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BIG EARTH OBSERVATION DATA AND MACHINE LEARNING FOR MAPPING CROP-LIVESTOCK INTEGRATED SYSTEM IN BRAZIL

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ABSTRACT

The adoption of crop-livestock (iCL) integrated systems has been pointed out as an important strategy for increasing production based on sustainable intensification of land use in Brazil. Mapping and monitoring the iCL areas would allow us to know the expansion rates and the adoption level of the integrated system, being an important instrument for public policy management. However, due to the time-space variability from integrated production systems, developing methods based on remote sensing remains a major challenge. In this sense, this work discusses the application of Big Data and machine learning concepts in Earth Observation Data as a strategy to compose a methodology for monitoring the iCL in Brazil. We tested the capacity of the Random Forest (RF) classifier applied to MODIS time series to iCL detection in the Mato Grosso State, Brazil. For this, we evaluated the classification accuracy for the years between 2012 and 2019, totaling 3,864 images processed. The overall accuracy founded was between 0.77 and 0.89 and an fscore average of 0.85 was found for the iCL class. The generated maps showed a trajectory of sustainable intensification, with the expansion of the iCL area from 1,100,000 ha in 2012/2013 to 2,597,000 ha in 2018/2019, an increase of 135%. The results indicate that the use of the RF classification technique with MODIS times series has great potential to compose an iCL monitoring methodology, requiring parallel and cloud computing applied to advanced algorithms.

Key words: agricultural sustainable intensification; MODIS time series; Machine learning

INTRODUCTION

FAO's global projections for 2050 indicate that the world population will still grow in the coming decades and that world agricultural production will have to increase by about 70% compared to 2005 production to meet the growing demand for food. Considering the low availability of areas for agriculture expansion, projections point out that about 80% of the agricultural production increase to meet this demand will have to occur through increased productivity and/or the intensification of production systems (FAO, 2009).

Considering the ongoing global climate change, with direct consequences for agriculture, a scenario of uncertainty, food insecurity, and production instability at the global and country-level is established. The scenarios signal increased environmental pressures as deforestation and greenhouse gas emissions. Overexploitation of water resources and degradation of soil quality will cause the loss of the productive area, in addition to the land competition, increasing global inequality and generating strong competition among producing countries. Thus, the major challenge for producing countries is the need to increase agricultural production from intensifying production systems and at the same time avoiding deforestation and reducing greenhouse gas emissions.

Going in this direction, on the UN Climate Convention, that took place in December 2009 in Copenhagen, Denmark, Brazil took a voluntary measure to reduce GHG emissions in the order of 36.1% and 38.9% with the international community setting reduction targets for each sector of the Brazilian economy.

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Fulfilling its commitment, the country signed the National Climate Change Policy and the National Climate Change Fund (Climate Fund) in the same year for adaptation and mitigation actions. For the agricultural sector, to consolidate a Low Carbon Economy in Agriculture, the Sector Plan for Mitigation and Adaptation to Climate Change (ABC Plan) aims at management practices that reduce the emission of greenhouse gases. The ABC Plan constitutes an explicit state policy for reducing carbon emissions both by its paradigmatic scope, established targets, and by the amounts of public investments.

However, a decade after the launch of the ABC plan, the challenge is still to create efficient mechanisms for monitoring these initiatives. As the study “The Governance of the ABC Plan”, produced by FGV's Agribusiness Center (GVAgro, São Paulo), concluded, the absence of instruments to monitor the application of resources and the goals of mitigating greenhouse gases has caused serious governance problems for the plan. Today, the estimation of the implementation of these systems is made by costly surveys in time and resources, such as the survey conducted by Gil (2015), who, through interviews with 134 producers and specialists in a period of 6 months, extracted information about the expansion of iCL systems in the municipalities of the state of Mato Grosso (MT) for the 2012/2013 crop year. Another study, conducted by the Klefman Group, which in 2017 generated the iCLF report in numbers (EMBRAPA, 2017), which also conducted interviews, conducted an iCLF inventory by states of Brazil. Surveys like that not allowing annual monitoring, as well as require a huge amount of data collection work.

Monitoring the expansion of the integrated system is essential to plan the agriculture sector in Brazil, besides enabling the monitoring of GHG emission reduction targets established by Brazil (BUSTAMANTE et al., 2012; RAJAO; SOARES-FILHO, 2015).

Considering this evidence, this study aims to evaluate methods based on the use of remote sensing in contribution to the establishment of a methodological protocol for monitoring Low Carbon Agriculture in support of the governance of the ABC Plan. The present work takes part in the GeoABC Project: Methodologies and technological innovation for satellite monitoring of low carbon agriculture in support of Brazil's ABC Plan.

MATERIAL AND METHODS

The Mato Grosso (MT) state was chosen because, containing three biomes: Amazônia, Cerrado, and Pantanal, it presents a great variability of environments and climatic gradient, which made it possible to test the robustness of the developed method. The state is one of the main national producers of cattle and soybeans and its expansionist model has often been criticized for its impacts on environmental resources, especially in tropical forests (ARVOR et al., 2017) and savannah areas (MYERS et al., 2000).

According to data from the municipal agricultural survey, IBGE (SIDRA, 2019), the agricultural production of 95% of the agricultural state area in the year 2019 corresponded to the production of 3 main crops: soybean with 58.47%, corn with 30.22%, and cotton with 6.65%. According to this information, we focus our efforts on mapping the pasture soybean system, with or without the presence of corn. Thus, we focus our efforts on mapping the pasture after the summer soybean crop, with or without the succession of corn.

The approach of this study was based on the use of machine learning techniques, performed in cloud computing for the annual mapping, where each map represents the crop succession system for an entire crop year, totaling 07, between 2012/2013 to 2018/2019. The MODIS time series of the spectral bands NIR and MIR were used together with the NDVI and EVI vegetation indices, representing a feature space of 92 images for each year and each image tile (6 total). We used the Random Forest classifier (BREIMAN, 2001) applying 100 random trees, associated with a learning/validation dataset containing approximately 25,000 pixels. The platform used was the Google Earth Engine, which consists of a catalog of data ready for analysis with high-performance cloud processing accessed and controlled through an API (application programming interface) accessible on the Internet (GORELICK et al., 2017). A hierarchical structure was applied, which was composed of 04 levels presented below, following the structure already existing in version 5 of MapBiomas:

- Level 0: In this first level, a mask was applied to the class “Soy” of the MapBiomas collection 5.0;

- Level 1: In the second level, a binary classification was carried out, containing the class (SC) that represents soy in a single system, and the class (DC) that represents the succession of any other type of crop after soybean harvest;

- Level 2: For the third level, the mapping universe was isolated to the DC class mapped in the previous level, which was stratified in the three most common systems in the state, that is, soybean in succession with cotton (SA), soybean in succession with corn, millet, sorghum or sunflower (SCe) and soybeans with *brachiaria*, with or without the presence of corn, millet or sunflower (iCP);

- Level 3: The fourth level is composed of the iCP1 class, which represents pasture in succession of soy and the ILP2 class that represents pasture in succession of soy intercropped with corn.

RESULTS AND DISCUSSIONS

The overall accuracy at all three levels is between 0.70 and 0.96. The 01 level showed greater stability, with less variation each year. Levels 02 and 03 showed the lowest accuracy in 2013/2014. The mapping of iCL zones, shown at level 02, showed a consumer precision between 0.8 and 0.94 and a producer precision between 0.68 and 0.88. If, on the one hand, the prevalence of error of omission underestimates the area implanted with iCLs, on the other hand, it suggests an increase in the certainty of the mapped areas. The study chose to produce a more conservative mapping to avoid classifying Soybean+Corn areas as iCL. Conversely, iCL areas may have been classified as Soybean+Corn.

Sequential systems associated with soy are currently prevalent in Mato Grosso and had already been pointed out by other authors (ARVOR et al., 2012; KASTENS et al., 2017; PICOLI et al., 2018; Spera, 2017) preferentially for corn, which has been replacing millet, followed by cotton as the second ILP. based on the result found with this methodology, sustainable intensification by integrated systems more than doubled in the state, from ~ 1,100,000 ha in the crop year in the year 2012/2013 to ~ 2,600,000 ha in the year 2018/2019. It was possible to observe that among the sequential cultivation options, ILPs have been gaining more importance, going from 18.6% to 28.9%, as cotton increases its proportionality from 4.6% to 11.1%. Among the analyzed period, the SCe system loses its proportional importance, falling from 76.9% to 60%, suggesting a phase of increase in intensification in an integrated way between crop-livestock system.

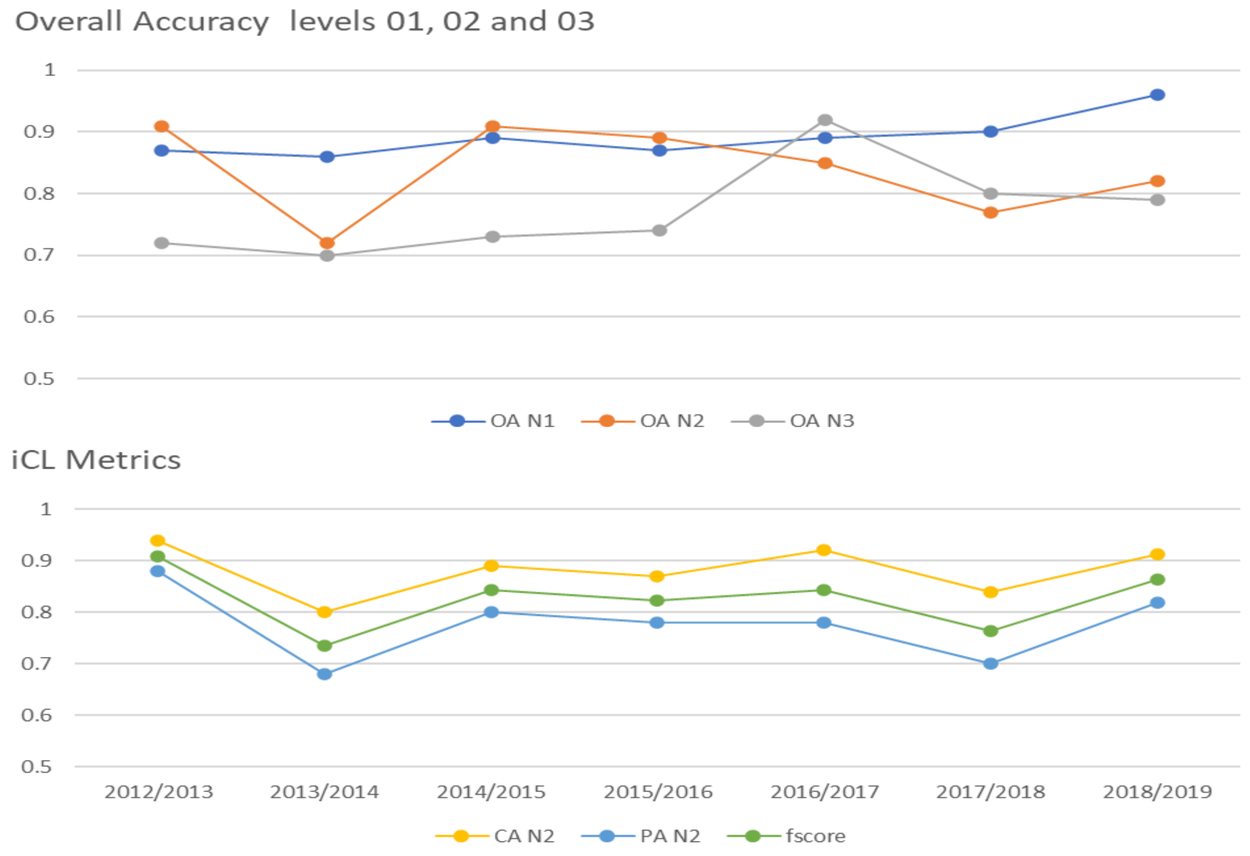

Figure 1. Annual evolution of the F-score of the classes of cultivation system of Level 01 (continuous line), Level 02 (large points) and Level 03 (small points), calculated on the scale of the State of Mato Grosso.

It was possible to observe in previous sessions that the integration of Integrated Systems in Mato Grosso is gradually occupying the space of conventional systems, showing a significant increase in this state. To facilitate spatial reading, two maps were created with the Kernel Density Index, where each pixel in the iCP area was exported to point shapes. In the first agricultural season of the analyzed series, it is possible to identify greater importance in the Middle North region, with a greater concentration of iCP areas between the towns of Sinop and Sorriso, but with areas well dispersed in the north-south axis of the region. There are spots of concentration of zones, limited however in the West, South-East and Center-South regions. Insignificant areas are found in the North-East and North-West regions (Figure 2). For the 2018/2019 campaign, it is possible to identify the consolidation of the Middle North region as the most important, but a more dispersed pattern is presented. A sharp increase is seen in the South East and North West regions, an increase in the North West region and one starting in the North region. In the Center-South regions and in particular, in the West, the gain in surface area is not significant to the point of presenting visual differences (Figure 2).

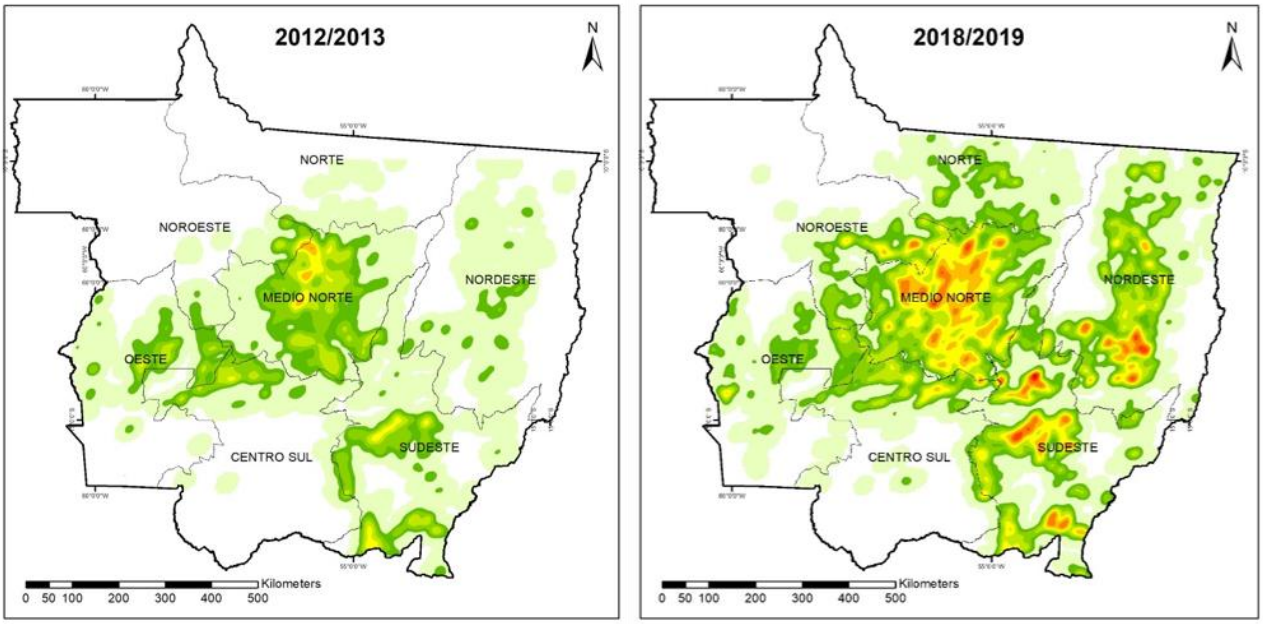

Figure 2. Kernel density maps for dispersion analysis. (a) The density of the areas implanted in the crop year 2012/2013 and (b) Density of the areas implanted in the year/harvest 2018/2019.

CONCLUSIONS

The results indicate the expansion of the integrated livestock farming systems in the state of Mato Grosso in the period of 2012/2013 to 2018/2019.

The estimates of area occupied with iCL are compatible with the surveys performed but it is still a great challenge to find reliable estimates for validation, especially for integrated systems.

The composition of the time series using MODIS data showed great potential in mapping iCL systems, including the approach to the use of an increased depth of variables. The limitations of spatial resolution, which lead to the lower accuracy of the areas to be mapped, as well as the difficulty of detecting small plots in the field, are tolerable limitations due to the substantial gain of temporal resolution

The techniques tested and the modeling performed in this study are promising to make up a methodology for monitoring complex sequential crop systems, especially integrated livestock-farming systems (iCL).

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