I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:

Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

September 4th and 5th, 2023

Research Centre for Greenhouse Gas Innovation

USP

FAPESP

PROGRAMME AND BOOK OF ABSTRACTS

I SEMINAR ON NATURE-BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:

Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

September 4th and 5th, 2023

RCGI Nature Based Solutions Programme Director:
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We gratefully acknowledge the support of the RCGI – Research Centre for Greenhouse Gas Innovation, hosted by the University of São Paulo (USP) and sponsored by FAPESP – São Paulo Research Foundation (2020/15230-5; 2014/50279-4) and Shell Brasil, and the strategic importance of the support given by ANP (Brazil's National Oil, Natural Gas and Biofuels Agency) through the R&DI levy regulation.

Welcome

It is a great pleasure to present this e-book of the I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY: Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil, occurred virtually in September 4th and 5th, 2023. This event was one initiative of Nature Based Solution (NBS) program of Research Center for Greenhouse Gas Innovation (RCGI).

To mitigate global warming and climate changes is one of the major challenges for humankind in the XXI century. Bearing in mind the importance of joint action by all countries in the world to mitigate GHG emissions and the negative impact of climate change, the Paris Agreement was signed by most of the countries aiming to ensure global warming below 2 °C by 2050 with efforts to limit it to 1.5 °C. Brazil assumed a voluntary commitment (Nationally Determined Contributions - NDCs) to reduce GHG emissions by 37% by 2025 and 50% by 2030, compared to baseline (2005). To do so, one the commitments of Brazil's NDC was strengthening its sectorial policies to promote the adoption of nature-based solutions (NBS), such as restore 12 million of ha of native vegetation, rehabilitate 30 million ha of degraded pastures and enhancing 5 million ha of integrated agricultural systems (IASs).

In this context, the Research Center for Greenhouse Gas Innovation (RCGI) – a center sponsored by FAPESP and SHELL, created in 2021 a new research program called Nature Based Solution (NBS). The NBS program has the main goal of "**promoting the development of sustainable solutions that help Brazil to fulfill its goals (NDCs) in the Paris Agreement aiming to mitigate global warming, as well as to support the provision of ecosystem services, encourage social well-being and support the elaboration of public policies**". The NBS program is composed by three thematic projects intitled i) "Restoration of native vegetation for carbon sequestration – RestoreC", ii) "Soil carbon sequestration through integrated agricultural systems in Brazil – Ag4C", and iii) "Improving pasture management as NBS for soil carbon sequestration in Brazil – Pasture4C". The NBS program involves more than 20 researchers and 70 students and postdocs distributed at "Luiz de Queiroz" College of Agriculture (ESALQ)/ University of São Paulo (USP), the host institution of NBS coordination, and other partners renowned Universities and Research institutions of Brazil.

The program of the I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY included the welcome from RCGI and NBS coordination and SHELL NBS Technology Lead.

In the sequence of the first day, distinguished researchers presented important concepts, advances and perspectives in three roundtables related to the application of NBS from macroscale to microscale, including forest restoration strategies and opportunities, carbon farming and challenges to measure greenhouse gas emission and C sequestration in the soil.

The second day of event was dedicated to presentation of students associated to the projects. In the total, 36 abstracts were submitted and 25 were selected to presentation. The students and postdocs presented the main achievements of their research, as well as allows the audience to realize the quantity and the quality of information that are being generated in the NBS program, including short- medium and long-term studies in different biomes, type of soil and experimental designs. In addition, valuable studies of literature review, meta-analyses, modelling, and scenario analysis have been performed.

I would like to acknowledge the brilliant work of the colleagues that composed the Organizing Committee, Scientific Committee and the RCGI Design & Communication Support.

The success of this event was necessarily due to your effort and competence. Finally, I would like to thank all speakers, moderators, students, and external public that attended in the I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY.

I am looking forward for having the second edition!

Prof. Dr. Maurício Roberto Cherubin
Deputy-director of RCGI Nature Based Solution Program

PROGRAMME

September 4th, 2023

Data	Slot	Activity	Speakers:
4th September	09:00 -10:00	Abertura	Júlio Romano Meneghini (Diretor Científico do RCGI) Barbara Samartini Queiroz Alves - NBS Technology Lead (SHELL) Carlos Eduardo Pellegrino Cerri (ESALQ) Organizing Committee
4th September	10:00 – 12:00	Round Table	The use of "Nature-based Solutions" to mitigate GHG emissions: multiple approaches from macro to micro. Speakers: David Montenegro Lapola (UNICAMP) Ricardo de Oliveira Bordonal (CNPEM) Pedro Henrique Santin Brancalion (ESALQ) Moderators Leidvan Almeida Frazão (UFMG) Stoécio Malta Ferreira Maia (IFAL)
4th September	14:00 - 15:30	Lecture	Strategies and challenges in assessing carbon sequestration in the soil. Speaker: Cimélio Bayer (UFRGS) Moderators João Luís Nunes Carvalho (CNPEM) Newton La Scala Júnior (UNESP)
4th September	15:30 – 17:00	Lecture	Carbon sequestration in agricultural areas: opportunities and market. Speaker: Mauricio Roberto Cherubin (ESALQ) Moderators Dener Márcio da Silva Oliveira (UFV) Carlos Gustavo Tornquist (UFRGS)

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Full Presentations are available in:
https://www.youtube.com/RCGIUSP

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September 5th, 2023

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	NOVEL FIELD-BASED MODELS TO MONITOR ABOVEGROUND CARBON ACCUMULATION OF FOREST UNDER RESTORATION
08:45 – 09:00	Ana Paula Ferez Orientador: Pedro Brancalion (ESALQ)
	ADDRESSING LIMITATIONS IN THE CLASSIFICATION OF SUCCESSIONAL STAGES TO IMPROVE THE CONSERVATION OF THE ATLANTIC FOREST
09:00 – 09:15	Angelica Faria de Resende Orientador: Pedro Brancalion (ESALQ)
	GRAZING EXCLUSION: A NATURE-BASED SOLUTION TO INCREASE SOIL ORGANIC CARBON IN BRAZILIAN DESERTIFIED DRYLANDS
09:15 – 09:30	Antônio Yan Viana Lima Orientador: Mauricio Roberto Cherubin (ESALQ)
	DATABASE PREPARATION FOR MODELING SOIL CARBON DYNAMICS
09:30 – 09:45	Bianca Ott Andrade Orientador: Carlos Gustavo Tornquist (UFRGS)
	SPATIAL VARIATION OF SOIL ORGANIC CARBON CONTENT IN BRAZILIAN SOYBEAN CROPLANDS
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10:15 – 10:30	Crislâny Canuto dos Santos Orientador: Stoécio Malta Ferreira Maia (IFAL)
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	Orientador: Carlos Eduardo Pellegrino Cerri (ESALQ)
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	Orientador: João Luiz Nunes Carvalho (CNPEM)
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16:45 – 17:00	Thamirys Suelle da Silva
	Orientador: Stoécio Malta Ferreira Maia (IFAL)
	SOIL CARBON CHANGES AFTER INTENSIFICATION OF AGRICULTURE AND LIVESTOCK IN THE BRAZILIAN BIOMES: A META-ANALYSIS
17:00 – 17:15	Warley Rodrigues de Oliveira
	Orientador: Leidivan Almeida Frazão (UFMG)

ABSTRACTS

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

GRAZING EXCLUSION: A NATURE-BASED SOLUTION TO INCREASE SOIL ORGANIC CARBON IN BRAZILIAN DESERTIFIED DRYLANDS

Antônio Yan Viana Lima[1]; Lucas Tadeu Greschuk[1]; Arthur Prudêncio de Araújo Pereira[2]; Maurício Roberto Cherubin[3].

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Keywords: Sustainable Development Goal; Brazilian semiarid; degraded land restoration.

Impact: Grazing exclusion led to a substantial increase in soil organic carbon levels in Brazilian drylands, effectively countering desertification. This nature-based solution is in alignment with the United Nations Sustainable Development Goals, highlighting its paramount importance in carbon recovery within Brazilian desertified drylands.

Highlights: Grazing exclusion in Brazilian drylands successfully increased SOC levels. Restoration techniques emerge as efficient strategies to contain desertification. Grazing exclusion promotes implications for carbon recovery in Brazilian drylands.

Abstract: Desertification is advancing rapidly in Brazilian drylands, driven by climate change and incorrect land management. Restoration techniques, such as grazing exclusion, emerge as efficient strategies to contain the advance of desertification and recover soil health, mainly by increasing soil organic carbon (SOC). This research aims to evaluate the effects of grazing exclusion on SOC levels in desertified drylands in Brazil. The study was performed in the Desertification Nucleus of Irauçuba (Ceará State) in three sites with two different managements each: i) grazing exclusion for 21 years (RE) and ii) desertified areas by overgrazing (DE), in addition to areas of native Caatinga vegetation (NV) as a control treatment. Soil samples were collected in the 0 - 10 cm layer during the dry season, totaling 54 samples (three sites x three (two managements + one control treatment) x three blocks x one season). The analyses were performed in RStudio® software and the significance of the means was tested by Tukey's test ($P < 0.05$). NV and RE areas presented the highest SOC contents, 21.02 g dm^{-3}, and 26.77 g dm^{-3}, respectively, without differing statistically, indicating an increase in SOC in RE. The DE area showed the lowest SOC values (8.61 g dm^{-3}), suggesting a lack of significant SOC accumulation in the desertified areas.

SOC boosted soil biological quality in RE, causing indicators such as β-glucosidase enzyme activity and microbial biomass carbon to increase significantly. Grazing exclusion was successful in restoring SOC levels to a state similar to that of native vegetation. These findings underscore the importance of nature-based solutions within the context of the United Nations Sustainable Development Goals (SDGs) for restoration of soil health in the Brazilian desertified drylands. Funded by Ceará State Foundation for the Support of Scientific and Technological Development (FUNCAP) for the promotion of the research grant.

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SUSTAINABLE INTENSIFICATIONS: BOOSTING YIELDS AND CARBON INPUTS WHILE ENRICHING SOIL FERTILITY

Lucas P. Canisares[1], Helio W. Joris[2], Salathiel A. Teixeira[2], Alberto M. Peper[3], Jonatas Galván[3], Maurício R. Cherubin[1]

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Keywords: Agricultural intensification; agricultural diversification; soil fertility.

Impact: Study highlights the importance of intensification/diversification for sustainable agriculture, ecosystem services.

Highlights: Intensification and diversification boost maize/soybean yields in specific conditions. Higher soil potassium with increased cropping intensity (fertilizer inputs). Short-term stability of soil carbon and nitrogen stocks.

Abstract

To promote sustainable agriculture and alleviate deforestation pressure, enhancing cropping system intensity and diversity is crucial. This study aimed to evaluate the effects of intensification and diversification on grain yield, soil fertility, and carbon sequestration in maize and soybean systems. A four-year field experiment was conducted in southern Brazil, employing three intensity levels, including an intensified system with oats or cover crop mixtures. Intensification and cover crop use significantly influenced soybean and maize yields, with the highest intensity combined with cover crop mixtures showing increased yields compared to non-intensified systems. Yield responses, however, varied depending on the year and crop. In the second and fourth harvest seasons, soybean and maize yields were 0.5 and 0.8 Mg ha^{-1}, and 1.2 and 3.0 Mg ha^{-1} higher, respectively, in high-intensity systems with cover crop mixtures compared to non-intensified systems. Soil quality indicators were assessed, including soil carbon (C) and nitrogen (N) stocks, and soil chemical properties. Increasing intensity levels resulted in significantly higher soil potassium (K) concentration, likely due to greater fertilizer inputs. Nonetheless, there were no significant differences in soil C and N stocks among different

intensification levels or cover crop mixtures. Overall, the study demonstrated that intensified cropping with diversified cover crops can enhance maize and soybean yields under certain conditions and years. The legacy effect of intensification on soil K concentration was highlighted, while short-term changes in soil C and N stocks were not significant. However, the increased carbon input could have long-term implications for carbon sequestration. This research highlights the importance of sustainable intensification in improving crop yields and soil health while alleviating deforestation pressure. The findings provide valuable insights for agricultural practices in similar regions, offering potential benefits for both farmers and the environment. Continuous monitoring of soil health and carbon sequestration is crucial to understand the long-term impact and optimize sustainable intensification strategies for future agricultural sustainability.

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A COMPREHENSIVE ASSESSMENT OF GREENHOUSE GAS EMISSIONS STUDIES DEVELOPMENT IN BRAZILIAN CERRADO BIOME: A REVIEW

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Keywords: Nature-based solutions; climate change; conservationist agriculture.

Impact: The present work brings a first assessment of the current state-of-art of the development of greenhouse gas (GHG) studies in the Brazilian Cerrado. The results indicate a large disparity in the number of documents comparing soil organic matter and GHG studies and suggest the need to advance in the subject.

Highlights: A literature review to characterize the state-of-art of GHG studies was performed. Most retrieved studies only mentioned GHG terms but did not assess them. The few studies that measured GHG were mostly conducted in short-term experiments.

Abstract:

The continental extension of the Brazilian territory and its great potential for agricultural development placed the country in a privileged condition for nature-based solutions (NBS) development. Despite that, one of the main challenges that remain concerns the availability of field data, especially related to the emissions of the so-called greenhouse gases (GHG). Our objective was to access the current state-of-art of GHG studies developed in the Cerrado biome. We performed a literature review based on three filters (F): i) soil organic matter (SOM) and GHG-related terms for Brazil (F_1); ii) SOM and GHG-related terms for Cerrado (F_2); iii) and only GHG-related terms for Cerrado (F_3). Then, we explored the differences in the number of studies of each search; the main keywords mentioned; and we identified the methodological characteristics of the studies that evaluated GHG emissions in the Cerrado. We observed a significant gradient in the number of studies retrieved for F_1 (5,453), F_2 (1,140), and F_3 (208). The number of studies retrieved in F_3 (only GHG-related terms for

Cerrado) represented only 18% of the number of studies obtained in F_2 (SOM and GHG terms for Cerrado), indicating an important lack in the number of published documents that mention GHG terms compared to SOM. Similarly, the co-occurrence maps of keywords showed that the most cited terms are mainly related to deforestation and the land-conversion process, while GHG-related terms present a low occurrence and small connectivity with other keywords on the map. Looking specifically at F_3 (only GHG terms in Cerrado), we identified that from a total of 208 documents, only 32 measured GHG emissions in the field, while the greatest proportion of studies retrieved in the search mentioned but did not measure GHG data. Out of the 32 studies we identified, we saw that most were conducted in the south-central region of the Cerrado biome and were based on short-term experiments and restricted monitoring periods/sampling strategies. Our study suggests that there is an important gap related to GHG emissions monitoring studies in the Brazilian Cerrado biome, and efforts should be destinated to advance in the subject.

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ARE ENTISOLS (LITHIC) AN ALTERNATIVE FOR DRYLAND BIOFUEL PRODUCTION IN BRAZIL?

Carlos Roberto Pinheiro Junior[1]; Lucas Pecci Canisares[1]; Maurício Roberto Cherubi[2]; Tiago Osório Ferreira[2]; Gonçalo Amarante Guimarães Pereira[3]; Carlos Eduardo Pellegrino Cerri[2].

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Keywords: Caatinga biome; Drought coping strategy; Nature-based solutions.

Impact: The transition of the energy matrix to renewable sources is one of the main strategies to mitigate climate change. The production of biofuel from Agava sisalana is shown as an alternative for socio-economic development of drylands in Brazil and contributes to climate change mitigation.

Highlights: Entisols (Lithic) represent almost 20% of the soils of the Caatinga. *Agave sisalana* is an alternative for biofuel production in drylands. 54% of the Entisols (Lithic) occur in favorable topography for Agave cultivation.

Abstract: Entisols (Lithic) are shallow soils, characterized by contact with the rock in the first 50 cm from the surface, and represent almost 20% of the pedological cover of the Caatinga biome (drylands). The small effective depth of these soils intensifies water deficiency and hinders food, fiber and fuel production, and increases the risk of soil erosion, especially in sloping areas. In recent years, studies have shown high potential for biofuel production from *Agave sisalana* in the drylands of Brazil, due to the plant's adaptation to shallow soils and long periods of water deficit. Here we aim to identify the dryland regions of Brazil with the most favorable topographic conditions for expansion of *Agave sisalana* cultivation. We used a database with 50 Entisol (Lithic) profiles under semi-arid and dry sub-humid climate in the Caatinga biome to obtain the relief class according to the slope percentage of the terrain, namely: 0-3% (flat); 3-8% (gently wavy); 8-20% (wavy); 20-45% (strongly wavy). 54% of the Entisols (Lithic) in our study occur on flat or gently wavy relief, conditions that favor land use with Agave sisalana cultivation. Areas with this topography were observed with greater expression in the states of Bahia, Piauí, Alagoas, northwestern Sergipe and central Ceará. Wavy and strongly wavy relief conditions were observed in 46%

of the Entisols (Lithic) in our study and are unsuitable for agricultural use due to the high risk of water erosion. The occurrence of sloping relief was observed most frequently in the states of Rio Grande do Norte, Paraíba, Pernambuco and in the southern region of the states of Ceará and Sergipe. The expansion of *Agave sisilana* cultivation under Entisols (Lithic) in the drylands in Brazil is shown as an alternative to produce biofuels, improve the socio-economic development of the region and contribute to climate change mitigation. We thank Shell Brazil and ANP (National Agency of Petroleum, Natural Gas and Biofuels) for the strategic support given through the regulatory incentive of Research, Development & Innovation.

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INTEGRATION CROP-LIVESTOCK-FOREST SYSTEM IN THE SEMI-ARID OF CEARÁ MEDIATE CHANGES IN SOIL C STOCK

Crislâny Canuto dos Santos[1]; Thamirys Suellen da Silva[2]; Lucas Mariano da Silva[3]; Stoécio Malta Ferreira Maia[4]; Maurício Roberto Cherubin[5]; Carlos Eduardo Pellegrino Cerri[5].

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Keywords: soil organic matter fractions; carbon management index; Semiarid.

Impact: Integration of crop-livestock-forest systems (ICLF) can have a positive impact on the carbon footprint, mitigating climate and environmental changes. Therefore, investigating the effects of different ICLF systems on carbon dynamics in the semi-arid can promote the adoption of such strategies in this region.

Highlights: The adoption of ICLF Systems in Caatinga was investigated. ICLF systems changed soil C accumulation. Spacing between NTS of 28 m increases the MOP of ICLF systems with GM e GB.

Abstract: Climate change has global implications and reducing greenhouse gas (GHG) emissions presents a significant challenge. Integration of crop-livestock-forest systems (ICLF) has been proposed as a promising approach to mitigate the impacts of traditional agricultural and livestock systems. Therefore, we investigated soil C dynamics in ICLF systems in the semi-arid of Ceará state, Brazil. The study was conducted in an experimental area with four ICLF systems: sorghum (SO), forage cactus (FC), massai grass (MG) and buffel grass (BG), each with different spacing between native tree strips (NTS) in the Caatinga (7 m – S7, 14 m – S14 and 28 m – S28). These systems were compared with an area of native vegetation (NV) and also with NTS. Soil carbon stocks were determined, and soil organic matter (SOM) was physically fractionated into particulate organic matter (POM) and mineral associated organic matter (MAOM) in the 0-30 cm layer. also has been calculated the C management index (CMI). Adoption of ICLF

systems in NV areas has reduced soil C stocks. However, the effects varied according to the species and system spacing. Our results show that the adoption of greater spacing (S28) in the system with FC reduced the C stock and MAOM fracion by 10% and 12%, respectively, compared to the S7. Conversely, in the system with MG, S28 produced a 10% increase in soil carbon stock. Likewise, increases of 36% and 22% in the POM fraction were observed at S28 in the systems with BG and MG, respectively, relative to the S7. These increase in the POM fraction resulted in CMI similar to that of NV for BG (100%). As for the system with SO, POM was reduced in aproximally 12%, relative to the E14 and E7, resulting in the lowest CMI (61%) for SO at E28. In NTS, C stocks and MAOM were higher in 7% and 12%, respectively, compared with NV, but C loss occurred in POM fraction, which was lower in 15%. The results of the present study provided information on how C dynamics in the soil were influenced to the different spacing adopted between tree strips in ICLF systems in Caatinga.

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SOIL CARBON DYNAMICS IN INTEGRATED AGRICULTURAL SYSTEMS IN MINAS GERAIS STATE, BRAZIL: A META-ANALYSIS

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Keywords: Silvopastoral systems; Agrisilvicultural systems; Climate change.

Impact: Our regional-level meta-analysis provides an assessment of the impact of the implementation of integrated production systems [i.e., integrated crop-livestock (ICL) and integrated crop-livestock-forestry (ICLF)] on soil carbon stocks in the state of Minas Gerais which currently has 4.8 million hectares of severely degraded pasture.

Highlights: Integrated production systems are tools for mitigating global climate change. Both ICLF and ICL systems are associated with positive rates of soil SOC change. SOC stocks are highest in integrated systems aged between 4 and 8 years.

Abstract: The state of Minas Gerais, Brazil, has one of the highest rates of carbon dioxide emission in the country with a large part of these emissions attributed to extensive livestock on degraded pastures. Integrated agricultural production systems are considered a promising strategy to alleviate the negative impacts on soil caused by agriculture (e.g., soil carbon emissions) while keeping food production. However, the extent to which integrated systems [i.e., integrated crop-livestock (ICL) and integrated crop-livestock-forestry (ICLF)] can contribute to counterbalance soil organic carbon (SOC) loss is limited. Here, through a meta-analysis, we provide a regional-scale assessment of changes in SOC stocks associated with the adoption of ICL and ICLF systems. Additionally, we further investigated how SOC dynamics in these systems are affected by distinct soil (e.g., texture, depth) and climatic (e.g., temperature, precipitation) variables. Our results indicate that both ICL and ICLF systems resulted in SOC accrual after their implementation. However, the latter presented a response ratio slightly greater compared to the former. The age of the system affected SOC stocks only

in the ICLF system, particularly between 4 and 8 years, in which SOC stocks increased at an average rate of 1.3 Mg ha^{-1} yr^{-1}. While SOC stocks decreased in clay-sandy soils under ICLF systems, they increased in clay loam soils (1.06 Mg ha^{-1} yr^{-1}). No clear trend was observed for ICL systems regarding soil texture. Positive effects of precipitation on SOC stocks in ICLF and ICL systems were observed only between 880-1000 and 1500-1700 mm, respectively. Clear effects of temperature on SOC stocks were observed only between 22-25ºC in ICLF systems. Soil depth had no significant effect on the rate of SOC stock change in the systems evaluated. Although the observed results help to better understand how integrated agricultural systems can affect SOC dynamics, the lack of detailed information in the studies used in our meta-analysis limits statically comparisons. However, our results indicate clear trends that ICLF and ICL systems can contribute to increasing SOC sequestration, which climate and soil characteristics might be considered to maximize the efficiency of these systems in increasing SOC.

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COMPARISON BETWEEN CARBON STOCKS IN DIFFERENT LAND USE SYSTEMS IN MINAS GERAIS

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Keywords: Organic matter; Pasture; Integration crop-livestock-forestry.

Impact: The major impact of this work is to show how land use can influence soil carbon storage. In addition, this research seeks to provide data on how correctly managed systems can present greater C storage in the soil to the detriment of unmanaged systems.

Highlights: Soils under managed ICLF sequester more C than soils under ICLF without management. Soil under managed pasture stores more C than soil under unmanaged pasture. Managed pasture and newly installed ICLF store the same amount of C in the soil.

Abstract: Currently the planet suffers from climate issues related to the increase of greenhouse gases (GHG) in the atmosphere, mainly carbon dioxide (CO2). Soil is the main reservoir of carbon (C) in the atmosphere. Therefore, the objective of this work is to provide C storage data in two land use systems in different locations: pasture and integrated crop-livestock-forest (ICLF). Soils were collected in Viçosa and Florestal, both cities located in Minas Gerais. The samples were air-dried, sieved and macerated. The C content was quantified according to Yeomans and Brenmer (1988). To quantify the density, the samples were dried in an oven (105 ºC) for 48 h and then weighed. Carbon stocks were calculated considering the depths 0-10, 0-30, 0-50 and 0-100. The results were submitted to the Tukey test (5%). First, the two land uses for each location were compared separately. When comparing ICLF and pasture installed in Viçosa, there was no statistical difference between them for all depths. Probably because the pasture in this location is managed correctly, respecting the maximum number of animals and resting the area. The same phenomenon was observed when comparing the two systems installed in Florestal. When comparing the ICLF

in Viçosa and Florestal, for layers 0-10 and 0-30 (34.36 and 77.71 Mg ha^{-1}, respectively), the ICLF in Viçosa stored more C in the soil, and for the other depths there was no significant difference. It is important to point out that the trees installed in the ICLF of Viçosa were farther apart than the ICLF of Florestal, with a clearer development of cover crops in this system and consequent greater deposition of organic material in the surface layers of the soil. When the pastures installed in the two locations were compared, for all depths, the Viçosa pasture showed higher C stock values than Florestal. This result reinforces the importance of pasture management for C storage. It is concluded that a correctly managed pasture and an ICLF can store more carbon than a degraded pasture and an ICLF that also does not receive proper management.

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EVALUATION OF SOIL ORGANIC MATTER FROM DIFFERENT MANAGEMENTS SYSTEMS USING SPECTROSCOPY

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Keywords: elemental composition; chemical composition; aromaticity index.

Impact: The evaluation of organic matter by the infrared spectroscopic technique (FTIR) infers the presence of more recalcitrant or more labile functional groups, allowing inferences about conservationist agricultural practices and soil management.

Highlights: Integration crop-livestock-forestry shows high aliphatic concentration on surface due to tree component integration. Integration crop-livestock-forestry and managed pasture showed potential to preserve labile organic matter in depth. Degraded pasture showed a loss of labile SOM and a high concentration of aromatic structures.

Abstract:

Most studies on the impact of management on soil carbon are limited to the quantitative assessment of Soil Organic Matter (SOM). However, SOM can be categorized into recalcitrant and labile fractions. These fractions are affected by land use and management, and assessing changes in SOM composition can be illuminating for climate change mitigation purposes. This study aimed to evaluate the structural composition of SOM under three management systems: Managed Pasture (MP), Integrated Crop-Livestock-Forest (ICLF), and Degraded Pasture (DP) at three depths (0-10, 30-40, and 80-100 cm) on the Zona da Mata-MG, using the Fourier transform spectroscopic technique (FTIR). After removing the mineral part of the soil samples, infrared spectroscopic analysis of the treatment was performed using the ATR Thermo Nicolet FT-IR iS50. To assess the degree of SOM saturation, we calculated the aromaticity index (I_A), relating the Relative Intensity (RI) around 1630 cm^{-1} (referring to aromatic groups) and 2920 cm^{-1} (referring to aliphatics groups). The MP presented a more evident RI 2920 cm^{-1}, indicating the presence of more hydrophobic MOS. The ICLF presented a relative intensity around RI 2920 cm^{-1} in the surface of the soil related to the deposition of solid waste with a high content of polyphenols or lignin as a consequence of the introduction of the tree component in this system. For the RI 1072 cm^{-1} (referring to carbohydrates), the increase in depth can be explained by the entry of polysaccharides via root exudation from the SOM and for the physical protection of the clay fraction. by the clay fraction, leading to the physical stabilization of carbon. The higher I_A of the DP suggests a more recalcitrant SOM with alkyl and carbonaceous compounds negatively influencing soil microbial activity.

Conservative management showed the potential to preserve the labile fraction of the SOM, while the DP showed a loss of labile structure and a higher concentration of recalcitrant structures.

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SOIL CARBON STORAGE IN BRAZILIAN DRYLANDS: STATUS, OPPORTUNITIES AND CHALLENGES

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Keywords: nature-based solutions; carbon stock; Semiarid.

Impact: The present work provides an assessment of the current state of the art in the development of soil carbon stock (SOCs) studies in Brazilian drylands. The results indicate a great disparity in the number of documents that compare the SOCs in monoculture/pastures, integrated agricultural systems and native caatinga.

Highlights: A literature review to characterize the state-of-art of SOCs studies was performed. The median value of SOCs for integrated farming systems was the highest (65 Mg ha^{-1}). The lowest SOCs (27 Mg ha^{-1}) were observed and monoculture/pasture studies.

Abstract: Integrated agricultural systems have great potential to increase soil organic matter, directly influencing the carbon and nitrogen content of the soil. However, information on the influence of these systems on soil organic carbon (SOC) stock in the Brazilian drylands is still scarce. Therefore, the aim of this study is to perform a meta-analysis to recognize the current state, opportunities, and challenges for carbon storage in agricultural systems in the Brazilian semi-arid region. Carbon stock data were extracted from about 53 articles considering the use of cultivated plants and pasture areas, 28 articles in areas of native Caatinga, and 9 articles in integrated agricultural systems of the Brazilian drylands. In the three types of land use, soil organic carbon stock data were evaluated up to 0.3 meters in depth. Differences in soil carbon stock indicate that integrated agricultural systems have an average of 65 Mg ha^{-1}, followed by native Caatinga with 50 Mg ha^{-1}, and agriculture (including pastures and monoculture) with 27 Mg ha^{-1}. Therefore, the greatest difference observed in soil carbon stock was 38 Mg ha^{-1} between integrated agricultural systems compared to pasture and monoculture areas. The smallest difference observed in carbon stock was 23 Mg ha^{-1} between native Caatinga compared to pasture and monoculture areas. In

this way, the adoption of integrated agricultural systems can be considered an opportunity to increase the stock of carbon in the soil. However, several challenges must be considered due to the level of aridity and water availability in the region. In conclusion, the demand for more research to assess the potential of different agricultural systems to store carbon up to one meter deep in the Brazilian semi-arid region is remarkable.

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SOIL ACIDITY ALLEVIATION AND N IMPROVE HUMIC SUBSTANCES IN AGGREGATES

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Keywords: Lime; nitrogen fertilization; carbon stability.

Impact: Improve soil carbon storage in more stable fractions, in addition to improving the productivity and sustainability of production systems in tropical environments.

Highlights: Gypsum prevented fulvic acid decline under liming and nitrogen fertilization. Greater humin concentration was found in larger soil aggregates.

Abstract: Soil acidity alleviation associated with adequate nitrogen (N) availability can be a strategy to improve crop biomass and root development, leading to better soil aggregation. However, the role of different classes of aggregates in protecting soil humic substances is still unknown. The objective was to evaluate the effect of limestone and gypsum, associated or not with N, on the accumulation of humic substances in stable aggregates. A no-till field experiment was conducted in Botucatu, State of São Paulo, Brazil. The treatments consisted of a control, lime, and lime + gypsum with zero and 240 kg ha^{-1} of N. The better N availability increased the fulvic acid (FA) content, mainly in smaller diameter aggregations. In addition, liming also improved the FA content in the soil, with little benefit from the liming+gypsum association. However, the main effect of soil correction (lime + gypsum) was for the humin fraction in the surface layer of the soil, in larger diameter aggregates, that is, soil correction improved the humin content. The best strategy to improve the levels of humic substances in the soil is to associate lime, gypsum, and nitrogen fertilization, with the humic fraction being the most affected by management. We thank São Paulo Research Foundation for their support with the PhD scholarship for the first author, process (2020/07559-7).

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SOIL AGGREGATES AND CARBON CYCLING IN MAIZE-FORAGE INTERCROPPED SYSTEMS FERTILIZED WITH NITROGEN

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Keywords: intercropping; carbon dynamics; soil physics

Impact: Our results unveil to what extend intercropping maize with forage species supplied or not with N affects soil aggregation, C cycling and SOM fractions within micro and microaggregates in a seven-year experiment.

Highlights: The absence of N resulted in bigger soil aggregates after seven years. Maize-forages intercropping enhances C cycling at the uppermost soil layer. Aggregates > 2.0 mm hold 36% more carbon compared with 0.105 mm.

Abstract: Intercropping maize with forages is an alternative for intensifying food production while building up soil resilience strategies on a changing climate. Our research aimed to investigate to what extend the new carbon (C) input affects the cycling of the already stabilized soil C, soil organic matter (SOM) fractions and within micro (<0.250mm) and macroaggregates (>0.250mm), especially when fertilized with nitrogen (N) in a seven-year experiment with maize intercropped with ruzigrass, palisade and Guinea grass fertilized or not with N. The absence of N resulted in larger aggregates compared with N fertilization. Intercropping increased $\delta^{13}C$ values in the bulk soil (8.9%), in particulate (4.4%) and mineral-associated (7%) organic matter fractions, and within micro and macroaggregates (7.5%) through the soil profile (0-40cm) disregard forage species and N application. However, N supply increased the intercropping-carbon derived in the particulate organic matter 6.3% at the 10-20 cm soil depth. Guinea grass resulted in 10.5% more carbon into aggregates compared with ruzigrass. Yet, aggregates larger than 2.0 mm showed on average 36% more carbon than that beheld at 0.105 mm aggregates across the soil profile. Soil total N was not affected across >2.0, 1.0, and 0.5-mm aggregates, but was 23.9% higher than that at the smallest aggregate. These findings contribute to a better understanding of C dynamics in intercropped systems. Our results showed that N supply resulted in smaller soil aggregates compared with no N, but the mechanisms are unknown and needs further scrutiny. Intercropping replaces the already stabilized carbon in different soil structures and carbon pools, but there are no consistent differences between forage species and response to nitrogen rates. São Paulo State Research Foundation (FAPESP), grant - 2021/05167-7.

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ORGANIC MATTER IN AGROFORESTRY SYSTEMS: MOLECULAR CHARACTERISTICS AND THERMAL STABILITY

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Keywords: Quality of soil organic matter; spectroscopy FTIR; Thermal analysis.

Impact: Faced with global challenges in relation to climate change, food security and the environmental impacts of agriculture, our study provides the evaluation of soil organic matter (SOM) characteristics in an agroforestry system (AFS) located in the Cerrado, pointing to improvements in the quality and structural and thermal stabilities of SOM.

Highlights: AFS are considered a sustainable alternative in soil conservation and agriculture. Preservation systems are associated with preserving the quality of SOM. The incorporation of trees increases the structural and thermal stability of the SOM.

Abstract: Soil organic matter (SOM) plays an important role for agriculture, ecosystem functioning and in the global carbon (C) balance, however, changes in land use and management affect its dynamics. Agroforestry systems (AFS) are a promising alternative land use, with the potential to improve the quantity and quality of SOM. The objective of this work was to evaluate the impacts of the implementation of AFS s and their components (Mombasa, agricultural and forestry) located in the Cerrado biome on the characteristics of MOS, through chemical, spectroscopic (FTIR) and thermogravimetric (TG/DSC) techniques. In order to verify the influence of soil management, soil samples under managed pasture (MP) and degraded pasture (DP) were analyzed. The experimental area is located in the municipality of Abaeté-MG (19°17'S, 45° 39'W). The AFS covers 2.0 hectares with grass management, alternated with agricultural crops in annual crop rotation, the alternating strips are separated by rows of trees. Soil samples

were collected at six depths (0-10,10-20; 20-30; 30- 40; 40-50; 90-100 cm). The results showed the ability of conservation systems, such as AFS and MP, in preserving the quality of SOM with the highest carbon contents. The spectroscopic analysis allowed to characterize the SOM, in which, the AFS presented evidence of greater lability (IR1082) and the DP enrichment of aromatic groups (IR1630), being confirmed by the highest aromaticity index (IR1630/ IR2920), which measures the degree of saturation of the SOM. The highest mass losses occur in the third temperature range (230-420 °C) and gradually decrease with depth, suggesting that the thermal stability of SOM increases with soil depth. The AFS presented the highest thermogravimetric index (TGI) indicating greater recalcitrance compared to pastures. The greater diversity of plants in the AFS provides a more variable chemical composition of C, increasing the quality and structural and thermal stabilities of SOM. The results point to the potential of AFS and MP as sustainable management practices and promising strategies for climate change mitigation and adaptation.

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EFFECTS OF LAND USE CHANGE AND MANAGEMENT PRACTICES ON SOIL CARBON STORAGE IN PASTURES

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Keywords: annual crops; integrated production system; livestock.

Impact: Improvement in the carbon accounting of production systems in Brazil that involve the change of land use from native forest to pasture, as well as the evolution of extensive pasture to an intensive integrated system or the conversion into areas for grain production.

Highlights: Conversion of natural vegetation to extensive pasture deplete soil carbon stock. Conversion of extensive pasture to cropland decrease soil carbon stock. Reversal of SOC losses occurs when good management practices are adopted.

Abstract: The land use change is identified as one of the main factors responsible for the emission of greenhouse gases in Brazil. However, mainly in the already consolidated production areas and respecting the current environmental legislation, it is possible to revert part of the carbon (C) loss by improving the productive management of crops and pastures. The objective of this research is to determine factors of loss and gain of soil C considering the natural vegetation (Atlantic Forest biome) converted into extensive pasture that can later be intensified through an integrated production system with mahogany or can be used in grain production area. The approach used was to pair areas of the same type of soil, classified as Oxisol, and different uses or management; samplings were carried out to determine the soil bulk density and the C content, for later obtaining the soil C stock in each area. Undisturbed samples for soil bulk density were collected from four pits in each area, for depths 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80 and 80-100 cm; soil C content was determined for the same mentioned depths, but from composite samples collected with an auger around each pit. It is expected to determine the land use change conversion factor from natural vegetation to extensive pasture and from extensive pasture to grain crop field; in the case of intensification of production by adopting an integrated system with mahogany, it is expected to obtain the pasture management factor, changing from a system with a lower level of intensity to

another with a higher level of intensity. These results may help future planning in the context of changing the land use and land cover, as knowledge of carbon dynamics in areas subjected to this is essential for making decisions consistent with sustainability and mitigation of greenhouse gases in livestock. This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) and the Research Center for Greenhouse Gas Innovation (RCGI).

NOVEL FIELD-BASED MODELS TO MONITOR ABOVEGROUND CARBON ACCUMULATION OF FOREST UNDER RESTORATION

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Keywords: Carbon stocks; restored forests; remote sensing

Impact: Forest restoration goals are being pledged internationally as strategies for mitigating climate change, although there are still uncertainties regarding the dynamics of carbon storage of restored forests. This work contributes to develop novel models for aboveground biomass (AGB) estimation of forest under restoration to support large-scale recovery of degraded areas.

Highlights: Development of robust allometric equations for AGB estimation for forests under restoration. Novel ratios between LiDAR-metrics and direct AGB measurements valued destructively. The models will enable forest restoration to be effectively implemented as NBS.

Abstract:

Monitoring the carbon storage in tropical forests under restoration is crucial to support the ambitious international pledges, but there are still missing appropriate equations to estimate AGB of forest under restoration. Considering the great biodiversity and complexity of tropical restored forests, it is important to increase the accuracy of AGB estimates. Hence, the development of new reliable methodological approaches to measure carbon stocks is key to endorse forest restoration as a natural climate solution at scale. Remote sensing (RS) has been used to predict AGB in forests, however current methods are based on relations that combine LiDAR-metrics with indirect estimates of AGB, calculated by pantropical equations, non-appropriate for forest restoration areas. The aim of

this study is to generate direct estimates of AGB for different forest under restoration (forest plantations and natural regeneration) in the Atlantic Forest, in order to fill the gap of the field-based data used on those RS approaches. Through the destructive method, 80 trees from 20 native species of different sites (SP and BA experimental field trials) will be systemically selected based on the most recent inventory data and sampled to develop site-specific allometric equations for AGB estimation of restored forests. In order to up reach the scale of these critical field-data, we will explore a novel RS methodology that not yet tested in recent research. LiDAR data will be collected from airborne laser scanning (ALS) and terrestrial laser scanning (TLS) assessments in both sites and AGB will be calculated destructively in a 30m x 30m plot (900 m2) in which all trees' individuals present will be sampled. The significance relationships with canopy structure attributes will now be developed using direct measurements of AGB. As result, it is expected to provide greater accuracy in the prediction of AGB using LiDAR-metrics, deepening the understanding of the dynamics of AGB accumulation in different restoration systems aimed at mitigating climate change. In addition, this study will generate a valuable database for other studies relating the AGB of forest landscapes under restoration with the canopy structure, provided accurately by remote sensing as LiDAR data.

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IMPACT OF CONVERTING PASTURE AREAS INTO SUSTAINABLE AGRICULTURE ON SOIL ORGANIC MATTER DYNAMICS

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Keywords: conservation practices; organic carbon stock; quality and quantity of soil organic matter.

Impact: Long-term scenarios of pasture conversion to sustainable agriculture can contribute to the dynamics of organic matter, through carbon sequestration and consequently the mitigation of climate change.

Highlights: Develop strategies and increase the adoption of sustainable agricultural practices; Sustainable practices can contribute to the increase and stabilization of soil organic matter; Impact of land use change on soil health.

Abstract: Soil carbon sequestration is one of the main strategies for reducing the growing CO_2 emissions caused by human activities in recent decades. In order to meet the world demand for food, fiber and biofuels, agricultural areas cultivated in Brazil have expanded strongly in the last decade. The change in land use and the intensification of production systems alter the concentration of CO2 in the atmosphere, transforming the soil into a sink or emitter of carbon (C), influencing climate change. In this sense, the replacement of areas of natural vegetation by areas of pasture or agricultural crops has been associated with the absence of conservationist management practices, recent publications have shown that sustainable management practices contribute to the increase of soil C levels, restoration of soil health and GHG mitigation. Our project aims to evaluate the impact of converting pasture areas (PA) to sustainable agriculture (AS) on soil organic matter (SOM) dynamics, covering tropical and subtropical climates. Through quantification of soil C and N contents under the effects of land use change, physical fractionation of total soil OM, through techniques that differ in terms of aggregation, composition, permanence and function (e.g. MOAP and MOP) , which will allow with greater sensitivity to identify changes in SOM under different uses and managements and durations, and to understand the dynamics of SOM. In the end, the data will be integrated to evaluate the effects on the conversion of PA into AS, and the different levels of intensification of the

productive systems. In this way, we will quantify the impacts generated on SOM, C stocks and stabilization and permanence in the soil, through this, allowing the identification of management practices with the potential to mitigate C in the tropics and subtropics of Brazil, thus guaranteeing a sustainable development of agriculture.

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

GEOGRAPHIC DISTRIBUTION OF POTENTIAL SOIL CARBON SEQUESTRATION IN BRAZILIAN PASTURELANDS

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Keywords: soil carbon storage; spatial modeling; greenhouse gas emissions.

Impact: A first approach to locate hotspots of theoretical soil organic carbon storage in pastures was developed for the whole Brazilian country. A map showing gains and losses of soil organic carbon was developed to support spatial analysis of carbon dynamics in pastures.

Highlights: Largest patches of soil carbon loss are in the Amazon and Atlantic Forest biomes. Areas showing soil carbon gain, mainly in the Cerrado biome, were also identified. Finer scale analysis should include modeling of pasture management.

Abstract: The restoration of degraded pastures in Brazil is a milestone of environmental compliance and one of the key commitments of the Paris Agreement. However, it may not be the best alternative for reducing GHG emission since other forms of cattle ranching management may lead to both better financial revenue and smaller net carbon emissions. Additionally, it has been stated that as long as the national herd increases, GHG emissions will continue rising. Nevertheless, the potential of the country's soil to sequester and store carbon has not yet been fully explored. Consequently, this work aimed to generate a first approach by projecting the geographic distribution of the theoretical capacity of soil organic carbon (SOC) sequestration associated with Brazil's target of pasture restoration. We used output (10 km spatial resolution) from Sanderman et al. (2017) model of "SOC debt" derived from conversion of native vegetation to agriculture, to focus on the current distribution of Brazilian pasturelands and biomes. SOC sequestration hotspots, associated with SOC losses higher than 10% in the 0 - 100 cm soil layer were identified in the pastures across all biomes, with the largest patches in the Northeast region: Atlantic Forest and Amazon biomes. SOC gains were also identified, notably in the Cerrado biome. Moving from theoretical to attainable SOC sequestration, at finer scales, should include modeling of distinct management practices, of animals, grasses, and soil properties, which can lead to substantially different carbon inputs and

stocks in the soil. Financial Aid: FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo (Proc. No. 2022 09821-6) and Shell.

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

N_2O EMISSION FACTORS FOR NITROGEN FERTILIZERS AND ANIMAL EXCRETA IN PASTURES: A META-ANALYSIS FOR BRAZIL.

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Keywords: Greenhouse gases (GHG); Livestock; Mitigation.

Impact: Improve and customize information on national, regional, and sectoral GHG emissions from agriculture and livestock, based on information already available.

Highlights: Default values of N_2O emissions can generate misleading information for inventories. Different nitrogen sources and environmental conditions provide particular N_2O EFs. Knowledge of N_2O EF will support future agricultural strategies.

Abstract: Between 1985 and 2020, Brazil increased its pasture area by 38%, from 111 to 154 million hectares. In turn, N_2O emissions from the agricultural-livestock sector in 2016 accounted for 87% of the total emissions of this gas in the country. The determination of N_2O EF in national inventories is carried out using the values recommended by the IPCC, but there are limitations, since a default N_2O EF is used for diverse nitrogen fertilizers, in different situations of livestock practices and edaphoclimatic conditions. This standardization of the EF, mainly for a country like Brazil with continental dimensions and with great edaphoclimatic diversity, can lead to future mistakes in the dimensioning of the N_2O emissions caused by national livestock. Therefore, this review and meta-analysis study aimed to propose consistent and reliable N_2O EFs for each type of nitrogen fertilizer and animal excreta in pastures in Brazil. The selection of studies was carried out through a systematic review by consulting the databases of online scientific articles: Web of Science, Scopus, and Scielo from December 2018 to August 2022. The queries used the search syntaxes: "*Brazil" and "nitrous oxide emission" and "emission factor" and "pasture", "pasturelands", "grasslands", "livestock",* and 20 articles were considered suitable for analysis, which had information about the EFs or experimental conditions that allowed the calculations of the EFs. The meta-analysis was performed using the methodology without weighting for variance, where the means and 95% confidence intervals

for the EF were estimated using the bootstrap non-parametric resampling method. The mineral fertilizers evaluated in the studies were urea, ammonium nitrate, and ammonium sulfate presented EFs and confidence intervals (%) of 0.57 [0.46-0.68]; 1.16 [0.51-1.81] and 0.28 [0.13-0.43], respectively. As for animal excreta, results were found regarding feces, urine, and feces plus urine of 0.14 [0.12-0.16]; 0.75 [0.63-0.87]; 0.59 [0.34-0.84], respectively. The average value found for EFs from mineral fertilizers was 0.69 and from animal excreta was 0.48 compared to the default value of 1% by the IPCC. It is concluded that the values offered by the IPCC in relation to the N_2O EF would overestimate the real values found in Brazilian pastures.

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

NITROUS OXIDE AND METHANE EMISSIONS FROM SOIL UNDER PASTURE FERTILIZED WITH NITROGEN

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Keywords: Carbon footprint; Climate change; Greenhouse gas (GHG).

Impact: Quantify the fluxes of nitrous oxide (N_2O) and methane (CH_4) from soil under nitrogen-fertilized pasture, to improve the N_2O emission factor and, consequently, contribute to the quality of greenhouse gas (GHG) emission inventories.

Highlights: Improvement of regional and national GHG emission inventories. Characterize tropical pasture soils as the CH_4 drain. Appropriate fertilization strategies allow better use of nitrogen inputs.

Abstract: The contemporary global development model has been changing in order to reconcile productivity and sustainability. Harmonizing the environment and production fundamentally depends on the development and adoption of conservationist and sustainable agricultural practices. Livestock accounts for more than 60% of GHG emissions from the agricultural sector in Brazil, while nitrogen fertilization accounts for 35%, which are important aspects for promoting actions to reduce national emissions. The study will be divided into two parts: one in the field and another in the laboratory. In the field experiment, four nitrogen fertilization rates will be evaluated (0, 75, 150 e 300 kg $N.ha^{-1}$, in addition to a treatment with a dose of 150 kg $N.ha^{-1}$ split (50+100 kg $N.ha^{-1}$), regarding GHG emissions. The source of N will be ammonium nitrate, used in experimental plots of 14 x 14 m, with established pasture of *Urochloa brizantha cv.* Marandu. GHG emissions will be monitored using static chambers and periodic sampling after fertilization, until fluxes stabilize. The collected samples will be analyzed by gas chromatography. Next, the daily flows will be integrated and the data will be processed in order to verify the effect of N rates and split of fertilization on N_2O flows and emission factor of this gas and the effect on CH_4 emissions or consumption. For the laboratory research, 12 sources of N will be incubated with soil, under potentially favorable conditions for N_2O emission (temperature of 28ºC and soil moisture corresponding to 80% of the total pores filled with water).

Nitrogen sources will include animal excreta (urine and feces), conventional mineral fertilizers, use of inhibitors and slow-release fertilizers. For about 90 days or until the gas flows stabilize, N_2O and CH_4 will be monitored. It is expected that the results generated in the research will be incorporated into the literature that supports more regionalized and customized N_2O emission factors, contributing to the improvement of emission inventories and to the carbon accounting of livestock production systems.

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

SOIL AGGREGATES AS QUALITY INDICATORS IN CROP-LIVESTOCK-FOREST INTEGRATION SYSTEMS IN THE BRAZILIAN SEMI-ARID REGION

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Keywords: Soil stability; Aggregate index; Land use

Impact: The inadequate uses of the soil and the climatic characteristics have led to the process of environmental degradation, which directly affects the level of productivity in the Brazilian semi-arid region. Therefore, studies that can evaluate the physical quality and structure of the soil to implement ICLF systems are relevant.

Highlights: ICFL systems positively influence soil aggregate stability. Native vegetation and native tree strips showed greater stability. Soil management influenced the formation of aggregates and stability.

Abstract: In the Brazilian semi-arid region, traditional land use systems (agriculture and pasture) still predominate. However, integrated production systems, such as integrated crop-livestock-forestry (ICLF), have been tested as alternative and sustainable forms that seek to improve soil condition. The objective of the research was to evaluate the impact of the adoption of different arrangements of FLI systems in the semi-arid region of Brazil on soil aggregation, as well as to evaluate the potential of using different aggregation indices as indicators of soil quality. The study was conducted in an experiment area, located in the Teaching, Research and Extension Unit of the Federal Institute of Science and Technology of Ceará, Campus Limoeiro do Norte.The study was conducted in an experimental area with four ICLF systems: sorghum, forage cactus, massai grass and buffel grass, each with different spacing between native tree strips (NTS) in the Caatinga (7m–S7, 14m–S14 and 28m–S28). These systems were compared with an area of native vegetation (NV–Caatinga) and also with NTS.In each treatment five mini trenches (replications) were opened and soil samples were collected at depths of soil of 0-10, 10-20, 20-30 and 30-50 cm. The distribution of water-stable aggregates was evaluated considering the following diameter classes: macroaggregates (diameter>2.00mm), mesoaggregates (2.00-

0.25mm) and microaggregates (0.25-0.05mm), and the weighted mean diameter, geometric mean diameter,aggregate stability index, and sensitivity index were calculated. It is observed that at the depth of 0-10cm the NV and NTS presented lower aggregate stability formations in relation to the ICFL systems. On the other hand, in the mesoaggregates, it is observed that at the depths of 10-20cm and 30-50cm, there was greater stability of aggregates in the VN, which will imply a reduction in soil disturbance, which will contribute to the accumulation and decomposition of organic matter. Highlight for the NTS, which showed less stability in the distribution of soil aggregate classes among treatments, with the exception of mesoaggregates at the depth of 20-30cm, which may consider the influence of the cultivation of the ICFL system. Thus, it is concluded that ICFL systems positively influenced the distribution of soil aggregates in the semi-arid.

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SOIL CARBON SEQUESTRATION UNDER AGRICULTURAL SYSTEMS IN BRAZILIAN DRYLANDS

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Keywords: nature-based solutions, carbon stock, soil health.

Impact: This study will assess the change in soil carbon stocks (SOCs) in different agricultural systems in Brazilian drylands.

Highlights: Literature review to characterize the SOCs studies will be performed. A soil quality index will be developed through main component analysis. Carbon stock mapping for dry lands will be carried out.

Abstract: Land use change and soil organic matter (SOM) loss in agricultural areas are the activities that most contribute to greenhouse gas (GHG) emissions in Brazil. In this sense, the adoption of management practices that reduce GHG emissions, such as integrated agricultural systems (IAS), is fundamental to mitigating climate change and ensuring sustainable agricultural development. However, although the benefits of IAS have been proven in some regions, such as Cerrado and Atlantic Forest biomes, the potential of these systems are almost unexplored in the Brazilian drylands (Caatinga biome). Therefore, this study aims to assess the alteration in soil carbon storage in agricultural systems in the Brazilian drylands regions. Soil samples will be collected up to 1 m depth in the states of Ceará (CE), Piauí (PI), and Pernambuco (PE). The treatments will comprise areas with different levels of intensification of integrated agricultural systems, grassland, native Caatinga, and monoculture. Variations in total soil C and N stocks will be quantified, as well as SOM fractions obtained by the physical fractionation method. The data obtained will be submitted to variance analysis and, when significant, to Tukey's test ($p < 0.05$). Further, multivariate techniques will be applied to identify the relationship between the soil health indicators and the evaluated systems. A literature review will be applied considering the current state of the art about integrated systems and their capacity to store carbon in drylands. Similarly, the development of an index to assess soil health will be proposed. Modeling and mapping of carbon stocks will be prepared for the study area under current and future climate scenarios. IAS can be a powerful solution

to address global food and energy insecurity and climate change in the coming decades. Therefore, recognizing the potential of IAS to enhance C sequestration in Brazilian drylands can be a valuable scientific basis to help Brazil achieve its Nationally Determined Contributions and other climate actions, well as contribute to developing a baseline for the carbon market.

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LAND USE AND SOILTEXTURE INFLUENCE OVER VERTICAL CARBON AND NITROGEN DISTRIBUTION IN THE AMAZON-CERRADO FRONTIER

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Keywords: Deep soils; Tropical environment; Clay and sand contents.

Impact: Most of the studies assessing soil carbon and nitrogen stocks considerer the first one meter as a fixed soil depth. Our work discussed that 50% of the soil carbon and nitrogen stocks from 0-8 meters are located below 2.5 m and the amounts were very dependable of the soil texture.

Highlights: The first one meter stored 26-40% of total soil carbon and 29-51% of nitrogen stocks. Soil carbon and nitrogen stocks between 3-8 m were relatively uninfluenced by land use. Soil carbon and nitrogen stocks in the sandy were ~40% and 65% lower compared to clay.

Abstract: Land use and agricultural intensification drive the rapid expansion change in the Amazon-Cerrado frontier. Native vegetation removal for pasture or agricultural normally leads to carbon stocks and nitrogen decline in the soil surface. However, little is known about these changes deep in soil profiles. In this regard, we sampled soil carbon and nitrogen to 800 cm under different land uses on Tanguro Farm, an intensively agriculture region near the Amazon-Cerrado transition. Soil samples were collected from five points until 200 cm, and in three points until 800 cm on a native forest, minimum tillage soybean and soybean-corn cropland, pasture, and land that was deforested but never planted to pasture or crops. The forest, croplands, and deforested land were on similar medium-clay Oxisols but the pasture was on sandier Oxisols (all higher-clay soils in the region had been converted to croplands). We quantify total carbon and nitrogen concentration and soil bulk density. The top 100 cm contained ~30% and 40% of the carbon and nitrogen stock to 800 cm for areas of medium - clay texture and 40% and 50% for the sandy soil, respectively. About 50% of all soil carbon and nitrogen stocks were concentrated in the first 200 to 300 cm, regardless of the soil texture. Higher clay content led to higher total carbon and nitrogen stocks to 800 cm. Carbon and Nitrogen stocks between 300-800 cm were less impacted

by soil use but more dependent of parental material and soil texture. Because of the large areas of land change and agricultural intensification now taking place on deep tropical soil, more studies are needed to understand the generality of these patterns. The authors would like to thank IPAM (Instituto de Pesquisa Ambiental da Amazônia). GVP would like to thank FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) for the fellowship number 2019/25988-5.

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DISTINGUISHING MICROBIAL PATHWAYS RESPONSIBLE FOR N_2O EMISSIONS IN SOILS UNDER INTEGRATED CROP-LIVESTOCK SYSTEM

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Keywords: Root exudates; Greenhouse gases; Soil microbiota.

Impact: To the best of our knowledge, there aren't studies evaluating the impacts of brachiaria grasses on the main routes of N_2O production in tropical soils using ^{15}N isotope tracer. This technique has been widely applied to discriminate the N_2O emissions pathways by ^{15}N enrichment following application of ^{15}N-labelled fertilizers.

Highlights: Understanding crop production effect in N_2O is crucial to propose mitigation strategies. The brachiaria root system, when combined with N fertilizer, boost the N loss as N_2O. Higher N_2O emission in ICL may be related to the amount of brachiaria dry matter.

Abstract: Intensifying agricultural systems by the inclusion of grass species with vigorous root system change the soil physical and chemical attributes and can modify the mechanism of N_2O production in soils under integrated crop-livestock (ICL) system. This study is based on the hypothesis that the inclusion of brachiaria grass cultivated with maize modifies soil porosity, the input of organic carbon and nitrogen by roots decomposition and exudation, consequently changing the pathway and intensity of N_2O production. The objective of this study was to quantify the contribution of brachiaria on nitrification and denitrification processes to N_2O emissions using ^{15}N-labelled fertilizers. A glasshouse study was conducted in order to understand the ^{15}N-N_2O dynamics in soils with and without brachiaria grass. The N fertilizer applied was the ammonium nitrate, single and double labelled. The experimental units consisted of pots with 18 kg of soil on a dry basis. The experiment design was randomized with six treatments and four replicates. The treatments include: 1) Control (soil without plant and N); 2) Maize + Brachiaria without fertilizer; 3) Maize fertilized with $^{15}A^{15}N$; 4) Maize fertilized with $A^{15}N$; 5) Maize + Brachiaria fertilized with $^{15}A^{15}N$; 6) Maize + Brachiaria fertilized with $A^{15}N$. Along the experimental period, soil moisture was adjusted to 60% of the water holding capacity. The fluxes of N_2O were measured until the emissions stabilized to the level of control. The Maize + Brachiaria

significantly boost the N_2O production ($p \leq 0.05$) with an emission increase of 78% in comparison to maize monocrop and 85% when compared to the control. However, its increasing was observed only when N fertilization occurred. The Maize + Brachiaria without N fertilizer addition presented similar emissions than that observed in the control. The mineral N content presented the same pattern that N_2O emissions and in general, high concentration were observed in the first 12 DAF. Conversely, small quantities of dry matter (DM) were observed in the Maize + Brachiaria in comparison to the maize monocrop To conclude the real contribution of Maize + Brachiaria cultivation in the main microbial pathways responsible for N_2O emissions we have to finalized the ^{15}N-N2O calculations.

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EFFECTS OF IMPROVED PASTURES AND INTEGRATED AGRICULTURAL SYSTEMS ON SOIL CARBON SEQUESTRATION IN BRAZIL

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Keywords: crop-livestock-forestry; soc change; mixed-effect regression model.

Impact: The present study stands out for gathering information at the national level on soil carbon sequestration in areas with integrated agricultural systems, presenting carbon management coefficients for these systems. Our results propose a new approach to include the different categories of integrated agricultural systems in national greenhouse gas emissions inventory estimates.

Highlights: Mixed-effect linear regression models are effective to estimate effect size in meta-analysis research. Crop-livestock systems presents low potential to store carbon on soil. Silvopastoral systems are the most promising strategy for storing carbon from the conversion of degraded pastures.

Abstract: Brazil offers outstanding opportunities for contributing to climate change mitigation through carbon sequestration in pasture systems. Although several studies have been published assessing soil organic carbon (SOC), there is still a lack of information on the potential for carbon sequestration by improving pasture management, especially when integrated production systems are implemented. We aimed to derive factors for SOC stock change and potential sequestration rates for the conversion of extensive pastures into improved management and integrated production systems of crop-livestock-forest (CLFS), crop-livestock (CLS), and livestock-forest (LFS). We gathered primary studies by a systematic review process to build a database for Brazilian pasturelands, then, a mixed-effect linear regression model was fitted to estimate carbon management factors coefficients and SOC stock change rates. We included 283 data pairs comparing a reference (extensive or degraded pasture) and treatment, distributed in 37 field experiments from 30 published papers. The results pointed out that for 20 years, at a 0-30 cm depth, the improvement of exclusively pasture systems has the potential to increase SOC stocks by 18% from extensive pastures, while the adoption of integrated production systems can enhance by 34%, for LFS, 28%, for CLFS, and 3%, for CLS. We used these management factors to analyze the C stock change rates, providing a potential to sequester over a period of 20 years, in 0-30 cm depth, 0.21 Mg C ha $^{-1}$ year^{-1}, for improved

pastures, 0.39 Mg C ha $^{-1}$ year^{-1}, for LFS, 0.03 Mg C ha $^{-1}$ year^{-1}, for CLS, and 0.34 Mg C ha $^{-1}$ year^{-1}, for CLFS. The LFS presented the best opportunities to store C in soil, thus, we suggest more long-term research on this system to understand how time affects the change rates. These C factors contribute directly to national greenhouse gas emission inventories updates since they typically develop estimates based on regional studies. The results also raise new opportunities to assess the carbon change dynamics for specific categories of integrated production systems. Sponsoring Institution: Coordination of Superior Level Staff Improvement. Thanks to: Luiz de Queiroz College of Agriculture and Natural Resources Ecology Laboratory from Colorado State University.

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SOIL CARBON, YIELD AND GHG EMISSIONS RESPONSE TO COVER CROPS IN THE BRAZILIAN CERRADO

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Keywords: Soybean; particulate organic matter (POM); Carbon Dioxide Fluxes.

Impact: The Cerrado biome is the main producer of soybean in Brazil. Cropping systems such as soybean-fallow, which add a low amount of biomass, can lead to decreased soil health resulting in lower crop yields. Therefore, cover crops may serve as an alternative to promote the intensification of these systems.

Highlights: The mix of cover crops promoted higher POM contents. Soybean yield was lowest (14% less) in the fallow treatment. Average soil C-CO_2 emissions were 1.200 kg ha^{-1}.

Abstract: The simplified use of agroecosystems and the loss of soil organic matter in agricultural areas is considered one of the contributors to greenhouse gas (GHG) emissions. In this sense, the adoption of management practices that reduce GHG emissions is essential to mitigate climate change and promote sustainable agricultural development. The aim was to evaluate and investigate the best cover crop system to mitigate GHG emissions, increase soil carbon (mineral-associated organic matter - MAOM and particulate organic matter - POM) and soybean yield in the Cerrado. The study has 5 years of duration, with cover crops (off-season) and soybean (cash crop). Physical fractionation of soil samples was performed to obtain POM and MAOM fractions, calculate daily and cumulative GHG fluxes during the soybean cycle and soybean yield. There was no statistical difference between treatments for MAOM. The highest POM content was for the cover crop mix treatment (5g C/kg soil). The lowest CO_2 emissions were observed in the fallow treatment, with an average soil emissions of 1.200 kg C ha^{-1}. The emissions peaked during precipitation events and at lower soil temperatures. The release of greenhouse gases is a consequence of the integration of root respiration, microbial respiration, and soil carbon dynamics. Soil temperature and moisture control microbial activity and organic matter

decomposition and are recognized as the main factors that determine soil CO_2 fluxes. The greatest yield of soybeans was for the mix of cover crops (5.520 kg ha^{-1}) and Maize/*U.ruziziensis* (5.402 kg ha^{-1}). This information is essential for calculating the carbon balance of agricultural systems and defining the most promising management options for mitigating climate impacts. Funding institution: The São Paulo Research Foundation (2022/16368-6). Acknowledgments: Soil Health & Management Research Group, FAPESP and CAPES.

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

ROLE OF SOIL MACROFAUNA IN THE REGULATION OF CARBON DYNAMICS IN INTEGRATED AGRICULTURAL SYSTEMS

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Keywords: Soil aggregation; Biodiversity; C cycle.

Impact: Understanding the role of soil macrofauna in carbon regulation within integrated agricultural systems can have positive impacts on climate change mitigation, sustainable agriculture, soil health, biodiversity conservation, policy development, and global food security. It represents a valuable step towards more environmentally friendly and resilient agricultural practices worldwide.

Highlights: CLF area in Naviraí had a higher diversity index (0.3) than other land uses (PA 0.2; CL 0.1; EU 0.0). Greater emphasis on soil biodiversity was found in areas with native vegetation and pasture.

Abstract: Mitigating greenhouse gas (GHG) emissions and climate change has been a major global challenge. The implementation of Integrated Agricultural Production Systems (SIPAs) in Brazil is one of the main strategies for the accumulation of C in the soil. One of the main pillars for understanding the mechanisms by which LPISs act in the sequestration of soil C and GHG emissions is the understanding of the interactions of soil biology in this more diverse system. Soil macrofauna, mainly earthworms, ants, and termites, can modulate the physical protection of soil organic carbon (SOC) through the formation of macroaggregates, in addition, earthworms convert labile plant compounds into microbial necromass in water reservoirs stabilized carbon and increase the resilience of the COS. Therefore, the objective of this study is to evaluate the role of macrofauna in soil carbon sequestration under integrated systems and to understand the mechanisms used by macrofauna in the stability of biogenic aggregates. The project is being developed in four locations in Brazil (Caiuá - SP, Rancharia -SP, Naviraí - MS, and Ipameri-GO) the areas have sandy soil and a different degree of complexity of the system. The following systems were evaluated: Pasture (PA), crop-livestock integration system (CL), livestock-forest (LF), crop-livestock-forest, (CLF) native forest (NF), and eucalyptus (EU). The areas of monoculture pasture presented, in general, higher indices of diversity, uniformity, abundance, and richness for edaphic macrofauna, compared to the integrated systems. Notably, the native vegetation areas, used

as a reference, showed the highest soil biodiversity. The forest-livestock integration systems showed promise for reestablishing macrofauna richness at depth. The greater abundance of ants found in forest systems compared to other systems suggests that forest areas offer better conditions for the establishment and prosperity of these populations. To understand the role of macrofauna in this process and the contribution of the systems, assessments of soil aggregates (turnover of macroaggregates, aggregate formation pathway) and soil carbon fractionation are needed, still in analysis. This project is expected to clarify the importance of macrofauna in carbon sequestration and the benefits of integrated systems in the maintenance of these organisms. This knowledge is crucial to establish management techniques and relate gains linked to the abundance and diversity of macrofauna in various soil processes (e.g., aggregation, water infiltration, C sequestration), which are directly affected by the activity of these organisms.

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

ENZYMATIC ACTIVITY IN SOILS UNDER DIFFERENT USES IN THE BRAZILIAN CERRADO

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Keywords: Phosphatase acid, Arylsulfatase, Integrated systems.

Impact: Enzymatic activity is na indicator of soil quality, as they are sensitive to land use change. In this sense, this work evaluated acid phosphatase and arylsulfatase activity in two configurations of integrated systems and in reference áreas, in order to verify how land use changes this characteristic.

Highlights: Acid phosphatase and arilsulfatase activity were sensitive to land use change. Acid phosphatase activity in ILF did not differ from the reference areas in 0-5cm. Arilsulfatase activity was higher in PP up to 10 cm.

Abstract: Decomposition is mediated by enzymes that are mainly produced by soil microorganisms and some plants. The enzymatic activity is responsible for the mineralization of organic matter and can be altered by soil use and management. The objective of this study was to evaluate the activity of the enzyme acid phosphatase and arylsulfatase in different land use. For this, soil samples were collected in 2 integrated agricultural production systems (IAPS): Crop-Livestock (ICL) e Livestock-Forest (ILF); Cerrado (CE) and Permanent Pasture (PP), which were used as a reference. 5 (ICL, CE and PP) and 9 (ILF) repetitions per area were sampled, in layers 0-5, 5-10, 10-20 and 20-30 cm. Phosphatase acid and arylsulfatase activity was performed by spectrophotometry. Teste t was used as a statistical parameter, where land uses were compared in pairs ($p \leq 0.05$). All values presented are in “µg of p-nitrofenol h^{-1} g^{-1} soil”. The enzymatic activities decreased with increasing depth. For phosphatase acid, in the 0–5 cm layer, ICL (298.13 ± 59.34) was lower and different from PP, ILF and CE. Between 5-10 cm, all treatments differed, with CE (674.68 ± 86.64) highest activity and ICL (273.76 ± 20.21) lowest. Third layer, CE (546.56 ± 52.77) was superior and did not differ from

PP (480.38 ± 34.46). For arylsulfatase activity, in the first layer, PP (111.69 ± 35.52) differed from all land uses. Between 5-10 cm, PP (74.35 ± 15.19) was superior and different from ICL (32.89 ± 3.70), ILF (31.17 ± 9.97) and CE (46.43 ± 14.40). In 10–20 cm, PP (47.49± 8.02) and ILF (39.70 ± 16.19) did not differ, while ILF also did not differ from ICL (33.06 ± 2.33) and CE (34.85 ± 8.68). In the last layer, PP (22.30 ± 3.32), ILF (23.43 ± 4.98) e ICL (18.66 ± 3.09) were the same and ICL did not differ from CE (13.42 ± 5.49). The IAPS with the highest level of complexity (with forest) showed high enzymatic activity, reembling the reference areas in some soil layers, under the conditions of this study. Acknowledgment: Capes, FAPESP (Grant #2022/09977-6), RCGI, ESALQ/USP.

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Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

SENSITIVITY OF ENZYMES TO DETERMINE SOIL HEALTH

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Keywords: enzyme activity; healthy soil; forage crops.

Impact: This work determined the sensitivity of enzyme activity compared to other parameters to determine soil health in a soil management system with soybean in succession with forage crops.

Highlights: Enzyme activities are sensitive in soil management. The same scenario was repeated when evaluating enzyme activity and other parameters.
Forages in succession with soybeans increase the activity of enzymes in the soil.

Abstract: Extracellular enzymes act in various reactions that result in the decomposition of soil organic residues, nutrient cycling, and organic matter composition. In addition to these functionalities, the enzymes β-glucosidase and arylsulfatase can be important allies to assess soil health. Thus, the activity of these enzymes was determined in a long-term experiment in the state of Tocantins comparing with other soil and agronomic parameters to determine the sensitivity of these enzymes in determining soil health. The treatments with soybean in succession with U. brizantha cv. Marandu, U. ruziziensis, M. maximus cv. Mombaça and M. maximus cv. Massai obtained higher β-glucosidase and arylsulfatase enzyme activities compared to soybean in succession with millet and soybean fallow. With average values of 54.2 mg PNG kg-1 soil and 56.8 mg PNS kg-1 soil. Concomitantly with the other parameters evaluated, such as chemical and physical parameters, in addition to grain yield. The same scenario was repeated, with these treatments having higher values than soybean with millet and soybean fallow. These results show that enzyme activities are a sensitive parameter that allows for determining soil health since they can identify changes in soil management. Acknowledgments: Embrapa Pesca e Aquicultura and to the group Sohma (Soil Health & Management Research Group).

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I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

SOIL CARBON DYNAMICS AND MICROBIAL NECROMASS IN AGROFORESTRY SYSTEMS: IMPLICATIONS FOR SUSTAINABLE AGRICULTURE IN THE AMAZON

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Keywords: Climate Changes, Integrated Systems, and Soil Microbiome

Impact: Minimization of the environmental impact of agriculture through the increase of soil Carbon by adopting agroforestry in the Amazon, as well as the disclosure of a less explored component of soil organic carbon: microbial necromass.

Highlights: The adoption of agroforestry increases C levels in the soil similarly to a forest. Higher quantities of C in the form of POM were detected in the Agroforestry. Microbial necromass contributes up to 25% of SOC.

Abstract: In light of the challenge faced by agriculture to increase yields and mitigate environmental impacts, agroforestry systems (AFS) have been disseminated across Brazilian biomes, including the Amazon. However, scant research has been dedicated to understand the effects of this form of land use on the activity and death (products and residues of biomass - hereafter referred to as "microbial necromass") of the soil microbiome and its reflection on the soil's ability to sequester CO_2 in the form of soil organic carbon (SOC). Thus, the objective of this study was to understand the interrelationship between biological parameters, the content of C and N in soil organic matter (SOM) fractions, and the contribution of microbial residues to SOC in a long-term AFS in the Amazon. For this study, soil samples were collected between 2022 (dry season) and 2023 (rainy) in a native forest (F), monoculture of oil palm (CA) (*Elaeis guineensis*), and AFS with oil palm as an economically significant species, at different depths in Tomé-Açu (PA). For the 0-10 cm depth, F and AFS did not significantly differ in terms of enzymatic activity, C and N levels in MAOM and POM, with higher levels of SOC and N. At the depths of 10-20 cm and 20-30 cm, F was superiority in terms of acid phosphatase and arylsulfatase, C and N in MAOM and SOC, followed by AFS, while C in POM generally did not differ - with CA presenting the lowest levels. At the 0-30 cm depth, the contribution of microbial necromass to SOC varied between 8% and 25%, with a predominance of fungal over bacterial necromass. Such results could be associated with the net carbon balance derived from the input and decomposition of organic material in F and AFS in the top 10 cm. However, the higher C content in the stable fraction in the subsurface of F

and AFS implies that forested environments and agroforestry systems foster a more enduring form of C in comparison to CA, with significant contributions from microbial necromass to SOC. **Acknowledgments**: CAPES, Soil Microbiology Laboratory (ESALQ/USP), FAPESP (Process Nº.: 2022/10276-2), and RCGI-USP.

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SPATIAL VARIATION OF SOIL ORGANIC CARBON CONTENT IN BRAZILIAN SOYBEAN CROPLANDS

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Keywords: Soil Organic Matter; Brazil; Biomes

Impact: Brazil is critical for soil organic carbon (SOC) sequestration. A study of 18,055 records found higher SOC levels in the southern regions and soybean fields of the Atlantic Forest biome. These findings highlight Brazil's important contribution to global carbon sequestration and sustainable agriculture through climate and soil management.

Highlights: Southern Brazil has higher SOC content compared to the Midwest and Southeast. Soybean croplands in the Atlantic Forest biome have the highest SOC of the biomes studied. Climate and soil properties enhance SOC storage, supporting sustainable agriculture.

Abstract: Soil organic carbon (SOC) plays a central role in soil health and ecosystem functioning and is subject to a number of influences, including land use, microbial activity and management practices. Brazil occupies a prominent position in the global agricultural sector, with significant carbon sequestration potential due to its tropical climate and highly weathered soils. The objective of this study was to provide an overview of soil carbon content, specifically within the 0-10 cm layer under soybean cultivation, across different Brazilian biomes and regions. An extensive dataset of 18,055 records from 14 states was compiled, including data collected between 2021 and 2022 from the 0-10 cm soil layer. Carbon content was standardized to g kg-1. Exploratory analyses and box plots were performed to evaluate carbon levels in different biomes and regions of Brazil. Notably, carbon levels were significantly higher in the southern region, averaging 23 g kg-1, exceeding measurements from other regions such as the Midwest and Southeast. In terms of different biomes, soybean fields within the Atlantic Forest biome had the highest levels (about 23 g kg-1), slightly exceeding the Pampa and Cerrado biomes (about 20 g kg-1). These results correlate with climatic variables such as temperature and

precipitation; the humid subtropical climate (Cfa and Cfb) regulates soil carbon accumulation by influencing slower rates of organic matter decomposition and promoting higher plant biomass production, while the presence of highly weathered soils suggests specialized carbon sequestration mechanisms that further increase carbon storage potential. In conclusion, this study highlights the complex dynamics of soil organic carbon in Brazilian soybean croplands across different biomes and regions. The results highlight the influence of climate and soil characteristics on carbon storage potential, and ultimately underscore Brazil's ability to play a pivotal role in addressing carbon sequestration and advancing sustainable agricultural practices on a global scale. Financing institution: CAPES. Acknowledgements: Soil Health & Management Research Group.

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DATABASE PREPARATION FOR MODELING SOIL CARBON DYNAMICS

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Keywords: data wrangling; data management; soil carbon.

Impact: Database preparation and management are essential for creating accurate soil carbon (C) dynamics projections. We propose a framework that emphasizes data integrity and error checks. These data will subsequently model the impact of land use and land cover changes on carbon dynamics in open ecosystems.

Highlights: There is a lack of national-level studies that focus on C dynamics and local process. We provide a soil C database framework to integrate data from multiple origins. Relational database that considers the complexity of soil data is fundamental.

Abstract: Land use and land cover changes can disrupt biogeochemical cycles in open ecosystems, particularly C dynamics and greenhouse gas (GHG) emissions. Modeling of such data is crucial for informed public policies to prevent and mitigate climate change impacts. There is a lack of accurate information on C dynamics in managed open ecosystems. Within the “A.3 Improving pasture management as NBS for soil C sequestration in Brazil” project, we aim to tackle this problem and build and manage a database in a structured way that values data integrity and error checks. This data will be used for modeling using Daily Century Model (DayCent). We are working at the initial project phase which involves gathering data and converting raw data into a usable form. As first results, we have: (i) an experimental database structure that considers the input requirements of the DayCent model and the web modeling platform, (ii) we build a relational database structure that considers the complexity of soil data and also includes the local ecological and anthropogenic processes, and (iii) developed a structured process and code in R format to prepare the database and develop summary statistics. Effective data management practice is crucial to ensure the success and reliability of data modeling approaches. This project receives financial support from the BG E&P Brasil Agreement (Shell Group).

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STABILIZATION OF CARBON FROM ROOTS AND AERIAL BIOMASS OF WINTER COVER CROPS GROWN

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Keywords: ^{13}C; residue quality; organo−mineral association.

Impact: Quantify the contribution of winter cover crops to soil C accumulation and understand the main stabilization mechanisms. What will be possible to validate crop rotation systems that contribute to the increase of C in the soil.

Highlights: The aerial biomass of vetch has a higher C stabilization efficiency compared to oats. The remaining vetch rhizodeposition contributes to the accumulation of soil C. Organo-mineral association is the main mechanism of C accumulation in the soil.

Abstract: Soil C stability is crucial for sustainable agriculture in tropical and subtropical ecosystems. The objective of this thesis was to evaluate the efficiency and identify the stabilization mechanisms in soil of C from root and shoot biomass of cover crops. Soil columns were sampled with PVC tubes from an area under no-tillage for 20 years. Half of the columns (n=24) were kept under natural atmosphere (^{12}C) and the other part was enriched with ^{13}C through the application of weekly pulses of $^{13}CO_2$. Then, winter cover crops – oats and vetch– were grown. The first six columns were used as a reference, based on individual measurements of root and shoot biomass, C and N content, C isotopic ratio ($^{13}C/^{12}C$). The others were harvested and used in the experiment with a paired combination of enriched (^{13}C) and non-enriched (^{12}C) root and shoot biomass. At 10 and 21 months of incubation, the soil columns were stratified in four layers, and subjected to organic matter (OM) fractionation analyzes. All soil samples and soil organic matter (OM) fractions were analyzed for C content and isotopic ratio ($^{13}C/^{12}C$). After 10 months of incubation, vetch shoot biomass showed 35% greater soil C stabilization efficiency than oat shoot biomass and represented the highest proportion of soil C stabilized in the OM associated with minerals. However, in the same period, C from oat roots showed a soil C stabilization efficiency 38% greater than that from vetch roots, meaning that, on average, oats and vetches had similar soil C stabilization efficiencies. At 21 months of incubation, the soil C stabilization efficiencies from the different shoot biomass did not differ among themselves; however, oat roots had a stabilization efficiency two times greater than vetch roots, which resulted in greater soil C stabilization due to oat in that period. The OM fractionation evidenced that the key mechanism

of C stabilization was the organo-mineral association. Thus, the significance of C stabilization from oat roots and shoot biomass of vetch, and the short-term action of the mechanisms involved, reinforce the need of rotation of crops that bring a constant supply of C when the aim is to improve soil quality and C sequester in subtropical soils under no-tillage systems.

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INTEGRATED CROP-LIVESTOCK AS A STRATEGY TO INCREASE SOIL CARBON STORAGE AND STABILIZATION

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Keywords: soil aggregation; XPS; brachiaria; carbon sequestration

Impact: This study proposes to investigate the soil C sequestration mechanisms under systems based on brachiaria cultivation in well-managed pasture −P and integrated crop-livestock −ICL. Our findings indicated that ICL and P systems increased soil C storage and stability, providing a comprehensive understanding of C sequestration processes in integrated agricultural soils.

Highlights: Systems based on well-managed pasture and ICL increased soil C stock and stability. P and ICL promoted higher aggregate stability than CS and ICLF systems. P and ICL systems showed an increment in labile and recalcitrant C groups in soil.

Abstract: Systems based on well-managed pastures and integrated agricultural systems using brachiaria grass can be a promising nature-based solution to increase carbon (C) sequestration in soil. The main objective was to quantify soil C changes and understand the mechanisms of soil C storage and stabilization under integrated systems. A field experiment was conducted for >10 years in a randomized block design with four replications at Sinop/MT−Brazil, and four treatments were tested: Crop Succession –CS, Integrated Crop-Livestock –ICL, Integrated Crop-Livestock-Forest –ICLF, and Pasture –P. Soil samples were collected at 0-30 cm layer, and the total C concentration was quantified by dry combustion, aggregate stability was analyzed by wet-sieving, and the surface chemical composition was quantified by x-ray photoelectron spectroscopy (XPS). Our findings revealed that ICL and P systems presented 33% higher soil C stocks compared to both ICLF and CS. Higher values (4,9 to 6,0 mm) of the mean weight diameter of aggregates were observed under ICL and P, suggesting better physical protection of soil C by aggregate stability in these systems. The high-resolution C spectra data showed notable increase in the relative abundance of aliphatic/aromatic C groups in soils under P and ICL systems at 0-5 cm layer by 17 and 9% compared to both ICLF and CS, respectively, and increased abundance of the C associated with oxygen (hydroxyl, ether, carbonyl, carboxylic,

ester and lactone groups) was observed under P and ICL systems by

25%, and ICLF by 14% compared to CS. In the 5-10cm soil layer, the differences among the treatments were slighted, but showed higher abundance of both labile and recalcitrant C groups compared to the surface layer (0-5 cm). In the ICLF, results from the position below the eucalyptus rows were similar to the CS system, and the middle position of the area were similar to the ICL and P. These findings suggests that ICL and P systems increased soil C storage and stability, providing scientific basis for a comprehensive understanding of soil C sequestration processes in integrated agricultural soils. Financial Support: RCGI (FAPESP proc #2020/15230-5), CNPq (150892/2022- 5), FAPESP (2022/07665-7). Acknowledgements: Shell; ESALQ; LNBR/CNPEM; LNNano/CNPEM; Embrapa Agrossilvipastoril.

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POTENTIAL AREAS FOR SOIL CARBON SEQUESTRATION THROUGH THE RECOVERY OF PASTURE IN THE ATLANTIC FOREST

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Keywords: Soil carbon sequestration; Pasture recovery; Atlantic forest.

Impact: To reduce emissions from the agricultural sector, Brazil proposed as one of the goals of the ABC+ Plan to recover 30 million hectares of degraded pasture. This study contributes to an analysis identifying potential regions for carbon sequestration in the soil through pasture recovery in the Atlantic Forest biome.

Highlights: Atlantic Forest has 19 million hectares of degraded pasture. Atlantic forest has five strategic regions for pasture recovery. SOC stock of pasture in temperate Atlantic forest ranged from 35 to 88 Mg ha^{-1}.

Abstract: The recovery of degraded pasture areas is an important strategy (nature-based solution - NBS) for mitigating climate change due to its great potential for carbon sequestration in the soil. Brazil has a great opportunity to explore this technology since about 63% of the pasture area (95.5 Mha) is in a moderate or severe degradation stage. Among the areas that should be prioritized for expanding this technology are those in the Atlantic Forest biome, which has the highest accumulation rate of soil organic carbon (SOC) per unit area. In addition, the biome has approximately 20% of Brazil's total area of degraded pasture (19 Mha). Thus, this study aimed to identify areas for pasture recovery with greater potential for carbon sequestration in the soil of the Atlantic Forest. Data on carbon stock in the soil (0-20 cm layer) obtained from a bibliographical survey and pasture quality mapping (MapBiomas) for 2021 were used to identify these areas. Areas for pasture recovery are the regions: west of the state of São Paulo, northwest of Paraná, east of Minas Gerais, west of Rio de Janeiro and Espírito Santo, and southeast of Bahia. Soil carbon stocks of nominal and improved pastures for the Cfa climate, notorious in the northwest region of Paraná, ranged from 36.4 to 66.6 Mg ha^{-1}. In contrast, for the Aw climate, which is predominant in western São Paulo, the average value was 35 Mg ha^{-1}. The values for the Cfb, Cwa, and Cwb climates that comprise most of the regions mentioned ranged from 32 to 88 Mg ha^{-1}. Notably, the carbon stocks for degraded pasture areas in these regions vary from 25 to 30 Mg ha^{-1}, which allows inferring the potential gain with the recovery of these areas. The analysis

made it possible to identify important regions for the recovery of pasture in the Atlantic Forest biome and contribute to better directing the actions of the ABC^{+} Plan for this technology.

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USE OF SYNCHROTRON TOMOGRAPHY AS A STRATEGY TO ELUCIDATE N_2O PRODUCTION PATHWAYS IN TROPICAL SOILS

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Keywords: Greenhouse gases; ^{15}N-labelled fertilizers; Soil structure

Impact: The proposal brings a novelty in the study of the interface of soil structure of tropical soils, the application of high-resolution computed tomography (SRXCT) using a fourth-generation synchrotron source, and the use of stable isotopes from ^{15}N-labelled fertilizers to quantify the contribution of nitrification and denitrification pathways.

Highlights: Pasture and integrated crop-livestock enhances inter and intra-aggregate porosity. Pores with low connectivity promote *hotspots* for N_2O emissions. ^{15}N-labelled fertilizers are essential for quantifying N_2O emission pathways.

Abstract: Soil structure controls chemical, physical, and biological processes in the soil, including nitrous oxide (N_2O) emissions. Soil management practices such as integrated crop-livestock (ICL) interfere on soil aggregation mechanisms and pore space dynamics, mainly biopore formation. The hypotheses of this proposal are (i) the use of *Brachiaria* species increases inter and intra-aggregate porosity of pasture and ICL systems; (ii) the crop-succession system has pores with low connectivity, promoting *hotspots* for N_2O emissions for denitrification pathways by favoring sites of water accumulation; (iii) the increase in resolution and the identification of smaller pores within the aggregates provide information on the spatial heterogeneity of the microscale and are therefore expected to provide different information about the possible hotspots of N_2O emissions. Therefore, the main objectives of this purpose are to (i) quantify soil N_2O emissions in a controlled environment; (ii) decipher how soil pore space parameters, such as porosity, pore size distribution, connectivity, and tortuosity, and soil physical-hydric properties influence N_2O emissions; and (iii) identify correlations between N_2O emissions and soil pore space parameters. To achieve the objectives presented in this proposal, the Work Plan will be carried out in two phases. The first phase will include field sampling in experimental plots to better understand the influence of land use on soil physical-hydric properties. The

second phase of the plan will be related to an incubation experiment to verify the behavior of N_2O emissions and high-resolution computed tomography (SRXCT) experiments in the Mogno beamline of Sirius (LNLS/CNPEM). The experimental sites are located at EMBRAPA Agrossilvipastoril, in Sinop, State of Mato Grosso, Brazil. The experiment has been conducted to 12 years, under a Typic Hapludox, with clay texture. The results of this proposal will elucidate the dominant mechanisms of N_2O emissions in tropical soils under no-tillage, ICL system, and pasture. The proposal brings a novelty in the study of the interface of soil structure of tropical soils, the application of high-resolution computed tomography (SRXCT) using a fourth-generation synchrotron source, and the use of stable isotopes from ^{15}N-labelled fertilizers to quantify the contribution of nitrification and denitrification pathways.

Research Centre for
Greenhouse Gas Innovation

I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

ADDRESSING LIMITATIONS IN SUCCESSIONAL STAGES CLASSIFICATION TO IMPROVE THE ATLANTIC FOREST CONSERVATION

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Keywords: tropical forest, environmental legislation, ecological succession.

Impact: The Atlantic Forest, vital for global biodiversity, faces challenges due to imprecise successional stages classification. The Atlantic Forest Law restricts forest use, but state-level criteria lack precision, impacting permitting and offset strategies. Our study addresses these issues, proposing a more precise and practical framework, emphasising ecological assessment and private-land protection.

Highlights: Current succession stage criteria hinder permits & offsets due to subjectivity. New model: classify based on vegetation, biodiversity, social, and landscape factors. Urgent: Improve scientific credibility of succession classification for legal strength.

Abstract: The Atlantic Forest, a critical global hub of biodiversity, plays an essential role in maintaining its fragile state. Federal law 11,428/2006 has introduced restrictions on forest use, organised by successive stages of growth. However, the subjective and imprecise criteria used at the state level to categorise forest patches within these stages have concerning implications. This imprecision negatively affects environmental permitting and the implementation of offset strategies. Our study delves into the inherent limitations of applying this law and proposes practical alternatives to create a more precise, legally sound, and workable framework for assessing the conservation value of forest patches. Our analysis highlights challenges tied to sampling techniques, indicators, and methodologies. We present comprehensive guidelines for redefining the parameters that oversee the enforcement of the Atlantic Forest law, aligning with state-level regulations. Our suggested approach involves a straightforward two-step evaluation centred on vegetation composition, biodiversity richness, societal significance, and landscape indicators. This streamlined strategy emphasises the ability to evaluate ecological integrity across varying stages of forest succession

and distinct forest types. This becomes crucial as approximately 90% of the remaining Brazilian Atlantic Forest is privately owned. Enhancing this legal framework becomes pivotal to protecting the vulnerable biodiversity of this unique and endangered biome.

Research Centre for Greenhouse Gas Innovation

I SEMINAR ON NATURE BASED SOLUTIONS IN AGRICULTURE AND FORESTRY:
Strategies for Carbon Capture and Reduction of GHG Emissions in Brazil

SOIL CARBON CHANGES AFTER INTENSIFICATION OF AGRICULTURE AND LIVESTOCK IN THE BRAZILIAN BIOMES: A META-ANALYSIS

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Keywords: Agrosilvopastoral arrangement; Agroforestry; Regenerative agriculture.

Impact: The intensification of agriculture and livestock with agrosilvopastoral systems can reverse soil C losses. Additionally, the introduction of trees can increase soil C sequestration, supporting the potential of agroforestry systems to recover low-productivity areas in Brazil.

Highlights: Agrosilvopastoral system is the most efficient arrangement to accumulate soil carbon. Introduction of tree component in agroforestry increase carbon sequestration. There is a lack of data about soil carbon in integrated systems in the Caatinga biome.

Abstract: Brazilian Agricultural Policy for Climate Adaptation and Low Carbon Emission (ABC+) Plan was launched aiming to expand the agricultural land by 72 million ha and achieve an estimated mitigation capacity of 1.1 billion tCO2e by 2030. The adoption or maintenance of integrated production systems is a target of the ABC+ Plan, as it is a sustainable and efficient strategy for mitigating GHG emissions and increasing productivity by promoting the intensification of agricultural, livestock, and forestry production. This study aimed to summarize the data from literature using the meta-analysis to evaluate soil carbon stocks after intensification of agriculture and livestock in different biomes in Brazil. A survey was carried out by peer-reviewed publications available in the databases: ISI-Web of Science, Science Direct and Scientific Electronic Library Online (SciELO) between the years 2010 and 2022. The terms used were "agroforestry"; "agriculture intensification"; "agrosilvopastoral"; "crop-livestock-forest"; "integrated systems"; "livestock intensification"; "silvopastoral"; "soil carbon", and we selected studies performed in Brazil where the previous land use was degraded/low-productivity pastures. Considering the intensification of agriculture and livestock in Brazil, we found no studies for Caatinga biome with degraded

pasture as previous land use. We found the higher sampling value in Cerrado and Atlantic Forest because the adoption of different arrangement and composition of agroforestry systems is higher in these two Brazilian biomes. Our meta-analysis showed an increase in soil C stocks after the conversion of degraded or low-productivity pastures to integrated production systems. The agrosilvopastoral system was the model and arrangement that most contributed to increase soil carbon stocks, with emphasis in the Cerrado biome (64%). In the Pampa biome, the integrated production model adopted was the crop-livestock (agropastoral), contributing to an increase in C stocks by up to 15%. In the Amazon, the agropastoral and agrosilvopastoral systems showed an increase up to 39 and 35%, respectively. These findings indicate that the intensification of agriculture and livestock systems in Brazil can reverse soil carbon losses. Additionally, the introduction of trees can increase soil carbon stocks, supporting the potential of agroforestry systems as a regenerative agriculture model. Funding: CNPq; Fapemig; Fapesp; Shell.