IMPACT OF LAND USE MANAGEMENT ON SOIL CO_2 EMISSIONS IN MATO GROSSO DO SUL, BRAZIL

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ABSTRACT

The study investigates soil CO_2 emissions (FCO_2) across various land-use and land-cover types within three biomes of Mato Grosso do Sul, Brazil: Cerrado, Pantanal, and Atlantic Forest. It analyzes agricultural areas, eucalyptus plantations, pastures, and native vegetation using remote sensing models to assess variability in soil temperature, moisture, and CO_2 flux. Results show that eucalyptus and soybean areas in the Cerrado have the lowest FCO_2 emissions, while the Pantanal and Atlantic Forest, especially pastures, exhibit the highest. Eucalyptus plantations and native forests act as carbon sinks, highlighting the need to conserve native vegetation and promote sustainable agriculture for carbon neutrality. The study suggests expanding the scope to other regions and improving remote sensing models.

***Key words* —** Agriculture, CO_2 flux, remote sensing.

1. INTRODUCTION

Soil respiration, also referred to as carbon dioxide efflux (FCO2) from soil, is an essential element of GHG emissions to the atmosphere in natural ecosystems [1]. The temporal variability of FCO2 is influenced by biotic and abiotic factors, such as changes in temperature, moisture, physical attributes, litter amount, and organic matter content [1, 2, 3].

The replacement of native vegetation areas with agriculture can lead to alterations in the physical, chemical, and biological characteristics of the soil, triggering an imbalance in the dynamics of organic matter deposition, which consequently increases the carbon emission in the form of gases into the atmosphere [4, 5, 6].

Thus, knowing the variability of FCO2 emissions in agricultural areas and their relationship with climatic variables is crucial to drive sustainable development as well as contribute to supplying the growing carbon markets [7, 8]. Considering this, the objective of this study is to estimate the FCO2, the CO_2 flux model (obtained by remote sensing), temperature (ST) and soil moisture (SM).

2. MATERIAL AND METHODS

2.1. Study area

The investigation took place in the state of Mato Grosso do Sul (MS), located in the Central-West region of Brazil, covering an area of 357,145.32 km² and comprising 78 municipalities. The region exhibits a diverse range of edaphoclimatic characteristics, distributed across three main biomes: the Cerrado, the Atlantic Forest, and the Pantanal. (Fig. 1).

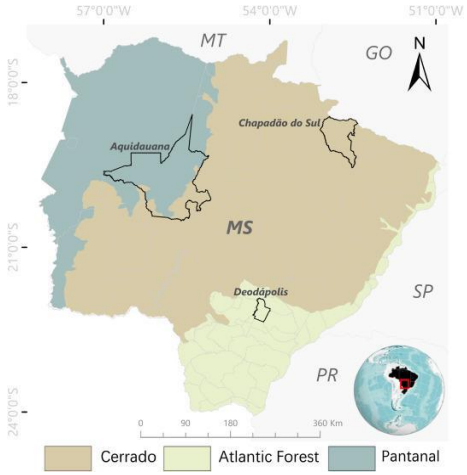


Figure 1. Location of municipalities (Chapadão do Sul, Aquidauana and Deodápolis) in the different biomes of the State of Mato Grosso do Sul (MS), Brazil.

2.1. Data

Four LULC classes were evaluated in each biome: agriculture, pasture, eucalyptus plantation, and native vegetation. For the class agriculture, areas that grow soybean during the first crop season (known as "safra") with a history of at least four crop years were chosen. In these areas, the evaluations occurred during the vegetative peak of the crop, approximately 60 days after emergence (DAE). The remaining evaluations were carried out in areas containing each LULC for at least four years. Additionally, native vegetation was evaluated as a way of having a reference LULC, i.e. areas with optimal CO_2 flow conditions due to the absence of anthropization.

The evaluations in the Cerrado, Pantanal, and Atlantic Forest biomes were carried out within the municipalities of Chapadão do Sul, Aquidauana and Deodápolis, respectively (Figure 1).

For soil CO_2 emission *in situ* (FCO_2) assessments, the portable EGM-5 system (PP-Systems, Amesbury, USA), model AGA560, was used at 100 points for each LULC in each biome. EGM-5 system has been used for in-situ data acquisition in recently published studies [9, 10, 11, 12].

FCO_2 was measured at each sampling point by adjusting the air CO_2 concentration inside the chamber according to a quadratic regression over the time after its closing and water offset. The measuring procedure to assess CO_2 emissions from the soil took 30 s at each point and the barometric pressure inside the chamber was calculated every 1.0 s, totaling 30 readings per sampling point. FCO_2 (µmol m^{-2} s^{-1}) was calculated was proposed by [13].

The soil temperature at the same collection points was monitored using a temperature sensor that is an integral component of the ACS044 system. Similarly, soil moisture was recorded using a HydraProbe sensor device (Stevens). Soil temperature and soil moisture assessments were performed together with soil CO_2 emission assessments. All measurements *in situ* along the LULC took place in the same week between November 16th and 19th, 2022. During these evaluations there was no rain in the evaluated areas.All measurements *in situ* along the LULC took place in the same week between November 16th and 19th, 2022. During these evaluations there was no rain in the evaluated areas.

CO_2Flux model [14] was adopted as a way of estimating CO_2Flux via remote sensing data and to assess the effectiveness of the vegetation-related carbon sequestration in the same 100 points of each LULC and biome evaluated. For this purpose, the scaled photochemical reflectance index (sPRI) was calculated proposed by [15] and [16]. This index is related to the carotenoid content in the leaves and, consequently, to the CO_2 storage rate [14].

Subsequently, the NDVI (Normalized Difference Vegetation Index) was proposed by [17]. This index is associated with the vigor of photosynthetically active vegetation [14].

2.2. Approach

Refining the accuracy and calibration of the CO_2Flux model in Brazil, using direct measurement of CO_2 fluxes through the turbulent vortex covariance technique, as described by [18] and validated by [19]. The spectral reflectance used for CO_2Flux calculation were obtained using images from the fully automated cloud-based Planet platform (https://www.planet.com/products/platform) for online image download, processing, and management with a 3 m spatial resolution.

3. RESULTS

Soil CO_2 emission *in situ* (FCO_2) showed high variability between biomes and LULC classes (Figure 2). Regardless of the biome, the lowest values were obtained in eucalyptus and soybean cultivation (agriculture). In LULC, the Cerrado biome presented the lowest values. The significant impact of land use activities, with pasture management, in the Pantanal and Atlantic Forest biomes resulted in elevated FCO_2 levels. Native forests presented intermediate FCO_2 and similar values across biomes.

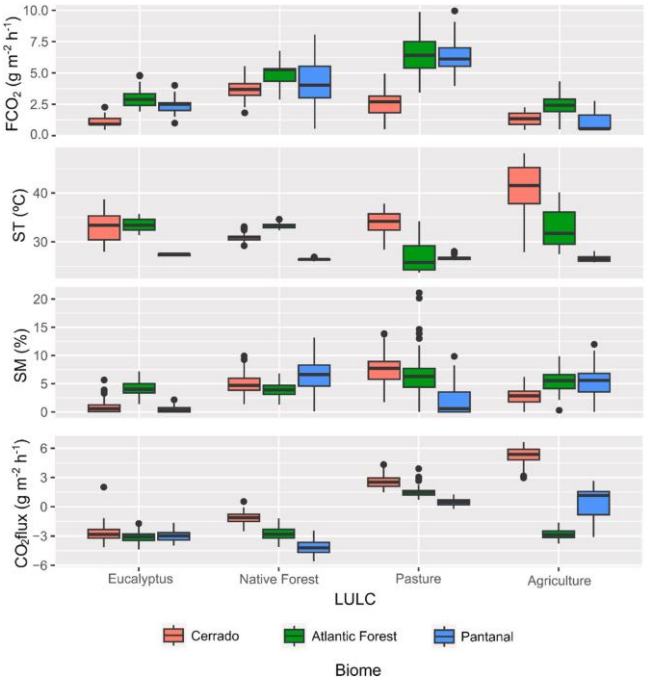


Figure 2. Boxplot para as variáveis emissão de CO_2 do solo *in situ* (FC_2), umidade do solo (SM), temperatura do solo (ST) e fluxo de CO_2 avaliadas em diferentes usos e coberturas do solo nos biomas do Mato Grosso do Sul, Brasil.

Soil temperature (ST) showed high variability in the Cerrado and Atlantic Forest biomes in all LULC classes, except for the native forest. Pantanal showed the lowest ST variability and means, regardless of LULC. In Cerrado, soybean cultivation presented the highest mean ST. On the other hand, eucalyptus plantation presented the highest mean

in the Atlantic Forest. Soil moisture (SM) obtained the lowest means and variability in eucalyptus cultivation, especially in the Cerrado and Pantanal biomes. The SM values in the native forest showed higher variability in the Pantanal biome, while the other biomes showed similar mean and variability. In Pasture, the lowest mean SM was obtained in the Pantanal, while in soybean cultivation the lowest mean was observed in the Cerrado.

Eucalyptus cultivation and native forests showed negative CO_2Flux values, regardless of biome. The remaining LUC classes presented positive CO_2Flux means in all biomes, except for soybean cultivation in the Atlantic Forest. Higher variability was found in soybean cultivation compared to the other LULC classes.

Figure 3 shows the PCA for the variables evaluated in the three biomes of the State of Mato Grosso do Sul. It is evident that the points sampled in the Cerrado biome are the most separated from the others in the biplot. These points are close to the ST vector, as this biome obtained the lowest means and variability for its LULC classes.

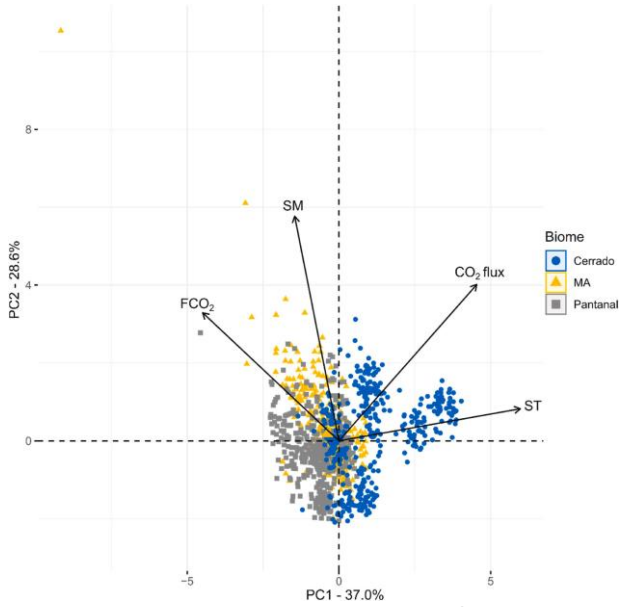


Figure 3. Principal component analysis for the variables soil CO_2 emission *in situ* (FCO_2), soil moisture (SM), soil temperature (ST), and CO_2Flux evaluated in the biomes Cerrado, Atlantic Forest (MA) and Pantanal of Mato Grosso do Sul, Brazil.

The similarity between Atlantic Forest and Pantanal is associated with the FCO_2 vector, where these biomes obtained the highest means and variability for this variable.

4. DISCUSSION

Differences in soil carbon dioxide flux in situ between LULC classes can be induced by soil property conditions, vegetation composition, soil organic matter (SOM), and interactions between these factors. The amount of carbon contained in SOM has been lost since the 1850s by land use change and increasing pressure on agroecosystems by rising global demand for energy and food [20, 21].

Eucalyptus and soybean cultivation exhibit the lowest FCO2 values across biomes due to their lower vegetation metabolic activity, resulting in reduced CO2 emissions. As noted by [22], soybean shows low FCO2 values in both high- and low-productive systems. These crops are economically and environmentally significant, making them suitable for carbon neutralization strategies, such as low-carbon agriculture. They can help restore degraded pastures or integrate with productive pasture areas in systems like crop-livestock-forest models.

Changes in land use in agriculture result in high carbon emissions, contributing to climate change. In addition, monoculture generates several environmental impacts, including soil restriction, loss of biodiversity, alteration of the hydrological cycle, and manipulation of hydrological resources due to the use of chemicals. From a socioeconomic point of view, large-scale agriculture tends to concentrate large areas and large financial values [23].

While the estimate of carbon loss during the transformation of the native landscape is a fundamental indicator, it does not encompass all the environmental and socioeconomic effects associated with this activity [24]. This underscores the importance of considering a broader perspective in carbon mitigation planning, integrating environmental, economic, and social dimensions to effectively address the challenges posed by land use changes in agriculture.

5. CONCLUSIONS

The results of this study show the variability of soil CO_2 emissions (FCO_2) across different land use and land cover (LULC) types and biomes. The lowest FCO_2 values were observed in eucalyptus and soybean cultivation areas, especially in the Cerrado, while the highest emissions were recorded in Pantanal grasslands and the Atlantic Forest. The Pantanal had the lowest average soil temperature, and eucalyptus cultivation showed the lowest soil moisture, particularly in the Cerrado and Pantanal. Additionally, the study identified negative CO_2 fluxes in eucalyptus plantations and native forest areas, highlighting their role as carbon sinks. This underscores the importance of preserving native vegetation and strategically growing soybeans and eucalyptus for carbon neutrality initiatives. Finally, it is recommended that future research expand the analysis to different geographic and climatic conditions and improve remote sensing models.

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