Soil carbon and land use dynamics in the greater part of Cerrado biome, Brazil

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Abstract. This study is aimed at assessing the dynamics of soil carbon (C) and land-use in the greater part of Cerrado biome between 2015 and 2020, and to predict the future scenario. Increasing anthropogenic activities, especially agriculture, has significantly impacted land-use, consequently the balance inflow and outflow of carbon under different land use. Data on soil C, land use-land cover (LULC), and other variables were collected from USGS EarthData, FAO, and Mapbiomas. By applying support vector machine and InVEST models, we identified the LULC and quantified the soil C stocks under each land use. Pastures (2,016,793 km^2) and savanna (1,789,150 km^2) covered more than 70% of entire biome. Significant land-use transitions occurred between 2015 and 2025 with croplands increasing by more than 10% in area. Integrated agricultural system (IAS) accounted for ~ 40% more SOC stock than business as usual (BAU). Unlike the BAU which involves the conventional farming systems, the IAS is a low-carbon agricultural practice which serves as a nature-based solution to enhance C sequestration. The findings from the study might contribute to closing the gap in knowledge about soil C stocks in the region, and in smart-climate agriculture agendas to improve carbon stocks, food security and other SDGs.
Key words: Integrated agricultural system, business as usual, Carbon sequestration, climate change, Brazil.

1. Introduction

Land use and its related changes contribute significantly as sources of carbon emissions which consist of about 23% of total anthropogenic greenhouse gas (GHGs) emissions from 2007 to 2016 [1]. These emissions occurred due to agricultural activities which constantly remove natural vegetation and consequently change the energy fluxes and balances between sinks and emissions of carbon pools [2].

Soils have been identified as the largest terrestrial carbon sink, contributing to about 75–81% of the total terrestrial carbon (C). The global reservoirs of C in the first meter of soil are approximately 1500 Pg of C, representing 2-4 times more carbon than the sum of aboveground and belowground biomass stock [3]. Therefore, infinitesimal decline in soil C

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might signify substantial carbon dioxide (CO2) emissions to the atmosphere. In Brazil, especially the Cerrado biome, most CO2 emissions result from changes in land use which are primarily being exacerbated by intensive and extensive agricultural practices [4]. Studies have established that Cerrado soils hold about 34% of Brazilian soil C stocks (71.3 Pg-C), sequestrating ~24 Pg-C within the top meter [5].

The cropland area in most regions of the Cerrado biome expanded from relatively zero in 1985 to 690 thousand hectares of soybeans in 2000 to ~1.6 million hectares in 2018, approaching estimated production reports of about 6 million tons of soybeans, 1.245 million tons of cotton, and more than 50 million tons of sugarcane, coffee, citrus and other crops produced in the recent decades [6]. This rapid advance of agribusiness in the region threatens the natural ecosystems by posing severe human pressure, increasing worries about the impacts of land use change on carbon stocks [7]. Although several efforts have been made to estimate and understand changes in SOC stocks as induced by changes land use in the Cerrado biomes but most of these studies were limited to smaller areas of the biomes. It could be concluded that this is one of the first studies to report and forecast the soil C and land use dynamics in the greater part of Cerrado biome. It is in this context that our work aimed at appraising soil C and land use dynamics in the greater part of Cerrado biome between 2015 and 2020, and to predict the future scenario. The findings from the study will close the gap in knowledge about soil C stocks in greater part of the Cerrado. It might further provide the policy makers and other stakeholders in agriculture, soil, environment, and food production systems the vital information necessary to enhance carbon stocks, mitigate climate change, and achieve most sustainable development goals (SDGs).

2. Materials and Methods

2.1. Brief description of the study area

The study covered the greater part of Cerrado biome is located at 3^0 S-25^0 S and 43^0 W-60^0 W. It stretches from the south, southeast to the north encompassing the States of Tocantins, Mato Grasso, Mato Grasso do Sul, Goias, Federal Capital, Maranhao, and parts of Minas Gerais, Sao Paulo, Piaui, Bahia, and Parana. As the second largest biome after Amazon, Cerrado is in the highlands of Central Brazil and with a landmass of about 2 million km^2 or 21% of the Brazilian territory [8]. The main climate of the region is humid tropical (Aw - Köppen classification). Mean annual precipitation ranging from 700 mm - 1600 mm, with annual temperature ranging from 15°C and 30°C, and varying soil types including a Typic Haplustox and Typic Acrustox, Latossolo Vermelho Amarelo, Dystrophic Red-yellow Latossol, and others.

2.2. Data: types, collection methods and sources, and analysis.

The variables used for this work, the sources and methods of analysis are described in Table 1 and Figure 1. We considered (1) availability of data (2) Periods with most significant change in the study area (3) the need for predicting for a closer year. Though, in the subsequent work that is ongoing, we are incorporating additional variables and predicting up to 2030 and 2050. Data covering all the related variables including land use-cover (LULC) were collected from the relevant sources as shown in Table 1. The LULC covered 2015 and 2020 (in raster format with 30m resolution). The data were preprocessed and geo-rectified in the GIS environment, and by the integration of R-statistics in RStudio, the MLA and geostatistical tools such as support vector machines (SVM) were employed to create a transition model (Fig.1).

Table 1. Brief description of datasets used for the study and analysis.

S/No	Data types	Resolution	Sources
1	Climate (Raster) • Land Surface Temperature • Humidity • Atmospheric Pressure • Precipitation • Soil Moisture	1km	USGS EarthData https://earthexplorer.usgs.gov/
2	SOC (Raster)	1km	FAO (https://www.fao.org/)
3	DEM (Raster)	30m	USGS EarthExplorer
4	Land use-land cover (Raster)	30m	Mapbiomas.com https://brasil.mapbiomas.org/
5	Biome Layer (Vector)	NA	SOTWIS, Mapbiomas
6	Administrative Boundary Layer (Vector)	NA	GADAM

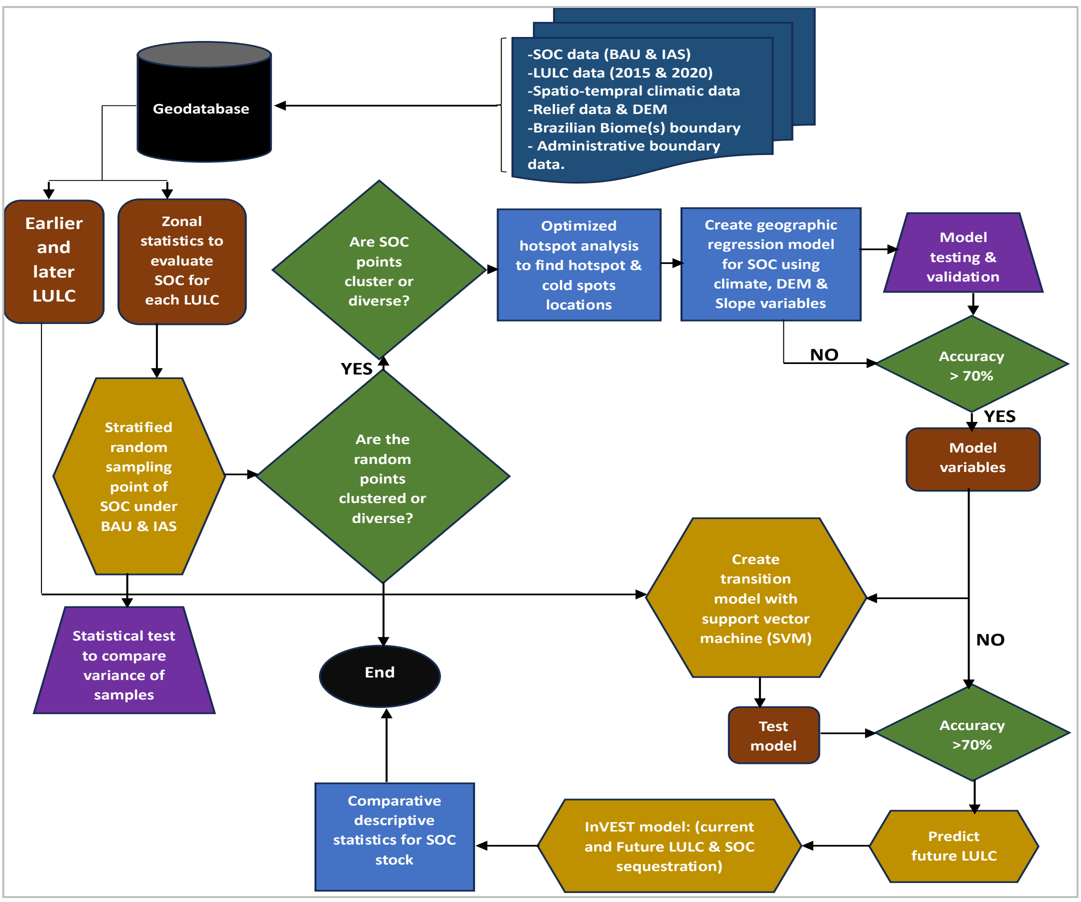

Fig. 1. Flowchart of the research methodology

The result passed through different test to ascertain a good accuracy (>70%). In GIS (TerrSet) a popular land use model software with very efficient tools for land use change modelling and prediction was used to predict the LULC change for 2025 by exporting the data for 2015

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and 2020 and running the required commands and processes. On the other hand, for the soil after determining the data for IAS and BAU, the InVEST model for carbon was used to model and predict the carbon sequestration/stocks. The InVEST Carbon Storage and Sequestration model is a spatially explicit model that utilizes maps of LULC coupled with stocks in four carbon pools to predict the rate of carbon stocked or sequestered in specific periods.

3. Results and discussions

3.1. Land use-land cover (LULC)

In all the years investigated including the predicted year, pastures (2,016,793 km^2) and savanna (1,789,150 km^2) covered more than 70% of the entire landscape when compared with the cropland areas and other LULC types (Fig. 2). The land areas for crops (e.g., sugarcane, soybeans, coffee, and other temporary and permanent crops) increased in 2020 and were predicted to cover about 10% more in areas in 2025 in place of the pastures especially. Furthermore, significant transitions were observed to have occurred between 2015 and 2020, and between 2020 and 2025, where agricultural areas and croplands increased in land areas (Fig. 3). This finding is consistent with previous studies in the area that reported the potential of crops particularly IAS serving as substitute for large areas of degraded pastures in the Cerrado biomes of Brazil [9]. The adoption of IAS with the growing of diverse crops and animal species has been identified as a more sustainable practice to promote the environmental and economic benefits of the region [9].

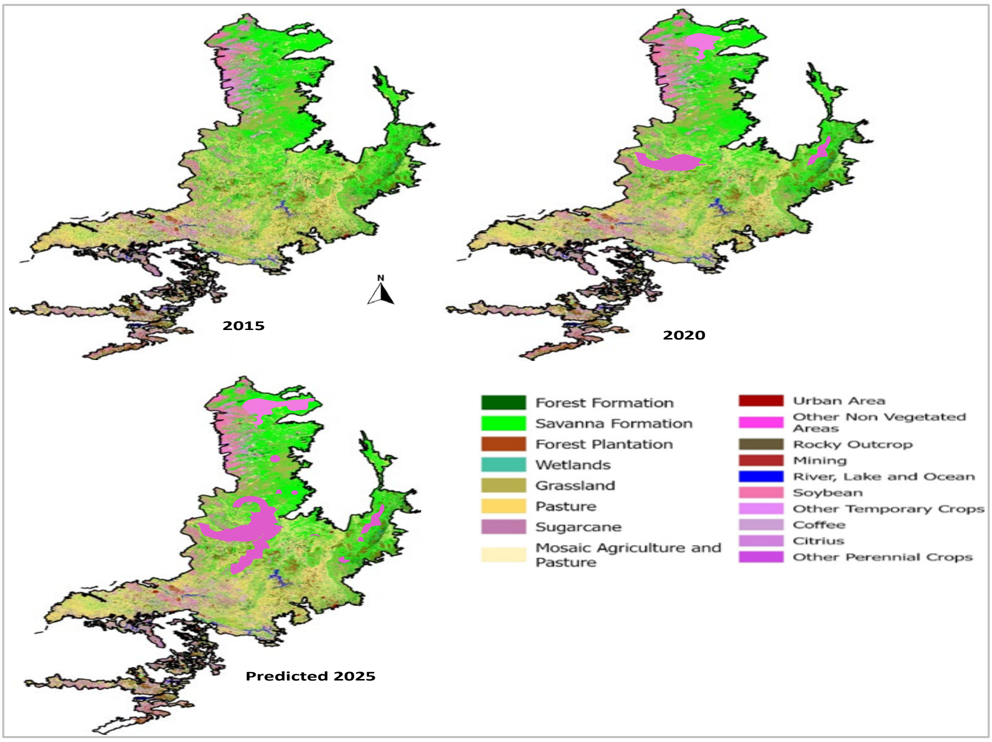

Fig. 2. Land use-cover in 2015, 2020, and 2025 in larger part of Cerrado, Brazil.

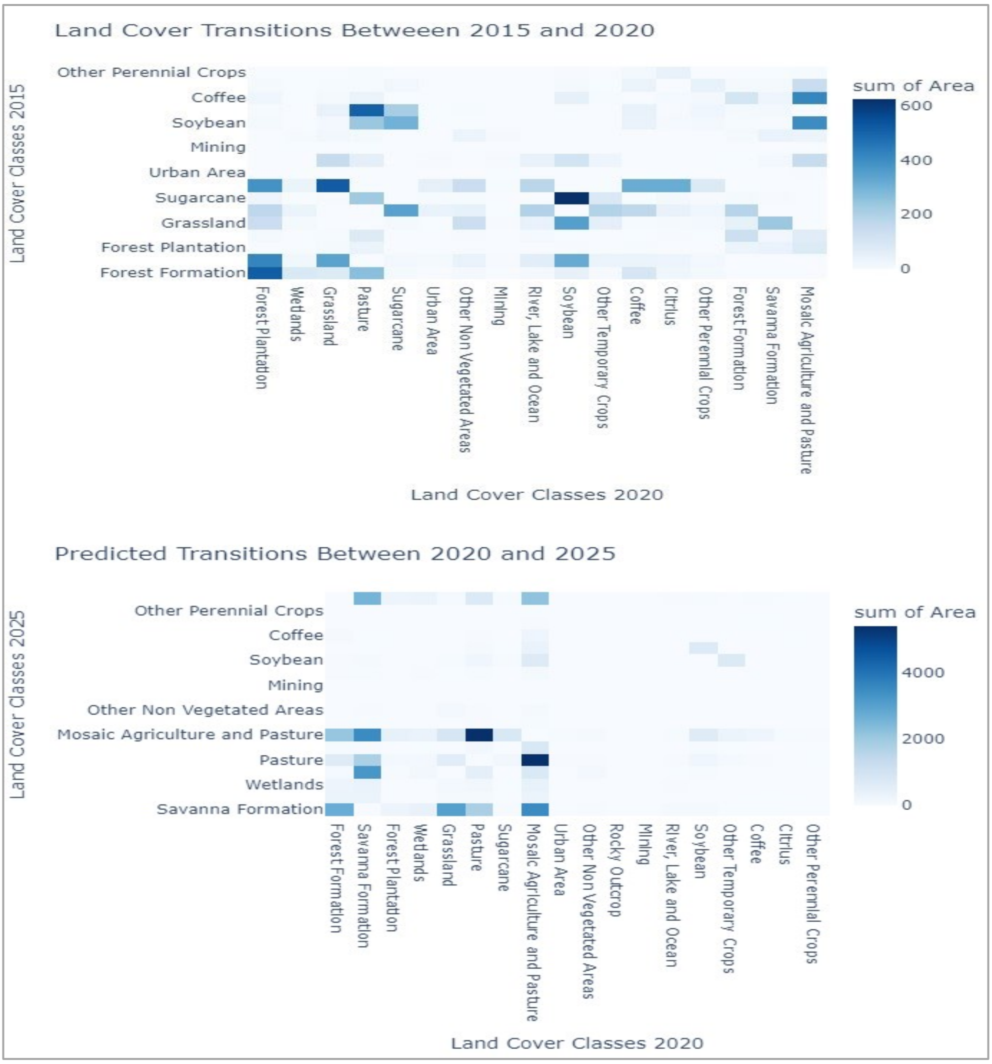

Fig. 3. Land use-cover transitions between 2015 and 2020, and between 2020 and 2025.

3.2. Dynamics in SOC

The integrated agricultural system/land management system (IAS/LMS) had the highest percentages of SOC in most of the land use-cover except for salt flat, other non-vegetated areas, urban area, wetlands, and mining areas where the business as usual (BAU) had more (Fig. 4a). Also, the study revealed that IAS recorded about 40% more SOC stock than BAU between 2015 and 2020 (Fig. 4b and c). It was not surprising to find higher SOC in the areas where most of the crops are sown especially soybean, sugarcane, and other temporary and permanent crop land areas. This could be attributed to the sustainable management of the agricultural through the intensive agricultural systems (IAS) which has diverse potential for promoting SOC stocks [10]. Integrated agricultural system has become a popular farming system adopted by the farmers since it has been inculcated Brazilian policies for the integration of crop-livestock-forest. Unlike the BAU which involves the traditional farming

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systems, the IAS is a low-carbon agricultural approach which serves as a nature-based solution to enhance carbon sequestration. Thus, supports the country in achieving sustainable environment with food security as well as meeting its National Determined Contributions (NDCs) agreement at the Paris Climate Change Summit [9].

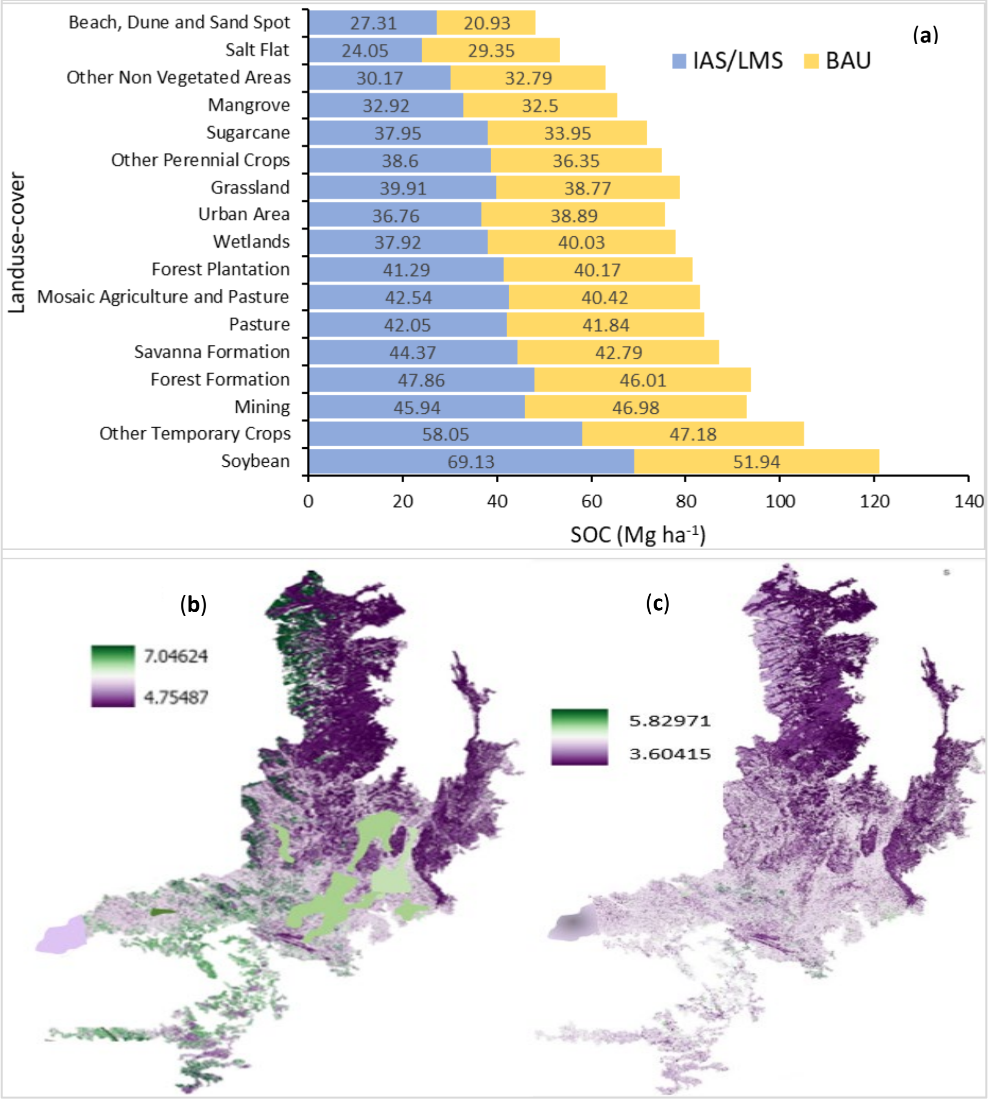

Fig. 4. (a) SOC stock for the IAS/LMS and BAU under the different land use-cover between 2015-2020, and SOC stock (kg m^{-2}) between 2015 and 2020 for (b) IAS (c) BAU

4. Conclusion

A larger part of Cerrado biome is however covered by pastures, savanna, and forest but the cropland areas are rapidly increasing, and might over time displace the pastures to become the most dominant land use. Significant transitions were found between 2015 and 2020, and between 2020 and 2025, with agriculture and croplands increasing in areas. The adoption of IAS could be principally responsible for this rise in croplands. The integrated agricultural system/land management system (IAS/LMS) accounted for the highest percentages of soil C in most of the LULC in comparison with the business as usual (BAU). The IAS had ~ 40% more SOC stock than BAU between 2015 and 2020. This might be explained by the environmental sustainability practices of IAS as a nature-based solution to achieving most SDGs including serving as a good sink for atmospheric CO_2, consequently enhancing C sequestration in the soil. The findings from the study will close the gap in knowledge about soil C stocks in greater part of the Cerrado. Results from the study has important information that could support the government of Brazil, the decision makers, and other stakeholders in smart-climate agriculture agendas to implement more IAS policies to improve carbon stocks and achieve more SDGs including food security.

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