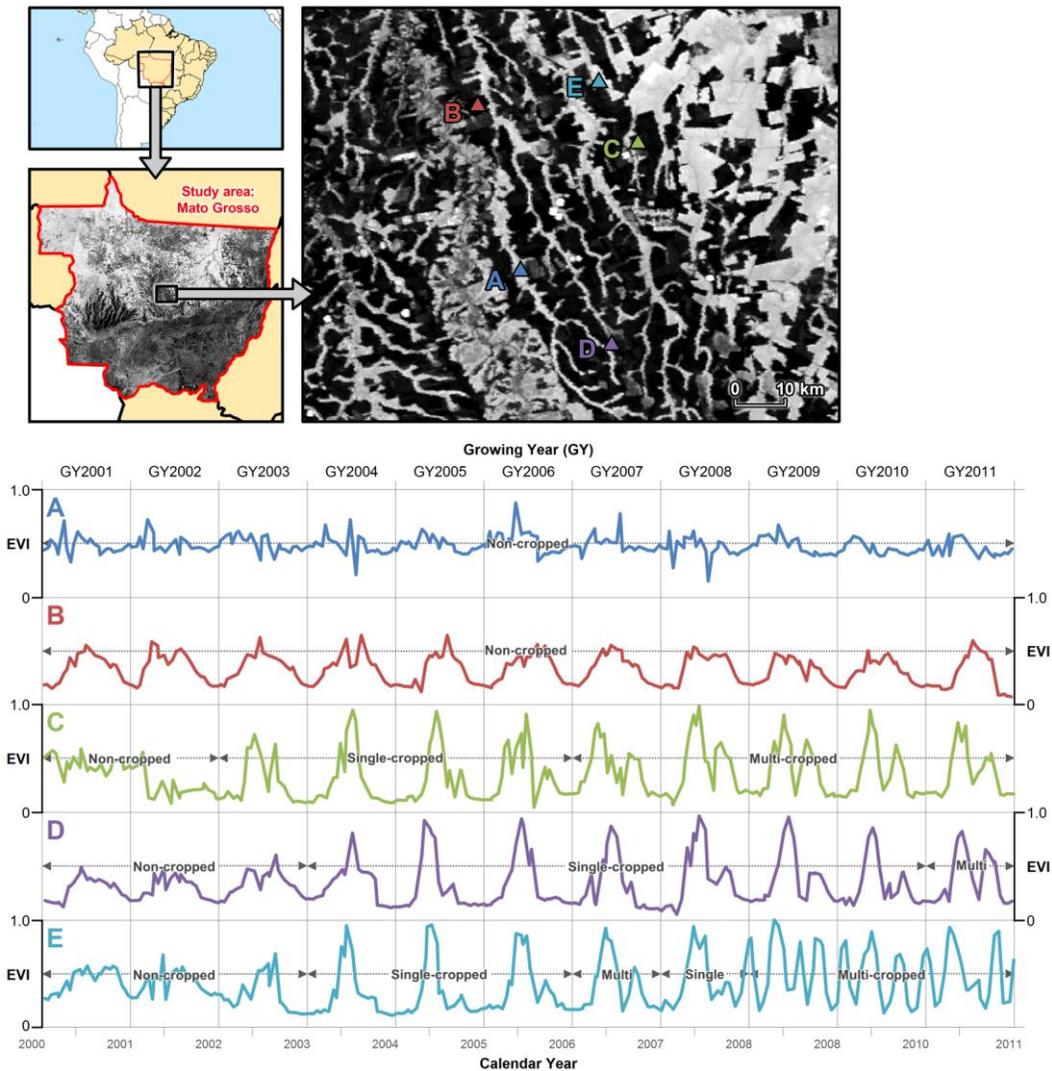
We have been very active in planning for the coming field season in Mato Grosso. The mapping has clearly established the location and nature of field sites that will be verified and validated. The new methods we are developing for determining crop type will be a key focus of the field work, gathering direct observations as well as working with our colleagues for share their fundamental field observations. Bernardo Rurdorf is a key

collaborator who has been instrumental in monitoring the effectiveness of the soy moratorium. Through that effort they have developed a superb data base of field data on cropping across a large area that include parts of Mato Grosso, though those data are focused on the Amazon, and our field site includes large swaths of the cerrado and cerrado. Field work is planned for the late spring/early summer of 2011. This will also be an important trip to solidify the working relationships with our Brazilian colleagues.

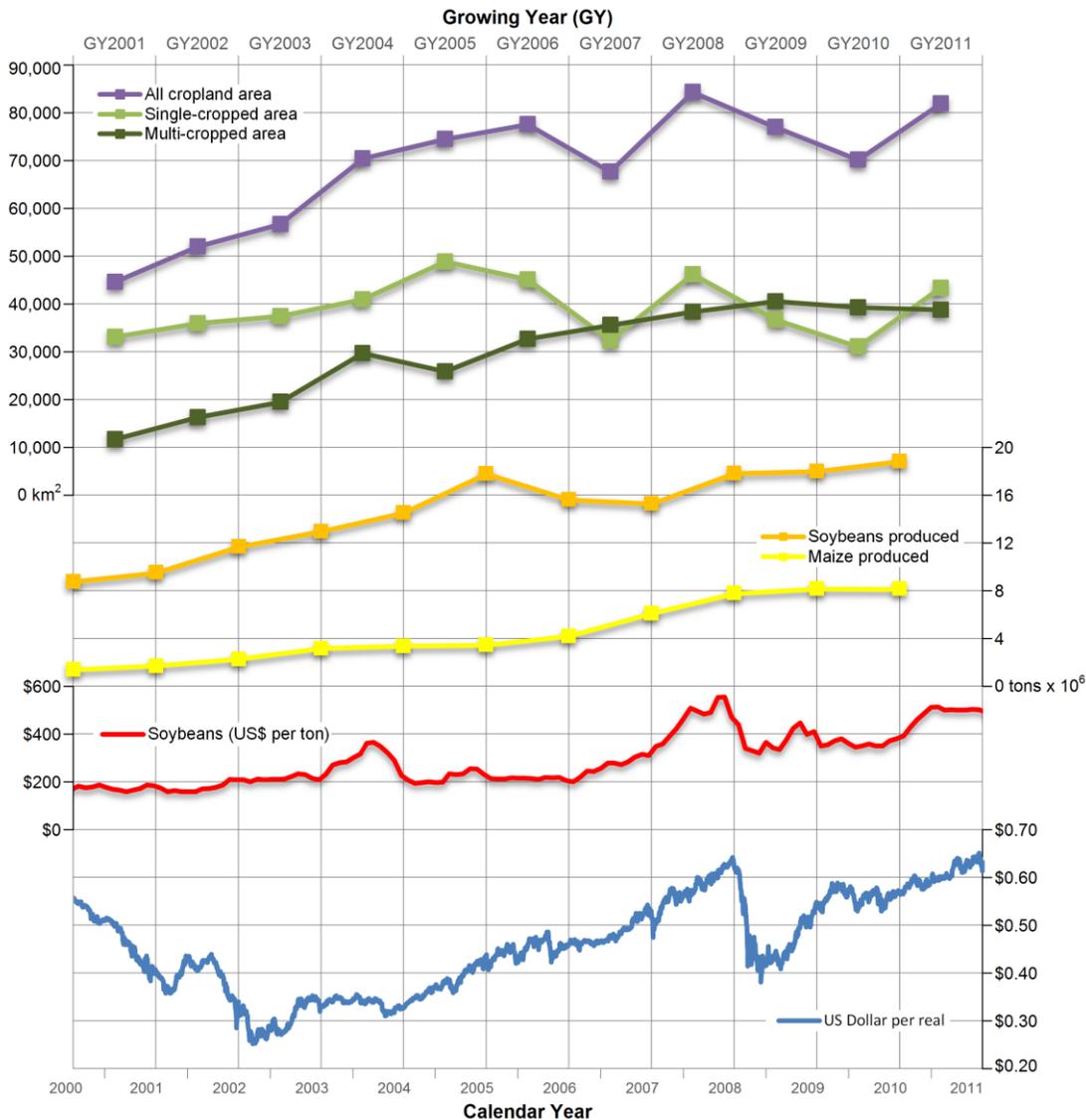
Leah Vanwey (Co-I) is organizing a workshop on Mato Grosso Brazil to be held the second week of March at Brown University. This will be a very important workshop for the research in our grant as it bring together key people working on Mato Grosso both in Brazil and the U.S.

We are in the final stages of preparing a paper to be submitted to Science that will draw heavily from the work that is the center piece of this grant. The paper citation is below.

Rapid, large-scale cropland intensification reduces deforestation in an agricultural frontier  
Daniel E. Mahr, John F. Mustard, Leah K. VanWey, and Gillian Galford (Submitted to Science)



**Fig. 1.** EVI time series of five example locations within the study area of Mato Grosso, Brazil. These show the distinct phenologies associated with non-cropland, single-cropping, and multi-cropping land cover. The **inset map** shows the source EVI data, which was composited from MODIS observations between 28 July 2011 and 12 Aug 2011. Darker areas represent the relatively low (closer to 0) EVI values of fallow fields during the dry season; lighter areas represent the relatively high (closer to 1) EVI values of forests. **Series A** shows a pixel in a riparian forest whose EVI usually remains between 0.4 and 0.6, with some high-frequency noise in the wet season due to contamination from clouds. **Series B** shows a pixel in a pasture that exhibits a broad, year-long oscillation corresponding to grass vernalization and senescence in the wet and dry seasons. **Series C** shows a pixel that was forest until it was converted to cropland in GY2003 and subsequently intensified to multi-cropping in GY2007. **Series D** shows a pixel that was pasture before conversion to cropland in GY2004. **Series E** shows a pixel that was pasture before conversion to single-cropping in GY2004, multi-cropping in GY2007, and then central-pivot irrigation in GY2008.



**Fig. 2.** Comparison of cropping observations and socioeconomic data. Our observations (**first panel**) show an 84% increase in cropland area growth (purple line), though most of the growth came from multi-cropping (dark green line) and less from single-cropping (light green line). The impact of this cropland growth on agriculture production is confirmed with data from SIDRA/IBGE (**second panel**), which shows a twofold increase in soybean production and a sixfold increase in maize production. We hypothesize that the rise in multi-cropping was enabled by the depreciation of the Brazilian *real* from 2002-2005 (**fourth panel**) and the spike in soybean prices in 2004 (**third panel**) that incentivized capital purchases of machinery. Even as the *real* regained its value, mechanized multi-cropping persists as these costs were already sunk.