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**UNIVERSIDADE ESTADUAL PAULISTA - UNESP  
CÂMPUS DE JABOTICABAL**

**CARBON DIOXIDE DYNAMICS THROUGH ORBITAL AND  
TERRESTRIAL MEASUREMENTS ON AMAZONIAN CROP  
AND FOREST LANDS**

**Fernando Saragosa Rossi**

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**Fernando Saragosa Rossi**

**Advisor: Prof. Dr. Newton La Scala Júnior**

**Co-Advisor: Prof. Dr. Carlos Antonio da Silva Junior**

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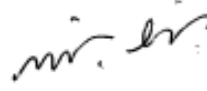
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## **AUTHOR'S CURRICULUM DATA**

**FERNANDO SARAGOSA ROSSI** – Son of Osvaldo Saragosa Rossi and Ana Aparecida Bandini Rossi, he was born in Ivaté - PR, on March 11, 1986. He attended minor elementary school at the Escola Estadual Ouro Verde and the middle school at the Colégio Ágora, in that same school he finished high school in 2003. From 2005 to 2006, he attended the technician/professional course in Technician in Informatics. Escola Tecnica de Viçosa, ETEV, Brazil and also took a technical/professional course in Technician in Electrotechnics. Charles Babbage Teaching Institution, UNIORKA, Brazil. In 2007, he joined the Computer Science course at Universidade Paulista, UNIP, Brazil with the course completion work entitled "Prototype in Interactivity Software for Digital TV" under the guidance of professor Mário Henrique Souza Pardo. He worked from 2011 to 2015 at the company Odebrecht Energia e Infraestrutura. In 2018, he started the Master's degree in Mestrado em Biodiversidade e Agroecossistemas Amazônicos, at the Universidade do Estado de Mato Grosso, UNEMAT, Campus of Alta Floresta - MT. On February 12, 2017, he submitted to the Master's defense, approved as a Master in Biodiversidade e Agroecossistemas Amazônicos. In March 2020, he started his Ph.D. course in Agronomy (Soil Science) also from FCAV-UNESP. In January 2023, he submitted the doctoral thesis to an examination panel, and received his Ph.D. degree in Agronomy (Soil Science) at UNESP/FCAV.

“You can look at a mistake as bullshit to be forgotten or as a result that points  
you in a new direction.”

Steve Jobs

## I DEDICATE

To my father **Oswaldo Saragosa Rossi** and my mother **Ana Aparecida Bandini Rossi** for their unconditional support in all the difficult moments of my life. This work is dedicated to them. Eternal gratitude.

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## DINÂMICA DO DIÓXIDO DE CARBONO ATRAVÉS DE MEDIÇÕES ORBITAIS E TERRESTRES EM TERRAS DE CULTIVO E FLORESTAS AMAZÔNICAS

**ABSTRACT** - A emissão de dióxido de carbono ( $\text{CO}_2$ ) do solo é reconhecida como o segundo maior fluxo de carbono (C) entre os ecossistemas terrestres e a atmosfera. Nas áreas agrícolas, é um processo resultante da interação de diferentes fatores, tais como clima, condições do solo e investimento tecnológico. Assim, estudos capazes de caracterizar a dinâmica do  $\text{CO}_2$  são importantes na busca da compreensão das relações entre os atributos do solo em diferentes sistemas de produção. O trabalho foi realizado em quatro capítulos, desenvolvidos no estado de Mato Grosso e Mato Grosso do Sul. No capítulo 1, foram apresentadas as considerações gerais do estudo. No capítulo 2, avaliamos a variabilidade temporal da emissão de  $\text{CO}_2$  do solo e sua relação com variáveis relacionadas como fluxo de  $\text{CO}_2$  ( $\text{CO}_2\text{Flux}$ ) derivado de processos fotossintéticos, Índice de Vegetação Melhorada (EVI), Produtividade Primária Bruta (GPP), Índice de Área Foliar (LAI), Temperatura do Solo (Ts) e Umidade do Solo (Us), no ano safra 2020/2021 na Fazenda Aurora, que está localizada no município de Cláudia no Estado do Mato Grosso com os diferentes usos e ocupação do solo: soja de baixo potencial de rendimento (SB); floresta nativa (FN); soja de alto potencial de rendimento (SA); bom pasto (PB) e pasto degradado (PD). Influência significativa ( $p < 0,01$ ) foi encontrada neste capítulo para todas as variáveis analisadas e entre os diferentes usos do solo e cobertura da terra. Os valores  $\text{FCO}_2$  para SA e SB com os valores mais baixos e para FN com os valores mais altos sendo o oposto para  $\text{CO}_2\text{Flux}$ . No capítulo 3, foi avaliada a relação entre o fluxo de dióxido de carbono no solo e os índices multiespectrais da vegetação em um sistema de monocultura de espécies de eucalipto, no campo experimental da Universidade Federal de Mato Grosso do Sul, Campus de Chapadão do Sul onde a área é composta por cinco espécies de eucalipto: *E. camaldulensis*, *E. urophylla*, *E. saligna*, *E. grandis* e *E. urograndis* e *Corymbria citriodora*. No capítulo 3, a umidade do solo apresenta uma correlação negativa entre  $\text{FCO}_2$  e significativa ( $p < 0,05$ ), provou ser um dos fatores importantes no controle da respiração do solo. Os índices de vegetação NDRE (Normalized Difference Red-Edge Index), NDVI (Normalized Difference Vegetation Index), SAVI (Soil-Adjusted Vegetation Index) e MSAVI (Modified Soil-Adjusted Vegetation Index) mostraram maior correlação negativa com  $\text{FCO}_2$ , e uma influência significativa de  $p < 0,001$  para as espécies *E. camaldulensis*, *E. saligna* e *E. urophylla*. No capítulo 4, a detecção remota foi usada para avaliar a dinâmica espaço-temporal do  $\text{CO}_2$  de 2015 a 2018 no estado de Mato Grosso, que é a principal fronteira agrícola do Brasil. Os resultados do capítulo 4 mostraram que a variabilidade temporal do fluxo de  $\text{CO}_2$  está positivamente correlacionada com a precipitação, enquanto que o  $X_{\text{CO}_2}$  está negativamente correlacionado com a precipitação. Portanto, não somente o  $X_{\text{CO}_2}$ , mas também o fluxo de  $\text{CO}_2$  estão diretamente relacionados ao uso da terra e à mudança de cobertura do solo (LULCC) em sistemas complexos que são afetados por variáveis e processos climáticos, como a fotossíntese e a respiração do solo.

**Keywords:** Fluxo de  $\text{CO}_2$ , Uso da terra e cobertura da terra, Agricultura, Gases de efeito estufa

## CARBON DIOXIDE DYNAMICS THROUGH ORBITAL AND TERRESTRIAL MEASUREMENTS ON AMAZONIAN CROP AND FOREST LANDS

**ABSTRACT** - The soil carbon dioxide (CO<sub>2</sub>) emission, is recognized as the second largest carbon (C) flux between terrestrial ecosystems and the atmosphere. In agricultural areas it is a process resulting from the interaction of different factors, such as climate, soil conditions and technological investment. Thus, studies capable of characterizing the dynamics of CO<sub>2</sub> are important in the search for understanding the relationships between soil attributes in different production systems. The work was conducted in four chapters, developed in the state of Mato Grosso and Mato Grosso do Sul. In chapter 1, the general considerations of the study were presented. In chapter 2, we evaluated the temporal variability of CO<sub>2</sub> emission from soil and its relation with related variables as CO<sub>2</sub> flux (CO<sub>2</sub>Flux) derived from photosynthetic processes, Enhanced vegetation index (EVI), Gross Primary Productivity (GPP), Leaf Area Index (LAI), Soil Temperature (Ts) and Soil Moisture (Ms), in the crop year 2020/2021 in Aurora Farm, which is located in the municipality of Cláudia in the State of Mato Grosso with the different land uses and occupation: low yield potential soybean (SB); native forest (FN); high yield potential soybean (SA); good pasture (PB) and degraded pasture (PD). Significant influence ( $p < 0.01$ ) was found in this chapter for all variables analyzed and between the different land uses and land cover. The FCO<sub>2</sub> values for SA and SB with the lowest values and for FN with the highest values being the opposite for CO<sub>2</sub>Flux. In chapter 3, were evaluated the relation between the flux of carbon dioxide from soil and multispectral indices of vegetation in a monoculture system of eucalypt species, in the experimental field of the Federal University of Mato Grosso do Sul, Campus de Chapadão do Sul where the area is composed of five species of eucalyptus: *E. camaldulensis*, *E. urophylla*, *E. saligna*, *E. grandis* and *E. urograndis* and *Corymbria citriodora*. In chapter 3 soil moisture has a negative correlation between FCO<sub>2</sub> and significant ( $p < 0.05$ ), proved to be one of the important factors in controlling soil respiration. The vegetation indices NDRE (Normalized Difference Red-Edge Index), NDVI (Normalized Difference Vegetation Index), SAVI (Soil-Adjusted Vegetation Index) and MSAVI (Modified Soil Adjusted Vegetation Index) showed higher negative correlation with FCO<sub>2</sub>, and a significant influence of  $p < 0.001$  for *E. camaldulensis*, *E. saligna* and *E. urophylla* species. In chapter 4, remote sensing was used to evaluate the spatio-temporal dynamics of CO<sub>2</sub> from 2015 to 2018 in the state of Mato Grosso, which is the main agricultural frontier in Brazil. The results of chapter 4 showed that the temporal variability of CO<sub>2</sub> flux is positively correlated with precipitation, while X<sub>CO2</sub> is negatively correlated with precipitation. Therefore, not only X<sub>CO2</sub>, but also CO<sub>2</sub>flux are directly related to land use and land cover change (LULCC) in complex systems that are affected by climatic variables and processes, such as photosynthesis and soil respiration.

**Keywords:** CO<sub>2</sub> flux, Land use and land cover, Agriculture, Greenhouse Gas

## CHAPTER 1 – GENERAL CONSIDERATIONS

### 1 INTRODUCTION

The conversion of land use and land cover is currently one of the main impacts to the environment, and as consequence of the loss of local biodiversity and carbon emissions. This data survey is essential to report on the fulfillment of the goals signed with the civil society and international organizations, besides being important in the elaboration of strategies for the improvement of public policies. While the preservation and conservation of vegetation is necessary for CO<sub>2</sub> recycling, there is a need for large-scale food production, relative to the world population increase.

The expansion and modernization of agriculture implies on socio-environmental impacts such as the different areas occupied by soybean cultivation and thus, forest areas were replaced by agriculture, promoting intensification of the forest fragmentation process (ITAQUI, 2002; SILVA; LIMA, 2018b). However, the factors favorable to soybean farming and the support of the Federal Government were fundamental for its rapid expansion in the country (BATISTA FARIAS, 2018; SOARES; SPOLADOR; OTHERS, 2016).

The soil is an important carbon pool, and its quantity variation has direct interference in CO<sub>2</sub> concentrations, and can signal low or high concentrations of this important greenhouse gas (GHG) in the system. Therefore, soil CO<sub>2</sub> emission rates (FCO<sub>2</sub>) is directly related to loss or gain of soil organic carbon, arising from the complex dynamics among soil attributes and the climatic conditions (LAL; NEGASSA; LORENZ, 2015; SILVA-OLAYA et al., 2013b) related to emissions variations, due to its great variability in time and space (DE BORTOLI TEIXEIRA et al., 2011; EPRON et al., 2006).

For better estimates of soil respiration, it is first necessary to describe its temporal variability and the relation among soil respiration and environmental variables, such as soil temperature and soil moisture (SILVA et al., 2019; XAVIER et al., 2020), both with orbital and in situ sensors. In this context, several studies seek the comprehension of agricultural practices and their respective productivities effects on increasing atmospheric concentrations of GHGs, particularly CO<sub>2</sub> (LA SCALA; BOLONHEZI; PEREIRA, 2006; MOITINHO et al., 2015; SILVA et al., 2019).

Thus, few works have sought to compare environmental variables assessed via remote sensing techniques against those obtained in situ with the flux chamber, and

especially to compare CO<sub>2</sub> emission data in areas of different levels of soybean crop productivity. Understanding the spatial variability of CO<sub>2</sub> emission at different levels of data acquisition in agricultural areas becomes important for the conduction of a controlled and sustainable management of the culture for the preservation of carbon in the soil, thus contributing to the reduction of the greenhouse effect and the agility in measurement with orbital data.

Sensors onboard land monitoring satellites obtain data that assist in understanding the global distribution of vegetation types, agricultural crops, as well as their biophysical and structural properties in spatial-temporal variations (DIDAN et al., 2015). Vegetation indices allow monitoring seasonal, interannual and long-term variations in vegetation structure, phenological and biophysical parameters (HUETE et al., 2002), as well as changes in climatic variables.

The hypothesis of this study is that changes in land use affects either the soil CO<sub>2</sub> emission (FCO<sub>2</sub>) or the CO<sub>2</sub> flux model (CO<sub>2</sub>Flux) and those could be related to vegetative aspects like Enhanced Vegetation Index (EVI) and Leaf Area Index (LAI), resulting from modifications of the land use and land cover (LULC) system and environmental factors, which exhibit spatial and temporal variability.

Thus, the objective of the study is to evaluate the spatial and temporal characteristics of FCO<sub>2</sub> and CO<sub>2</sub>Flux as function of climate and multispectral vegetation indexes in contrasting land uses in crop and forest lands of the state of Mato Grosso and Mato Grosso do Sul, Brazil.

## CHAPTER 5 – GENERAL CONCLUSIONS

Monitoring the Earth's surface and the dynamics of its vegetation studies using remote sensing techniques are essential to the environment. With the advent of automatics and programming technologies, it is possible to monitor the entire Brazilian territory using remote sensing techniques. These tools provide and contribute to the distinction and characterization of forests, agriculture, weather, and CO<sub>2</sub> flow. Sensors on board environmental satellites provide data that help to understand the global distribution of vegetation types, as well as their biophysical and structural properties and spatial-temporal variations.

Land use and land cover change is currently one of the biggest impacts caused to the environment and having several consequences, as the loss of local biodiversity and C (carbon) emission. This data survey is essential to report on the achievement of the targets signed with the civil society and international organizations, besides being important in the elaboration of strategies for the improvement of public policies. Thus, the land use and cover change survey in a timely and objective way contribute to action strategies for commercialization establishment, regulation of strategic stocks, and growth of new areas in a controlled manner, which makes it economically and environmentally important for a country.

The results found in this study present an important contribution to a better understanding of greenhouse gases dynamics in the states of Mato Grosso and Mato Grosso do Sul. Thus, in this study the total soil respiration and the multispectral vegetation indices used to evaluate the spatial-temporal dynamics in areas with contrasting land use with soybean cultivation in the state of Mato Grosso and in a monoculture system of eucalyptus species in the state of Mato Grosso do Sul, show that in areas of native forest there are higher emissions of FCO<sub>2</sub> and lower values for CO<sub>2</sub>Flux compared to soybean areas in the northern region of the state of Mato Grosso. When we applied remote sensing to assess the spatial-temporal dynamics of CO<sub>2</sub> across the state of Mato Grosso, we detected that not only X<sub>CO<sub>2</sub></sub>, but also CO<sub>2</sub> flux are directly related to land use and land cover change (LULC) in complex systems that are affected by climatic variables and processes, such as photosynthesis and soil respiration. For the state of Mato Grosso do Sul the results show that there is a strong correlation between canopy spectral response and chlorophyll content in eucalypt

species, with the most important spectral regions being green and near infrared. The results make it possible to differentiate FCO<sub>2</sub> among eucalypt species using sensors airborne to unmanned aerial vehicle. This relation depends on the contribution of roots, soil organic matter, plant residues, canopy spectral response, and chlorophyll content of the eucalypt species.

Therefore, in order to collaborate with sustainable production, reduction of C emissions and contribute to the 17 Sustainable Development Goals (SDGs), to take urgent action to combat climate change and its impacts, we suggest that the information obtained in this work can be used to support new research in decision making by society, over the effects of climate change through technical strategies, but also for agencies seeking solid strategies for environmental conservation and sustainable development.

In this sense, strategies such as agricultural inventories considering CO<sub>2</sub> emissions from the soil estimates over integrated agricultural systems, which include arboreal plants as an element of the agroecosystems, soil management, such as no-till farming practices, and crop rotation, can and should play an important role in mitigating deforestation and CO<sub>2</sub> emissions at the soil-atmosphere interface.

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