



Compilation of Greenhouse Gas Emission and Removal Factors in Brazilian Agriculture



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AGRICULTURA, PECUÁRIA
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**Compilation of Greenhouse
Gas Emission and Removal
Factors in Brazilian Agriculture**

MAPA's mission

To promote the sustainable
development of agriculture and
livestock, and its subproducts

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PRESENTATION

The Sectoral Plan for the Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture (ABC Plan) was created to implement Brazil's National Policy on Climate Change - PNMC (Law No. 12,187/2009) in the agricultural sector. The ABC Plan is one of the most important tools in Brazil's current agricultural policy. With the aim of expanding the adoption of sustainable production systems, the ABC Plan represents the sector's solid commitment to tackling climate change and other factors, by monitoring the results of actions to control agriculture and livestock-related greenhouse gas emissions (GHG).

Agriculture and livestock production play a fundamental role in food security. Furthermore, the progress observed after the adoption of sustainable agricultural production systems is also fundamental to foster an appropriate balance between income generation, economic sustainability, environmental conservation, and the provision of ecosystem services. Currently, the agriculture and livestock sector play an important role in national efforts to tackle climate change and in fulfilling Brazil's commitment to the United Nations Framework Convention on Climate Change (UNFCCC). Thanks to its solid scientific and technological base, strategy and effective public policy tools, as well as an inclusive management team that deeply involved the productive sector, the ABC Plan has been showing expressive results with regard to the increase of agricultural production, aligned with gross greenhouse gas (GHG) emission control. The implementation of the ABC Plan has made it possible for emissions associated to the agriculture and livestock sector to remain well below the initially defined targets, and certainly well below the projected emissions growth, without the need for interference from public policy. Thanks to the ABC Plan, the Ministry of Agriculture, Livestock and Food Supply (MAPA) has been able to fulfill its role in strengthening more sustainable agriculture enabling the reduction of GHG emissions, ensure security in food production, reduce vulnerability to climate change, strengthen resilience and the ability to adapt to growing climate uncertainties, thereby contributing sustainably to the increase of productivity in Brazilian agriculture and livestock.

Each nation has its own history, economy, and developmental trajectory, which are all linked to certain GHG emission levels. This is the basis behind the principle of common but differentiated responsibilities, which takes into account each country's economy, as established by the UNFCCC. At the same time, it emphasizes the importance of determining specific emission factors that reflect the reality of environmental and technological conditions in each country. Establishing national and sectoral emission factors is essential for more accurate quantification of GHG emissions, enabling the disclosure of appropriate information to national and international stakeholders, and above all, to guide the correct design for the national sector's national policy to combat climate change.

Emission estimates, and, consequently, their reduction, control, and removal capacity, are currently still elaborated with a high level of uncertainty. Although we cannot completely eliminate the intrinsic uncertainty in this very dynamic process, we can certainly improve the accuracy of these estimates by applying better data and appropriate methodologies according to each sector's specific characteristics. To this end, determining emission factors that are specific to the nature of each activity and appropriate for national circumstances is essential (IPCC, 2000).

Currently, there are several studies in Brazil that have been developed by universities and research institutions, aiming to establish specific emission factors for national agricultural systems. However, many stakeholders and partners are not aware of a large part of this data, given the difficulty of access to it. Consequentially, it makes it more difficult to recognize the potential that the results of

these studies and related information may have for calculating national emissions. This scenario has frequently forced Brazil to adopt IPCC standard emission factors for its GHG emissions calculations. Although valid on a global scale, these factors were developed from edaphoclimatic and technological realities that are different from the tropical and subtropical reality that characterizes the diversity of Brazilian agricultural and livestock production systems. Therefore, the potential for the removal and control of GHG emissions by national agriculture and livestock activities is not necessarily reflected in the figures obtained.

In order to promote dialogue between the various national actors, MAPA prepared the present “Compilation of Greenhouse Gases Emission Removal Factors in Brazilian Agriculture”, with the participation of several Brazilian researchers dedicated to the topic.

This publication presents an objective, albeit unexhaustive, picture of the current state of research towards creating a definition of both specific emission factors aimed at the main crops and production systems in the country, and the management alternatives to mitigate GHGs.

The information collected in this Compilation comes from scientifically based inputs aimed at strengthening the ABC Plan strategies for sustainable livestock, as well as improving methodologies for quantifying GHG emissions and removals in the agricultural sector.

We would like to thank all the collaborators and institutions that contributed to this strategy and wish them a pleasant read!

Tereza Cristina Corrêa da Costa Dias
Minister of Agriculture, Livestock and Food Supply

TABLE OF CONTENTS

INTRODUCTION	14
Transparency and reporting mechanisms of the United Nations Framework Convention on Climate Change and its rules modulations	18
Emissions from managed soils: methodological aspects and main emission sources	22
Conservationist and sustainable agricultural systems	28
1. EMISSION AND REMOVAL FACTORS FOR SUGARCANE	32
Sustainable strategies for mitigating greenhouse gas emissions in sugarcane production	34
Effects of unbrunt sugarcane harvesting on carbon dynamics and soil properties	42
Balance of greenhouse gases from the conversion of burnt sugarcane cane harvested areas for raw mechanized harvesting in Brazil	44
CO ₂ -C emissions from the soil before replanting sugarcane in southern Brazil	46
Development of indicators for the analysis of the sustainability of sugarcane cultivation through irrigation in traditional and expansion regions of the northeast	48
Removal of sugarcane straw and its implications for greenhouse gas emissions from the soil in the state of São Paulo, Brazil	50
N ₂ O emissions from the application of nitrogen fertilizers for sugarcane cultivation in the Mid-Southern Region of Brazil	52
Expanding sugarcane cultivation: transforming degraded pastures into sugarcane plantations and changes in greenhouse gas emissions	54
Observation and modeling of greenhouse gases CO ₂ , CH ₄ e N ₂ O, emissions, in a sugarcane plantation	56
Emissions of greenhouse gases from sugarcane cultivation soils in Brazil: effects of the application of synthetic and organic fertilizers with straw accumulation	58
N ₂ O emissions in sugarcane with the application of nitrogen fertilizer and stillage in the Cerrado	62
Paradigms in sugarcane straw management: conservationist agriculture versus energy cogeneration?	64
2. EMISSION AND REMOVAL FACTORS FOR GRAINS	66
Grain production: strategies to mitigate GHG emissions and maintain crop productivity	68
CH ₄ e N ₂ O emissions and the potential of intermittent irrigation systems to mitigate these gasses in rice fields in the state of Rio Grande do Sul	77
Fluxes of nitrous oxide from the soil under different crop rotations and soil tillage systems in Southern Brazil	80

Nitrous oxide flows derived from pasted urea fertilizer inputs in corn production under conventional tillage system in the state of Sergipe	82
Evaluation of methane emissions from rice cultivation irrigated through flooding	84
Carbon balance and greenhouse gas dynamics in soy/corn, soy/sorghum, soy/millet systems in the Cerrado biome	86
Carbon balance and greenhouse gas dynamics in corn/undergrowth crop systems in the Cerrado biome	88
Nitrous oxide (N ₂ O) fluxes under different land use soils in Brazil	90
Impacts of nitrogen fertilization management on greenhouse gas nitrous oxide emissions and irrigated rice (<i>Oryza sativa</i> L.) productivity in the Cerrado	92
Assessing Nitrogen (N) sources to reduce N losses from volatilization of N-NH ₃ and N-N ₂ O emissions in irrigated common beans cultivation under a no-till system	94
Irrigation systems and water management practices such as greenhouse gas emissions mitigation strategies in rice cultivation	97
N ₂ O emissions in corn production systems under no-tillage and conventional tillage in Latosol Cerrado soils	100
Nitrous oxide (N ₂ O) fluxes under different land use soils in Brazil	102
The potential of soil and vegetation practices management to mitigate greenhouse gas emissions in lowlands	104
Volatilization of ammonia (NH ₃) and emission of nitrous oxide (N ₂ O) after application of pig slurry in corn cultivated soil	106

3. EMISSION AND REMOVAL FACTORS FOR INTEGRATED PRODUCTION SYSTEMS AND PLANTED FORESTS **108**

Integrated production systems as an effective strategy for agricultural sustainability	110
Evaluation of nitrous oxide emission in pastures under rotational and continuous management in the Southeastern Region of Brazil	116
Modeling nitrous oxide emissions from pastures of pure Gramineae and intercropped Gramineae with legumes in Western Brazilian Amazon	118
Ammonia (NH ₃) volatilization and nitrous oxide (N ₂ O) emissions after application of pig slurry in corn cultivated soil	120
Overwintering of ryegrass in soybeans to mitigate nitrous oxide emissions in a crop-pasture system in Southern Brazil	122
Emission of nitrous oxide during the decomposition of summer undergrowth plant cultivation residues in subtropical climates	124
Biomass and carbon stock from eucalyptus trees in integrated livestock production systems	126
Carbon balance in rural properties with agrosilvopastoral planting	128

CO ₂ emissions and soil carbon stocks in agricultural areas and planted forests in the Cerrado region of Mato Grosso do Sul	130
N ₂ O emissions, increased nitrogen and reduced carbon in the soil through organic management in citrus orchard	132
Organic carbon stock and greenhouse gas emissions from the soil in an area with native species of the Pampa biome	134
Soil quality indicators in an integrated low carbon emission livestock system in the Amazon biome	136
Statistical modeling of soil carbon in a specialized production crop-livestock-forest integration system in Paragominas-PA	138
Emission of greenhouse gases and environmental indicators in a eucalyptus planted forest in the core Cerrado region	140
Annex - References continuation	142

ACRONYMS

ANP	National Petroleum, Natural Gas and Biofuel Agency
TB	Total Biomass
BTR	Biennial Transparency Report
BUR	Biennial Update Report
C	Carbon
CaO	Calcium oxide
Ca(OH) ₂	Calcium Hydroxide
CaCO ₃	Calcium Carbonate
CO	Carbon Monoxide
CO ₂	Equivalent Carbon Dioxide
CO ₂ eq	Carbon Dioxide Equivalent
CF ₄	Tetrafluoromethane
CFC	Chlorofluorocarbons
CH ₄	Methane
CBDR	Common but Differentiated Responsibilities
CNB	Carbon Neutral Beef
DMI	Dry Matter Intake
CONAB	National Food Supply Company
COP	Conference of the Parties
DNDC	Denitrification-Decomposition Model
COD	Chemical Oxygen Demand
Embrapa	The Brazilian Agricultural Research Corporation

EPE	Energy Research Office
WFPS	Water-Filled Porous Space
FAO	Food and Agriculture Organization of the United Nations
BNF	Biological Nitrogen Fixation
EF	Emission and Removal Factor
SEF	Standard Emission Factor
GHG	Greenhouse Gas(es)
Gg	Gigagram
Gt	Gigaton
GTP	Global Temperature Potential
ha	Hectare
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HNO ₃	Nitric Acid
IBGE	Brazilian Institute of Geography and Statistics
EI	Emission Intensity
ILA	Integrated Landscape Approach
ICL	Crop-Livestock Integration System
ICLF	Crop-Livestock-Forest Integration System
IPCC	Intergovernmental Panel on Climate Change
Kcal	Kilocalorie
LULUCF	Land Use, Land Use Change and Forestry

MAPA	Ministry of Agriculture, Livestock and Food Supply
MCTI	Ministry of Science, Technology and Innovation
CDM	Clean Development Mechanism
SOM	Soil Organic Matter
MgCO ₃	Dolomite
MME	Ministry of Mines and Energy
N	Nitrogen
N ₂ O	Nitrous Oxide
NATCOM	National Communications
NH ₃	Ammonia
NMVOG	Non-Metallic Volatile Organic Compounds
NO	Nitric Oxide
NO ₂	Nitrogen Dioxide
NO _x	Nitrogen Oxides
GWP	Global Warming Potential
SCC	Summer Cover Crops
PNMC	National Policy on Climate Change
SF ₆	Sulfur Hexafluoride (tracer gas)
IPS	Integrated Production Systems
NTS	No-Tillage System
t	Ton
UNFCCC	United Nations Framework Convention on Climate Change
UNICA	Sugarcane Industry Union

INTRODUCTION

In 2020, the Sectorial Plan for the Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Economy in Agriculture, known as the ABC Plan, celebrated its 10th year anniversary. The ABC Plan has become a reference for public policies that promote sustainability in the agricultural sector, especially during a period in which environmental issues are at the forefront of concerns. These concerns are only increasing as the lack of adequate environmental conditions threatens the very maintenance of agricultural production capacity. The ABC Plan action strategy led to the implementation of initiatives that aim to ensure important economic gains to Brazilian farmers, intrinsically aligned with the establishment of production systems that foster resilience, ensuring farmer's ability to adapt in response to external impacts, while also controlling greenhouse gas (GHG) emissions associated to the sector. The ABC Plan's objectives and contexts are also aligned with concerns regarding strengthening sustainability in the national development process, especially in responding to challenges proposed internationally through the Sustainable Development Goals, in particular, SDG-2 (Zero Hunger and Sustainable Agriculture) and SDG-13 (Action to combat Global Climate Change)¹.

Through a close partnership with the scientific community and by fostering the most efficient existing sustainable production technologies, the ABC Plan has become a world reference in terms of public policy for adapting to climate change and for controlling GHG in systems of agriculture and livestock production in the context of the climate change debates. The ABC Plan is built on a solid scientific base and is the outcome of over 40 years of consistent investment in research. It incorporates groundbreaking proposals for innovative and sustainable technologies in tropical agriculture.

The transformation of productive processes in the field took place thanks to the fact that promoted ABC technologies were accepted and adopted by the productive sector, which ensured that the sector met the goals proposed from 2010 to 2020. Most of this success is a reflection of an innovative territorial policy, which made local partnerships possible. These partnerships established State Management Groups to create state ABC Plans in all Federal units.

In order to disclose GHG emissions mitigation outcomes resulting from the adoption of ABC systems and technologies, accounting for GHG emissions and removals is a must. Any official communication reported through the National Inventory must follow Intergovernmental Panel on Climate Change (IPCC) guidelines. Under the United Nations Framework Convention on Climate Change (UNFCCC), emissions from agricultural activities are accounted for mainly in two

¹ Goal 2. End hunger, enhance food and nutrition security, and promote sustainable agriculture; Goal 13. Take urgent action to mitigate climate change and its impacts.

sectors: the 'Agricultural Sector' (AS) and the 'Changes in Land Use Sector'². For these sectors, the assessment categories are predetermined within the scope of the guidelines that govern the respective national inventories.

Accuracy in estimating GHG emissions depends on both the availability and the quality of activity data and its emission and removal factors (ERF). Estimates from the 'Agricultural Sector', in the last National Inventory were still carried out using mainly IPCC standard emission factors (EF) (2006), which introduce an important level of uncertainty in the estimates from the agricultural sector, as they are the result of studies carried out in temperate farming systems.

In order to improve the accuracy of estimates in the agricultural sector, several research institutions in the country have been working on developing specific ERF for tropical conditions. However, the information generated through different surveys is very scattered and is often not easily accessed or well-known by official government agencies responsible for agricultural sector policy.

The General Climate Change Coordination (CGMC), from the Department of Sustainable Production and Irrigation, at the Secretariat of Innovation, Rural Development, and Irrigation, under the Ministry of Agriculture, Livestock and Food Supply (MAPA), within the scope of the ABC Cerrado Project and with the purpose of contributing to the reduction of these uncertainties, has prepared this publication, entitled "Compilation of Greenhouse Gas Emission and Removal Factors in Brazilian Agriculture."

Thus, this Compilation aims to bring together progress in scientific knowledge related to the generation of ERFs that are specific to national conditions, as well as strategies or alternatives proposed by researchers for controlling GHG emissions in production systems from different regions of the country. Researchers and national research groups were invited to present their data according to a general scripted framework, in order to generate information in more technical and less scientific language, including observations on solutions and challenges related to each subject. Thus, this work is organized in three chapters, namely: I. Sugarcane; II. Grains; and III. Integrated Production Systems and Planted Forests, in which the state of the research is presented based on obtained and implemented results from various projects and initiatives. Therefore, this document compiles valuable scientific information, which, besides adding to the GHG estimates in the agricultural sector knowledge base, aims to strengthen inter-institutional discussions towards building and/or improving policies aimed at ensuring sustainable agriculture.

² More details on this process are described in the texts from Mozzer & Bueno (p. 16) and Christo & Santos (p. 20), included in this compilation.

The information reveals a greater concentration of studies from the Midwest, Southeastern and Southern regions of the country, represented by 35 of the 52 collected studies. However, more than 50% of the studies (26) come from the Southern and Southeastern regions, indicating that there is a clear institutional, public and/or private effort in these regions aimed at promoting or supporting GHG emissions research in agricultural production systems. A clear example is the state of São Paulo. Given a combination of efforts from universities and research centers, research has been carried out to identify management strategies for more sustainable sugarcane and ethanol production, thus providing solutions for a sector that has a relevant role in the national and international scenario.

The variety of ERF values for the main GHGs in Brazilian agriculture - N_2O e CH_4 - found in this compilation's studies, as well as in other studies that are not included here, reveals the strong influence that the type of applied management practice has on a production system's emissions level. In addition, the difference in values for crop production systems developed under similar management, environmental, and soil conditions reveal the importance of working on generating regionalized FRE values for the country's main crop and production systems. This contributes to eliminating the uncertainties derived from using IPCC standard ERFs and consequently, to improving the accuracy of the national agricultural sector's GHG estimates.

This context confirms the importance of investing resources towards developing research related to GHG mitigation strategies and, specifically, towards generating ERF standards, in order to consolidate our current knowledge base and, above all, to foster its expansion through implementing new research projects in the Northern and Northeastern regions of the country.

The results in this compilation come from studies carried out in different Brazilian realities and biomes. The diversity and national scope contemplated in these studies reveal how these matters are being approached in Brazil, besides bringing to light the number of efforts that have been undertaken to date and the volume of material available on the subject. However, we are aware that this Compilation does not exhaust all existing research dedicated to the topic, neither does it fully represent other research groups that are also committed to contributing to this process.

Despite recent progress in research, there is still a great demand for data obtained by methods that are recognized by the scientific community and by those who can technically subsidize the best strategies aimed towards the sustainable development of agriculture and livestock. This compilation proposes to disseminate accessible information to the public, stimulating questions and suggestions on new strategies. It also has the intention of presenting scientific data to subsidize data-driven decision-making.

Although the results from this information survey do not cover the entire universe of research being carried out in the country, they do signal important factors regarding the state of scientific production, which may turn out to be important inputs for the development of sustainable agricultural policies. These aspects point towards the regionalization or geographic concentration

of research, given the focus on the subject and how it is being approached and the range of GHG ERF values for the same emission category within a specific region.

This publication is an initiative from MAPA, supported by the Ministry of Foreign Affairs (MRE), the Ministry of Science, Technology, and Innovation (MCTI), in partnership with the World Bank, the Brazilian Agricultural Research Corporation (Embrapa), and the National Service of Rural Apprenticeship (Senar), carried out within the scope of the ABC Cerrado Project. It was only made possible thanks to the effective participation of researchers who shared their studies towards contributing to the sustainability of the Brazilian agricultural sector.

Enjoy your reading!

Transparency and reporting mechanisms of the United Nations Framework Convention on Climate Change and its rules modulations

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Brazil was the first country to sign the United Nations Framework Convention on Climate Change (UNFCCC), as a result of the United Nations Conference on Environment and Development, held in Rio de Janeiro in June 1992, which was then ratified by the National Congress in 1994. Likewise, it was the first country to establish a National Designated Authority (NDA) to supervise the Convention - the Ministry of Science, Technology, and Innovation (MCTI).

The main commitment derived from the UNFCCC is the need for greater transparency and reporting, which translates into structuring a national system for periodic National Communications (NATCOM) elaboration and National Inventories of Anthropogenic Emissions from Sources and Removals by Sinks of Greenhouse Gases (GHG) not controlled by the Montreal Protocol (according to art. 4 and art. 12 of the Convention). This system is also essential for database and recalculations storage, and to foster the implementation of constant improvement and refinement, which ensures dynamic progress in the quality of inventories aligned to the development of scientific knowledge and data availability.

With the aim of ensuring transparent and reliable technical reviews, the Convention stipulates that inventories should preferably use comparable methodologies, which are proposed by the Intergovernmental Panel on Climate Change (IPCC) and agreed on by the Conference of the Parties (COP). Developed countries, referred to as Annex I in the context of the UNFCCC, have an additional commitment to present their inventories annually, in addition to undergoing a thorough review process that includes systematizing the data necessary to estimate national GHG emissions according to a standard tabular format: the CRF (Common Reporting Format). The justification for additional levels of commitment from developed countries, agreed on in the context of the Convention, was due to the historical difference in the contribution of Annex I countries when compared to Non-Annex I (developing countries) in GHG emissions according to the principle of common but differentiated responsibilities (CBDR), stipulated in art. 3. That is, although all Parties commit to efforts to stabilize GHG concentrations in the atmosphere, Annex I countries have a greater responsibility than Non-Annex I countries.

The Intergovernmental Panel on Climate Change (IPCC) is made up of scientists from 195 countries and, over the past 31 years, has developed three improvements to the methodological guidelines for the elaboration of national inventories: i) the IPCC Guidelines for National Greenhouse Gas Inventories; ii) the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories and iii) the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC Guidelines for National Greenhouse Gas Inventories. Furthermore, it delivered other documents and two good practice guidelines on uncertainty and land and forest use (LULUCF). In 2019, the IPCC proposed a revision of the 2006 Guidelines, entitled 2019 Refinement to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories¹.

The inventory structure is basically composed of: institutional arrangements, methods and data documentation, quality assurance and control procedures (QA/QC) description, file system description, key category analysis (KCA) and an improvement plan. Additionally, the inventory is divided into four sectors: energy; industrial processes and product use (IPPU); waste treatment, and agriculture, forests, and land use (AFOLU). In order to measure emissions and removals, a country must identify which activities contribute to GHG emissions or removals and estimate, by using emission or removal factors, the size of each contribution, in addition to potential carbon sinks that contribute to GHG removal.

Activity data is a quantitative measure of an activity level that contributes to GHG emissions; the emission or removal factors are coefficients that relate the activity data to inherent emissions or removals. The general principle of methodological guidelines is to make an extrapolation from activity data and emission or removal factors possible, resulting in GHG emissions or removals associated to a process or an operation.

Calculations of emissions and removals involve three hierarchical method levels that vary in standard data complexities and simple equations to the use of specific data and models that accommodate each country's national circumstances. The first level, or Tier 1, represents the first step and has the fundamental objective of enabling emissions estimates when very little or even no information is available. The calculation of emission estimates using Tier 1 represents, undoubtedly, the great majority of the estimates presented in greenhouse gas inventories, and its use is considered adequate except for categories classified as key², due to their level (relative value of emissions) or trend. In any of these cases, using more sophisticated methods is recommended.

The calculation of emissions using Tier 1 was designed by the IPCC to make conservative estimates³ of greenhouse gas emissions feasible for relevant sectors of the economy. In the 2006 methodological guidelines, the decision trees presented in each of the chapters must be carefully followed in the methodological choice process, including during the subsequent review phase. For this same reason, removal estimates cannot be made using Tier 1 methods, since the most conservative posture, in this case, is to not account for any removal in the inventory.

Tier 2 represents the methodological level at which activity data or domestic emission factors are used to estimate emissions. The use of a Tier 2 method implies replacing conservative assumptions adopted at the previous level (Tier 1) with data that is reliable and representative of the national reality. In this case, Tier 2 represents the gateway to an avenue of complexification and breakdowns that can be made depending on existing domestic data and the country's interest. Tier 3, on the other hand, represents a more sophisticated level of analysis⁴ that varies according to each sector and category, but in general, it can be represented by emission estimates based on data from mathematical models or from data collected at the unit level at installed factories or plants.

There are five structuring principles to determine how GHG inventories should be developed, specifically, the way emission and removal factors should be established as well as how activity data should be structured. The following principles also govern the way the entire review process

1 The updated methodology contributes to improving transparency and reporting, ensuring that the methodology used to determine these inventories is based on the latest available science.

2 Key category analysis (KCA) is fundamental for inventory preparation. This subject will be explored in further detail below.

3 From the perspective of the UNFCCC for greenhouse gas inventories in the data distribution curve context, conservative estimates represent the upper fringe containing the observations with the highest emissions.

4 Tier 3 methods, in cases where emission estimates are calculated based on models, is a notorious way to preserve sensitive data, thus avoiding the open exposure of emission factors inherent to the application of the Tier 2 method.

is carried out⁵. Namely: Transparency, Accuracy, Consistency, Comparability, and Completeness (TACCC); i) Transparency regarding clarity of the premises and methodologies that must be explicitly explained and documented; ii) Accuracy involves the precision of emission and removal estimates, including all measures adopted to reduce uncertainties; iii) Consistency is related to the nature of the data set, which should include a consistent historical series in which, preferably, the same methodologies and assumptions are used in the temporal series⁶; iv) Comparability describes the need to ensure that the estimates calculated in an inventory are comparable to estimates published by other Parties of the Convention in their respective inventories, and v) Completeness determines that all sources of GHG emissions are to be inventoried and reported.

Each country must establish a focal point to develop a national inventory system and produce NATCOMs; in Brazil, the competent body would be the General Climate Coordination⁷(CGCL), from the MCTI⁸. This focal point has the role of structuring institutional arrangements in order to establish a technical team in charge of database preparation, storage, and organization. The archival system⁹ should allow users to access historical series and ensure the application of quality control procedures (QA/QC)¹⁰, key category analysis (KCA) and an inventory improvement plan¹¹.

A robust archive system that allows dynamic access to all references, methodologies, expert opinions, reviews, and calculations for the entire historical series of the inventory is essential to ensure reported data transparency and consistency. KCA, in turn, is fundamental to point out areas where efforts should be prioritized, more specifically, to identify areas that should be inventoried using the country's activity data and specific emission or removal factors. Executing QA/QC is essential for the implementation of a continuous inventory improvement process.

Brazil has given strategic importance to its commitment to present its national communications; so far, it has already submitted three NATCOMs (2004¹², 2010¹³ e 2016¹⁴), with the National Inventory as an attachment. As part of the institutional arrangements established for the development of Brazilian national inventories, the Ministry of Agriculture, Livestock and Food Supply (MAPA) and the Brazilian Agricultural Research Corporation (Embrapa) play a fundamental role in research and data collection aimed at establishing activity data and emission and removal factors. The compilation of these elements and the initial preparation of the National Inventory agriculture chapter are also MAPA's and Embrapa's responsibility, along with supporting the inventory's focal point in aspects related to the other sectors, when necessary and timely.

Over the years, the negotiation process has tried to alter the original way in which the issues of Transparency and Comparability were dealt with in the context of the Convention and, in this sense, COP 13, through the Bali Road map¹⁵, established the biennial reports update (BUR) in 2007. The BUR aims to report actions developed at the domestic level to control GHG emissions, as well as reporting on needs and received support. Annex I countries are assessed through international

5 Reviews are conducted annually by expert teams (ERT) balancing their organization between representatives of Annex I and non-Annex I countries. There are three review models: Centralized Reviews, in which teams meet at the UNFCCC headquarters in Bonn, to review multiple inventories at once; On-site reviews (in country) in which a team of reviewers meets in the country to review the inventory and the national system in detail; and Desk Reviews, when for any reason one of the reviewers cannot participate in one of the previous modalities.

6 Temporal series start on the base year, determined by the country, or can start alternatively at any time if emissions in this category are not present in the base year.

7 Available at: <https://www.mctic.gov.br/mctic/opencms/ciencia/SEPED/clima/index.html>.

8 A key category is one that is prioritized in the national inventory system because its estimate significantly influences a country's total GHG inventory in terms of absolute levels, trends, or uncertainty in emissions and removals (IPCC, 2006).

9 In Brazil, the archive system is called the National Emissions Registry System (SIRENE) and is coordinated by the MCTI. Available at: <https://www.mctic.gov.br/mctic/opencms/textogeral/sirene.html>.

10 QA (quality assurance) is different from QC (quality control) since the first is carried out by external evaluators to the inventory team, while the QC is performed routinely by the team responsible for preparing the national inventory.

11 The improvement plan aims to increase the quality of the calculations and data used in inventory compilations and contributes to the aforementioned continuous inventory improvement process.

12 1st NATCOM - single volume Available at: <https://unfccc.int/documents/66128>.

13 2nd NATCOM - volumes 1 and 2 Available at: <https://unfccc.int/documents/69067>.

14 3rd NATCOM - volumes 1, 2 and 3 and Executive Summary Available at: <https://unfccc.int/documents/66129>.

15 Available at: <https://unfccc.int/process/conferences/the-big-picture/milestones/bali-road-map>.

evaluation and review (IAR)¹⁶; and for Non-Annex I countries, assessment is carried out through international consultation and analysis (ICA)¹⁷. Since then, Brazil has presented three BURs: in 2014¹⁸, 2017¹⁹ and 2019²⁰.

With the Paris Agreement entering into force²¹ in 2020, a new cycle of modulation is now fostering increasing Transparency and Comparability in the Convention's reposting mechanism, called the Enhanced Transparency Framework (ETF). This new process reduces the gap between Annex I and Non-Annex I countries in terms of review obligations, by establishing a single model of technical expert review (TER). The new standard should unify the reporting model into a common database, defining compatible criteria under which inventories will be tabulated according to a Common Tabular Format (CTF). In addition, the process of Global Stocktake (GST), structured by the Paris Agreement, will aim to improve global governance, imposing dynamism to a continuous process of increased ambition, thus exerting pressure for the Nationally Determined Contributions (NDCs) to reflect on the global need for ambition aiming to stimulate the increase of domestic efforts.

By January 2022, Parties to the Convention must submit their latest BURs, which will be reviewed by the beginning of 2024, the year in which the reposting model will transition to the Enhanced Transparency Framework. Thereafter, all countries should periodically start presenting their Biennial Transparency Reports (BTRs). In the coming years, the political impacts arising from GST and the implementation of the Paris Agreement will mark the transition to the ETF, which will translate into new inventory and scrutiny obligations for the national system for Non-Annex I countries. Therefore, it is imperative that Brazil carries out robust preparations by: continuing to implement inventory improvements; consolidating the national system; generating and systematizing activity data and specific emission and removal factors; conforming to the CTF; planning a continuous inventory improvement process; in order to prepare for ETF technical review cycles.

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¹⁶ International Assessment and Review Available at: <https://unfccc.int/IAR>.

¹⁷ International Consultation and Analysis Available at: <https://unfccc.int/ICA>.

¹⁸ 1st BUR Available at: <https://unfccc.int/documents/180611>.

¹⁹ 2nd BUR Available at: <https://unfccc.int/documents/180612>.

²⁰ 3rd BUR Available at: <https://unfccc.int/documents/193513>.

²¹ Available at: <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>.

Emissions from managed soils: methodological aspects and main emission sources

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Brazil instituted the National Policy on Climate Change (PNMC), through Law No. 12,187/2009, enacting its voluntary national commitment to adopt mitigation actions towards reducing its greenhouse gas (GHG) emissions between 36.1% and 38.9% in relation to projected emissions for 2020. According to Decree 7,390/2010, which¹ regulates the PNMC, the projection of GHG emissions for 2020 was estimated at 3,236 Gt CO₂. Thus, the reduction percentages established for this year are between 1,168 Gt CO₂eq e 1,259 Gt CO₂eq, respectively.

As a signatory country to the United Nations Framework Convention on Climate Change (UNFCCC), and in compliance with the National Policy on Climate Change, one of Brazil's main obligations is the elaboration and periodic updating of the National Inventory of Anthropogenic Emissions by Sources and Removals of Greenhouse Gases Sinks Uncontrolled by the Montreal Protocol. The Ministry of Science, Technology, and Innovation (MCTI) is the body responsible for preparing, updating, and reporting on national GHG emissions.

The preparation of the inventory has the Intergovernmental Panel on Climate Change (IPCC) as a basic technical guideline, which provides methodological instructions preparing national inventories. Within the Inventory, emissions from five sectors are accounted for: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land Use, Land Use Change and Forests (LULUCF) and Waste, providing an overview of emissions from the country's main economic sectors. Agriculture and Livestock is a prominent sector in this sense, which in 2015 represented 31% of national emissions in terms of CO₂ and².

Emissions from the Agriculture and Livestock sector comprise the emissions of methane (CH₄) and nitrous oxide (N₂O) from five subsectors, namely: Enteric Fermentation, Waste Management, Rice Cultivation, Managed Soils and Burning of Agricultural Waste, excluding indirect GHGs³. In the Fourth National Inventory, which will follow the 2006 IPCC methodologies, two more subsectors will be incorporated: Liming and Urea Application, that are responsible for carbon dioxide (CO₂) emissions. Previously, the first was accounted for in the LULUCF sector; the second, in the

¹ Replaced by Decree 9.578, from 2018.

² Metric used: GWP/SAR. Data from the 5th Edition of Estimates, which can be accessed at: <https://sirene.mctic.gov.br/portal/opencms/publicacao/index.html>.

³ Carbon monoxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOC) (IPCC, 2006).

chemical industry, within the Industrial Processes and Product Use (IPPU) sector. In general, the Agricultural sector estimates are calculated from national data such as population and animal characterization, consumption of synthetic and organic fertilizers, agricultural production, technologies used for manure management, among others. Most of the historical data sets are acquired from official sources, such as from the Brazilian Institute of Geography and Statistics (IBGE).

One of the outstanding subsectors in the Agricultural sector is Managed Soils, which in 2016, contributed 36% of the sector's total emissions (BRAZIL, 2019)⁴. These emissions are the consequence of nitrification and denitrification processes from increased amounts of Nitrogen (N) in the soil, due to the use of inputs and the management of plants and soil, resulting in direct and indirect N₂O emissions. In Brazil, agriculture has intensified progressively, with increased use of inputs such as fertilizers, organic fertilizers, and agricultural operations, which cover an area of over 60 million hectares of crops and 160 million hectares of pasture in 2016 (IBGE, 2017a).

According to the IPCC (2006), N₂O emissions from soil management⁵ take effect directly or indirectly (Figure 1), due to N increases in the soil. Direct N₂O emissions result from the application of synthetic and organic fertilizers; the deposition and incorporation of crop harvest residues and pasture renewal; deposition of unmanaged manure from national herd species (eg on pastures); N mineralization resulting from soil organic matter loss; organic soils management. Indirect N₂O emissions also occur from the same sources of N as direct emissions (excluding organic soil management) and are caused when nitrogen molecules "move" from the deposit or mineralized location and are converted to N₂O in a new location, resulting in "nitrogen loss". The loss of nitrogen occurs through volatilization (N is transformed into vapor and moves through the air) and leaching (N in water is drained by soils and waterways).

In summary, emissions from soil management are calculated from the estimate of every source of N incorporated into the soil separately, meaning:

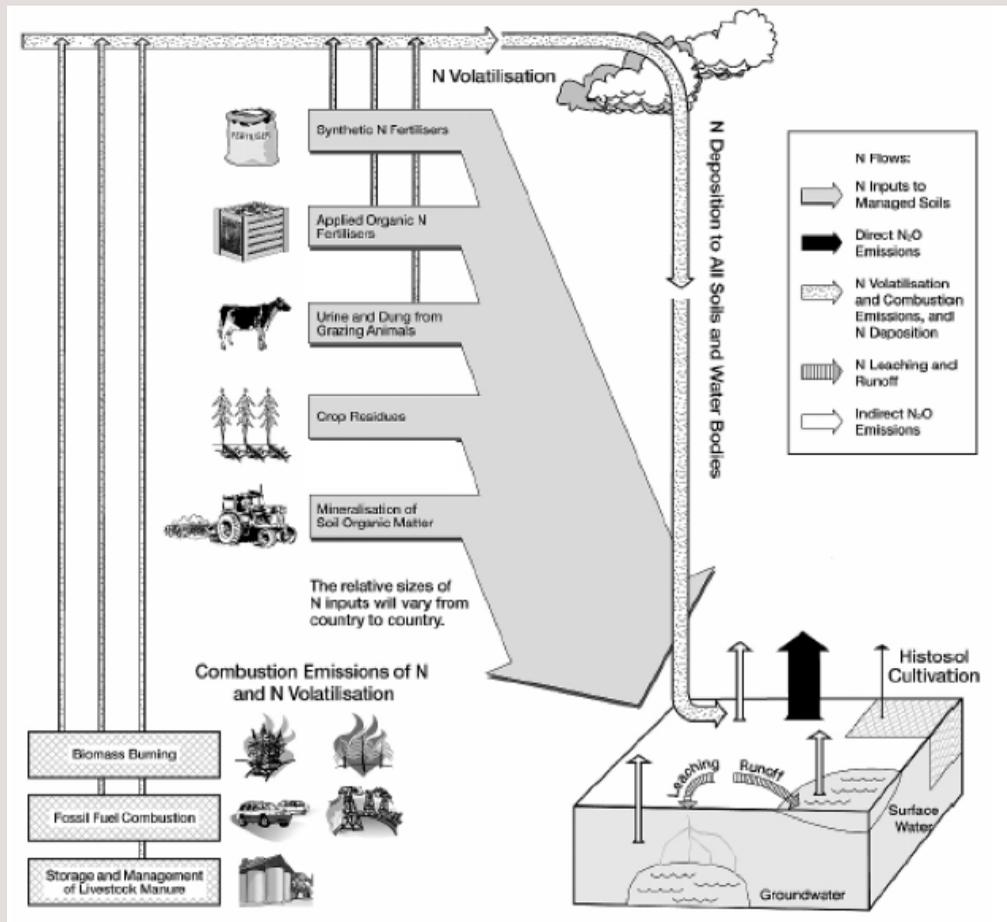
- I. sources of N related to soil management (application of synthetic and organic fertilizers, deposition and incorporation of crop harvest residues, and pasture renewal and mineralized N resulting from soil organic matter loss);
- II. sources of N from organic soils;
- III. sources of N from manure directly disposed on pasture.

After calculating the amount of N from each identified source, it is multiplied by an emission factor, specific to each emission category, after which the final calculation of direct and indirect N₂O emissions is reached.

⁴ in terms of CO₂eq (GWP/SAR). Results from the 5th Estimates edition (BRASIL, 2020). In terms of CO₂ and (GWP/SAR). Results from the 5th Estimates Edition (BRASIL, 2019). Until the time of that publication, the sub-sector was called Agricultural Soils.

⁵ Methodology used to estimate Enteric Fermentation emissions in the Fourth National Inventory, based on the (2006) IPCC, which provides methodological updates in relation to previous editions.

Figure 1 - Diagram illustrating N sources and pathways resulting from direct and indirect N₂O emissions from soil management

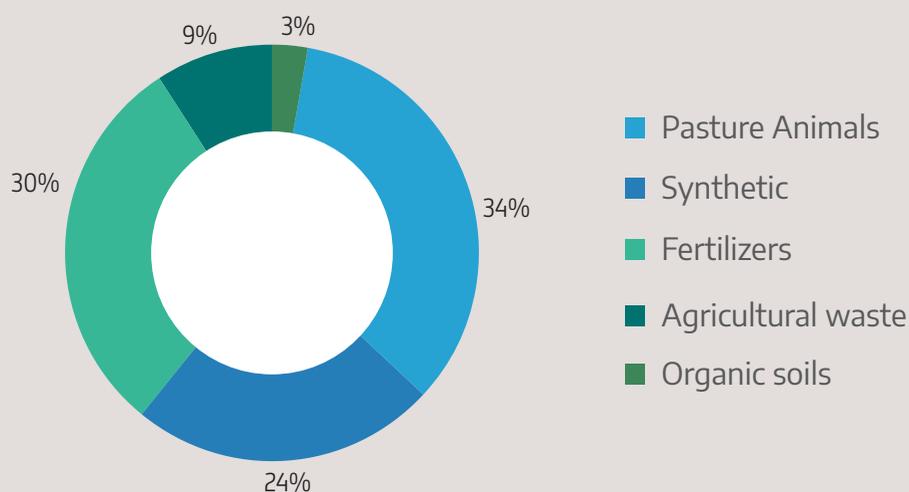


Source: IPCC (2006).

In general, national data (disaggregated per Federation Unit or region) are used for the calculation. This data ranges from animal populations, manure treatment system types, agricultural production, synthetic fertilizer consumption, pasture areas, and organic soil cultivated areas, in addition to a range of parameters from existing literature. These data and parameters are used to calculate every N source, which is multiplied by IPCC default emission factors, to arrive at the final N₂O result.

In 2016, direct emissions accounted for 62% and indirect emissions for 38% (these are divided into 8% of atmospheric deposition and 30% of leaching) of the total emissions from Managed Soils (BRASIL, 2019). This year, the largest source of emissions from a single source was from pasture animals, from the disposal of manure directly onto the soil, contributing to 34% of the subsector's emissions (the beef cattle category is the most representative). The second-largest source of emissions was the application of organic fertilizers, which contributed to 30% of the subsector's emissions (considering direct and indirect emissions). The other emissions from synthetic fertilizer application, agricultural residues incorporated into the soil, and organic soil management, contributed to a smaller share of emissions, as shown in Figure 2.

Figure 2 - Contribution of each emission category, in percentages, from the Soil Management sector (direct and indirect emissions).



Source: Brasil (2019).

As an example, in order to account for emissions from the disposal of manure into the soil, either directly through pasture animals or from organic fertilizer application, the main data considered are: animal weight, the excretion factor per animal head, and the type of destination/treatment for animal waste, in addition to activity data, which in this case is the animal population (disaggregated by age, sex, and confinement type). To estimate emissions, the amount of N excreted is first calculated for every animal category, per year and Federation Unit. Subsequently, the calculated results are multiplied per emission factor, specifically for each animal and emission category, to quantify the amount of N converted into N₂O (which is different for direct and indirect emissions).

In Brazil, most of the manure generated by cattle directly on the ground is unmanaged, that is, it is disposed of directly onto pastures. Only confined beef and dairy cattle manure is partly sent to some type of treatment, to be used later as organic fertilizer. Parameters such as weight and excretion factors have a major influence on the emission result. The heavier the animal, the greater the excretion, and consequently, the higher the coupled N₂O emission. The IPCC methodology (2006) proposes a single emission factor of 2% for all the N excreted by animals (including cattle) directly into the soil, which indicates that 2% of all the N excreted by animals would be issued directly in the form of N₂O. However, results found in national (CARDOSO, 2012; LESSA, 2011; SORDI, 2012) and international (YAMULKI *et al.*, 1998; VAN DER WEERDEN *et al.*, 2011; ROCHETTE *et al.*, 2014) literature indicate that there are differences between N₂O emissions between bovine manure disposed of in pastures, and urine and feces. These two qualities should be disaggregated. Because of this, after a literature review of national values for feces and urine, an average emission factor of 1.5% was defined, which will be adopted in the Fourth National Inventory.

Agricultural soil management is the main source of atmospheric N₂O, accounting for 85% of the country's total count, and is influenced by several factors that can be modified through agricultural management practices. The most important of these factors is N incorporated into the soil and is directly related to the deposition of manure in the soil and nitrogen fertilizer application, which has a direct influence on the increase of national livestock and agricultural productivity.

From 2010 to 2016, there was an increase of 12.7% of Managed Soils emissions in Brazil (BRAZIL, 2019). This is the direct consequence of an 18% increase in agricultural cultivation (permanent and temporary crops) areas (IBGE, 2017a), and of the 4% increase in animal heads, during the same period (IBGE, 2017). Therefore, on the one hand, if using nitrogen fertilizers is important to ensure increased agricultural performance, then on the other hand, its direct consequence is higher N₂O emissions into the atmosphere. Using the right dose, while avoiding waste at all costs, is a challenge and a way of mitigating GHG emissions.

Calculating emissions from soil management is a complex task and requires a wide range of data, parameters, and emission factors. This task becomes even more complex when applied to Brazil since differences between Federative units must be considered. These differences range from specific conditions of climate, soil, agricultural crops, and animal categories, which, in the case of beef cattle, disaggregated between age, sex, and type of confinement must be considered, as well as disaggregated for dairy cattle and productivity levels. This sheds light on the importance of studies and research in this area, in order to obtain data and factors that are more representative of the reality from the different regions of the country. Another important point is to explore the demands for N and N₂O emissions, in order to find management practices that maximize the yield of soil and plants, and that minimize N₂O emissions.

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Conservationist and sustainable agricultural systems

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Humanity currently faces rising challenges to produce food, fibers, energy, timber, and non-timber products in a way that is compatible with the availability of natural resources, especially soil and water. This is the main reason behind strong appeals throughout the world calling for the dissemination of the concept of sustainable agriculture (CORDEIRO et al., 2015).

Supplying society's growing demand for food while preserving natural resources at the same time constitute an important challenge for the 21st century. This challenge includes: I. increasing agricultural production to meet the food needs of more than 3.5 billion people in developing countries; II. Producing lignocellulosic biomass through species cultivation for the production of agroenergy; III. converting degraded soils and desertified areas to recovered areas; IV. carbon sequestration in soils and the use of biomass to offset emissions and stabilize CO₂ concentrations and other greenhouse gases (GHG); V. developing farming systems that improve water use efficiency and minimize water pollution, contamination and eutrophication; and VI. creating protected areas for species preservation and to increase the aesthetic value of landscapes (LAL, 2009).

Sustainable agriculture is a concept and a goal in itself, as it carries within its core a broad perspective of contemporary agriculture. According to the Food and Agriculture Organization of the United Nations (FAO, 1988), it can be understood "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations". Meaning, a type of agriculture that preserves the soil, water, and the genetic resources of animals, plants, and microorganisms, that does not degrade the environment and is technically appropriate, economically viable, and socially acceptable.

More recently, FAO (2014, p. 12) shared its vision for sustainable food and agriculture. It's a world in which food is nutritious and accessible to all, and where natural resources are managed in such a way that preserves ecosystem functions in order to provide support for present as well as future human needs. In our perspective, farmers, pastors, fishermen, foresters, and other rural residents today have the opportunity to actively participate and benefit from economic development, to have decent employment conditions, and to work in a fair price environment. Women, men, and rural communities live in security and have control over their livelihoods and equitable access to resources which they can use efficiently.

Likewise, conservationist agriculture is practiced according to the precepts of the science of soil conservation. This science comprises a complex set of systemic technologies with the purpose of preserving, maintaining, restoring, or recovering natural resources. It can

be understood as efficient or effective agriculture in the use of available resources and is based on: reducing or eliminating soil mobilization; soil cover maintenance; input of organic material in quantity, quality, and frequency compatible with the soil's biological demand; expansion of biodiversity through the cultivation of multiple cultivated species (cultures rotation, succession, or intercropping); diversification of productive agricultural systems (agropastoral, agroforestry, silvopastoral, agrosilvopastoral systems, etc.), among other factors (DENARDIN *et al.*, 2014).

There are several production systems that contemplate these precepts, such as the No-till farming, which is now consolidated as one of the greatest revolutions in sustainable tropical agriculture. In no-tillage soils, there are: increased levels of carbon and organic matter in the soil (SOM); improvement in structure; greater infiltration and water retention; and, mainly, less soil loss due to erosion (DERPSCH *et al.*, 1991; BAYER; MIELNICZUK, 2008). Thus, it is more tolerant to summer and it generates increased grain yield over time.

One of the ways to improve the soil structure is the inclusion of forage species, especially grasses, in the production systems; that is, the rotation of annual crops and pastures is one of the best alternatives to obtain sustainable management of soil and water in the tropics (LAL, 1991). Well-managed pastures have the ability to frequently increase the SOM content above observed original levels, through native vegetation. During 13 years of soy cultivation under conventional tillage, SOM content decreased by 24.4% in relation to its original value (which was 3.6%). However, after including *Brachiaria humidicola* into the system, managed through cuttings, the SOM content observed during the nine years of evaluation, increased to values above 4.0% (SOUSA *et al.*, 1997).

Additionally, integration systems are also excellent alternatives for sustainable agriculture and livestock systems. These systems integrate agricultural, livestock, and/or forestry activities in the same area or farmland, creating a single system through intercropping, succession, and/or rotation of crops or activities. According to Balbino *et al.* (2011), integrated production systems can be classified into four modalities:

I. Crop-Livestock Integration (ICL), or agropastoral systems; II. Livestock-Forest Integration (ILF), or silvopastoral systems; III. Crop-Forest Integration (CFI), or silviagricultural systems; and, IV. Crop-Livestock-Forest Integration (ICLF), or agrosilvopastoral systems.

According to Cordeiro *et al.* (2015), integrated production systems provide several benefits, such as: increased plant and animal productivity; improvement of the physical, chemical, and biological attributes of the soil, due to the increase in SOM; increase in the soil's carbon stock; a decrease in the pressure to deforest new areas due to the land-saving effect; promotes the recovery of degraded pastures; economic stability and increased income through activity diversification; cost reductions in the medium and long term; decreased vulnerability to climate risks; and improvement in farmer's and their family's life quality. Given all these aspects, and the fact that with the adoption of integrated systems production factors can be synergistically extended along with the environmental supply of agricultural areas between 90% and 100% of the time, we may conclude that these systems are efficient strategies for sustainable intensification of land use in tropical regions.

Historically, different public policies have promoted conservationist and sustainable agricultural systems. The main one today is certainly the ABC Plan (Low Carbon Emission Agriculture), which is one of the sectoral plans prepared in accordance with the National Policy on Climate Change (PNMC), which put the agricultural sector on another level in terms of its potential contribution to the mitigation of GHGs, promoting increased resilience in the adaptation of productive processes in rural communities. This plan is intended to encourage the adoption of sustainable production systems that ensure the reduction of GHG emissions and simultaneously increase the income of rural producers, especially through expanding the following technologies: Recovery of Degraded Pastures; Integration Systems (ICL, ILF, CFI, ICLF) and Agroforestry Systems (AFSs); No-Tillage Systems; Biological Nitrogen Fixation (BNF); Planted Forests; and, Animal Waste Treatment (BRASIL, 2012).

Other initiatives seek to increase the value of adopting sustainable agricultural production systems, such as, for example, the Carbon-Neutral Brazilian Beef (CNBB) certification. It is a concept brand that aims to attest to beef that has its GHG emission volumes neutralized during the production process through the presence of trees in silvopastoral (ILF) or agrosilvipastoral (ICLF) integration systems, which undergoes an audit and parametrized process. Furthermore, it aims to ensure, through the presence of shade, that the animals were produced in conditions of high well-being and thermal comfort. Through a partnership with the Marfrig slaughterhouse, this certified meat with neutralized methane emissions will be eligible to reach the consumer market in Brazil and abroad (ALVES et al., 2015; EMBRAPA, 2016).

Therefore, we may conclude that the adoption of different conservationist and sustainable agricultural systems have a high capacity to conserve soil and improve its quality, as well as its capacity to store carbon and water and, thus, promote significant gains to the productive potential, while presenting lower production costs and greater environmental conservation.

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1

SUGARCANE EMISSION AND REMOVAL FACTORS



Sustainable strategies for mitigating greenhouse gas emissions in sugarcane production

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Brazil ranks first in the world's sugarcane production, accounting for around 40% of the global stalk volume since 2008 (FAO, 2018). This diversification includes not only sugar, *cachaça*, and ethanol, but also electricity, yeasts, and other green chemistry derivatives (ALVES *et al.*, 2015). Also noteworthy is the use of vinasse, filter cake, and ashes as fertilizers (ROSSETTO *et al.*, 2008), to avoid the entry of external resources into the production system.

In the last decade, national stalk production increased by 13.6%, from 645.3 Mg of stalks in 2008 to 746.8 Mg in 2018 (FAO, 2018). From this amount, about 46% of total recoverable sugars was used to produce sugar, a commodity in high demand in the international market. The remaining amount is divided between anhydrous (21%) and hydrated (34%) ethanol (CONAB, 2019). However, in 2018 when *RenovaBio* (Law 13.576 / 2017) –a Brazilian biofuel policy that rewards producers with greater energy-environmental efficiency (BRASIL, 2019a)– entered into force, hydrated ethanol reached 45% of total recoverable sugars on its own, resulting in 23 billion liters (CONAB, 2019). This growth contributed to avoid global GHG emissions since ethanol, a renewable fuel, substitutes gasoline, a fuel derived from petroleum (EPE, 2016; BORDONAL *et al.*, 2018).

Biofuel produced with a low carbon footprint and bioelectricity generated from agro-industrial waste (*bagasse*) puts the sugar-energy sector in a relevant position in the implementation of national and global climate change mitigation strategies (POPIN *et al.*, 2019). Brazil is committed to reducing GHG emissions by 43% compared to 2005 levels by the year 2030 (BRASIL, 2019b), in addition to increasing the share of renewable energy in the country's energy matrix, within the scope of The United Nations Framework Convention on Climate Change (UNFCCC), more specifically, the Paris Agreement.

To reach these goals, Brazil is committed to reducing emissions by internalizing national policies for the implementation of a low carbon economy and by establishing national strategies to implement these commitments. For example, the transportation sector is interested in expanding its share of energy matrix biofuels to 18% by 2030, and in reducing carbon emissions by 37% by 2025, with the year 2005 as a reference (BRASIL, 2019a). However, estimates show that this will only be feasible if the current production of ethanol (~ 28 billion liters) is doubled to about 50 billion liters and most likely the current area of 8.4 Mha planted with sugar cane (CONAB, 2019) would need to be expanded by 3 million hectares (BRASIL, 2019c), following principles of good environmental performance.

In recent years, sugarcane production has been modified to strengthen its environmental sustainability. These changes include the extinction of the practice of burning in more than 91% of the areas harvested in Brazil (CONAB, 2019); the use of vinasse application plans, mainly in the state of São Paulo; the reduction of erosion through to straw maintenance after harvesting, without the use of burning (MARTINS FILHO *et al.*, 2009; CARVALHO *et al.*, 2017); the recovery of permanent protection areas; among other measures. Along with these practices, the sector has expanded its sugarcane cultivation over degraded pasture areas, thus reducing competition for land use and pressure on the forest (BORDONAL *et al.*, 2018).

Promoting the technological development of the sector by fostering the implementation of innovative solutions is of great importance to guarantee positive gains in the sugar and alcohol sector's environmental performance, especially in the climate change category, considering that 81-90% of the total GHG emissions from ethanol production, for example, are related to sugarcane's agricultural stage (SEABRA *et al.*, 2011; GARCIA SPERLING, 2017). Figueiredo (2012) recommends that different production scenarios should be simulated and studied to advance the definition of GHG emission reduction strategies to reach production sustainability, fostering direct and indirect benefits for society through the effect of lower GHG emissions, generating higher economical returns at the same time.

According to the National GHG Inventory (NI) carried out for Brazil's Third National Communication to UNFCCC, the emissions associated with sugarcane production are disaggregated - with values involving pre-harvest burning (Subsector Burning of Agricultural Waste), the use of nitrogen fertilizers (Synthetic Fertilizers or Organic Fertilizers Subsector) and the decomposition of residues left in the field (Soil Management / Direct Emissions / Agricultural Waste Subsector) - and are accounted for as CH₄ e N₂O emissions. CO₂ emissions from burning residues are not considered in the IN, because after it is emission, CO₂ is reabsorbed during plant growth through photosynthesis.

CH₄ emissions generated from burning residues, mainly sugarcane straw (BRASIL, 2016), are considered in the IN as remaining emissions, with only 1.5% (185.3 Gg of CH₄) of the total volume of CH₄ emissions from the Agricultural Sector. The Southeastern Region contributed the most to these emissions in 2010, representing 55.2% of the total emissions; followed by the Midwest, which contributed 20.6%; and the North, with only 0.4%. However, although the contribution volume of each source of emission of this gas is informed in the IN, methodological considerations regarding emission factors are not presented.

In 2010, the total N₂O emissions (direct and indirect) from nitrogen fertilizers and the decomposition of plant litter from post-harvest residues were 452 Gg. Considering only direct emissions (282 Gg of N₂O) the largest emission sources were: I. excrement deposited in the soil during animal grazing (170 Gg = 60%); II. nitrogen fertilizers derivatives (35 Gg = 13%); and III. sugarcane residue decomposition (5.5 Gg = 1.9%) (BRASIL, 2016). For emissions estimates from these three sources, the IPCC standard emission factors were used.

It is worth mentioning that, until now, official CH₄ and N₂O emissions estimates of sugarcane in Brazil are calculated according to the Tier 1 methodological approach. It is also noteworthy that the IPCC (2006) methodological guidelines provide instructions on how the methodological approach (Tier) level and ERF from the IPCC should be applied. For the fourth National Communication that is to be launched, the availability of national emission factors is fostering the use of Tier 2, to provide more robust and less uncertain calculations.

Reducing uncertainties through establishing country or region-specific emission data has been implemented by different research groups, which have been working to define specific

emission factors to the local climate and soil conditions, which provide improved calculations for emissions generated for the sector in the National Inventory, using Tier 2. In addition, research involving more efficient management practices to increase stalk yields - which, at the same time, mitigates GHG in sugarcane production - also contributes to improving the sector's GHG emissions calculations for the country's National Inventory.

In this chapter, results from research on sugarcane GHG ERFs and technological advances in production systems to reduce GHG emissions are presented. As expected, most of the findings are concentrated in the Southeastern region, since it comprised 64% of the total stalks produced in Brazil in 2019 (CONAB, 2019). São Paulo is the state with the largest number of researchers involved in this endeavor, with efforts from different universities and research centers, such as the Federal University of São Carlos (UFSCAR), the Agronomic Institute of Campinas (IAC), the Universidade Estadual Paulista (UNESP), the National Center for Research in Energy and Materials (CNPEM), the Center for Nuclear Energy in Agriculture at the University of São Paulo (CENA-USP), Embrapa Environment, among others.

Through this compilation of several research contributions, it is possible to evidence the important advances made in the knowledge of practices of sugarcane management systems that are necessary to ensure a more sustainable production of this crop, such as mechanized harvesting without burning, maintenance/partial removal of post-harvest straw, reduction of the frequency tillage in areas of raw harvested sugarcane, fertigation with N by subsurface drip, among others.

Following is a summary of some of the received contributions that show the current state of research and the emission factors found in the local conditions where the studies took place.

Aderson *et al.* (p. 56) compared the N₂O emissions resulting from the application of N doses in sugarcane with subsurface drip fertigation, with those resulting from conventional fertilization (via soil) in the sugarcane-plant phase harvested without burning. The findings show that the sugarcane production system under fertigation promotes lower N₂O emissions in comparison to conventional fertilization via soil. The fertigated treatments with 60 and 120 kg N ha⁻¹ showed reductions of 40.6 and 50.2%, respectively, in accumulated N₂O emissions over the cycle, in relation to their fertilizer counterparts via soil. The emission factors determined for fertigation were, on average, close (1.69%) to the IPCC value, while for conventional fertilization, they were above (4.26%) the value established by the IPCC (1%).

In a study on GHG emissions resulting from the addition of synthetic nitrogen inputs, Bordonal *et al.* (p. 58) evaluated the emissions N₂O and CH₄ from the soil derived from nitrogen fertilization under different scenarios of sugarcane straw removal in the state of São Paulo. Results showed that the CH₄ fluxes were very low for all evaluated sites, regardless of the straw removal scenarios, but that N₂O emissions were significantly affected by straw removal, ranging from 0.20 to 4.09 kg N₂O ha⁻¹ year⁻¹, indicating that straw removal reduces N₂O emissions. N₂O emission factors were highly variable between locations, ranging from 0.05 to 1.44% of applied N. The authors recommend further research to better understand this result, considering that the use of synthetic nitrogen fertilizer combined with the application of vinasse is a usual management practice in the sugar-energy sector and it can trigger significant increases in N₂O emissions.

Signor *et al.* (p. 60) also evaluated the effect of synthetic nitrogen fertilization with urea and ammonium nitrate, applied at doses of 0, 60, 90, 120, and 180 kg ha^{-1} , on N_2O emissions in sugarcane cultivation in two locations in the Mid-southern Regions of Brazil, one in Piracicaba-SP and in Goianésia-GO. The findings show that N_2O emissions depend on the applied N dose and the type of fertilizer. The N_2O emission factors varied depending on both the sources of N and the experiment's location. The authors concluded that due to the great variations in the proportion of N issued as N_2O , a pre-established emission factor value is difficult to use.

In experiments conducted by Carmo *et al.* (p. 62), CO_2 , N_2O and CH_4 emissions were assessed in areas of: I. extensive pasture; II. restored extensive pasture; and III. extensive pasture converted into sugarcane cultivation through conventional management, with and without nitrogen fertilizer applications. This study observed that the intensity of increased GHG emissions depends on the environmental conditions and adopted management practices. The emission factor estimated for restored pasture was three times higher than the estimated IPCC value (1%), indicating that this value for sugarcane may be underestimated given the growth of fertilizer application in the country, and also since in Brazil, applying vinasse with nitrogen fertilizers such as urea is a common practice.

Packer *et al.* (p. 70), carried out experiments in Araras (ARA) and Iracemápolis (IRA), in the 2012/2013 harvest, and in Guaira (GUA), in the 2014/2015 harvest, all in the state of São Paulo, with 1st ratooning in GUA and IRA and 3rd ratooning in ARA. The study evaluated how removing (partial or total) straw from the soil affects the emission of GHGs, mainly N_2O , from nitrogen fertilization. Therefore, the nitrogen fertilizer N_2O emission factors were obtained for applied doses of 0 and 120 kg ha^{-1} of N, in the form of ammonium nitrate (ratooning fertilizer), in the absence of or presence of straw up to 12 Mg ha^{-1} . The results showed that the EF was quite low in the absence of straw (0.03 to 0.10% of the applied N), but this value increased from 0.48 to 0.54%, when 12 Mg ha^{-1} of straw was kept on the ground. However, for both cases, the EF values for nitrogen fertilizer were lower than the IPCC standard of 1%.

After reviewing the results from the studies in this collection, as well as from other similar studies carried out in the country, an initial observation is that there are a variety of EF values for the calculation of direct N_2O emissions in sugarcane, ranging from, for example, values of 0.05% to 4.59% in treatments with the application of synthetic and organic fertilizers, while the standard value defined by the IPCC is 1%.

The following table shows the different EF values found for the cultivation of sugarcane:

Table 1: Values of greenhouse gas emission and removal factors found for the production of sugarcane in different studies in Brazil.

Crop: sugarcane				
Treatment	N ₂ O (%) emission factor		Location (State)	Reference (Authors)
		EF**		
Application of nitrogen fertilizer in planted furrows and in the upper straw layer	<	0.46 ± 0.33	São Paulo	Siqueira Neto et al., 2016
Vinasse application	<	0.65 ± 0.29		
Filter cake application	<	0.13 ± 0.04		
Application of nitrogen fertilizer with vinasse, without irrigation	<	0.05 ± 0.006	Distrito Federal	Fonseca da Silva et al., 2017
Application of vinasse without irrigation	>	1.11 - 4.59		
Removal of residues with the application of nitrogen fertilizer and nitrification inhibitor	~	0.12 - 1.44	São Paulo	Gonzaga et al., 2018
Application of synthetic and organic fertilizer and straw residues on soil emissions				
Ammonium nitrate + without vinasse	~	0.68 - 2.03	São Paulo	Carmo et al., 2012
Ammonium nitrate + with vinasse	~	0.59- 3.03		
On the sugarcane plant				
Urea + without vinasse	>	1.1		
Urea + with vinasse	>	2.65		
No-Till	<	0.20		
Reduced soil tillage	<	0.25		
Use of mineral fertilizer in the conversion of extensive pastures into sugarcane and in the intensification of remaining pastures				
Pasture (without preparation) with fertilizer application only	<	0.41	São Paulo	Carmo et al.* (p. 62)
Extensive pasture with tillage (restored) and fertilizer application	>	3.36		
Conventional soil tillage for planting sugarcane, with fertilizer application	<	0.46		

Crop: sugarcane			
Treatment	N ₂ O (%) emission factor	Location (State)	Reference (Authors)
	EF**		
Different scenarios for the removal of straw residues			
Total removal (TR)	< 0.28	São Paulo	Bordonal et al.* (p. 58)
High removal (HR)	< 0.44		
Low removal (LR)	< 0.70		
Without removal (WR)	< 0.56		
Application of different doses of N (kg ha ⁻¹) by fertigation and conventional fertilization			
Fertirrigated - 60	> 2.87	Piauí	Andrade Júnior et al.* (p. 56)
Conventional - 60	> 4.26		
Fertirrigated - 120	> 1.69		
Conventional - 120	> 3.77		
Effect of maintaining straw on the soil for emissions.			
Absence of straw	< 0.03 - 0.10	São Paulo	Packer et al.* (p. 70)
4.3 and 7.7 Mg ha ⁻¹ of straw	< 0.13 - 0.17		
12 Mgha ⁻¹ of straw	< 0.48 - 0.54		

Source: Authors.

Key: * Information extracted from the contributions of the researchers in this collection; ** where, in relation to the IPCC standard value (2006) of 1% for N₂O are: <= below the standard; > = above the standard; and ~ = intermediate in relation to the standard.

The variety in values reveals, on the one hand, the direct relationship that exists between the type of treatment and/or agricultural management practice and environmental conditions where they were defined and the level of N₂O emissions; on the other hand, it gives scientific evidence of the high sensitivity to which GHG emissions calculations are subject for the sugarcane sector, due to the use of the IPCC default value (1%) in the estimates made in the IN.

Although these results do not cover the entire universe of research carried out in the country, they do demonstrate the effective effort of the scientific community to generate results that subsidize GHG emissions assessments with data that are more representative of adopted practices and edaphoclimatic conditions. Regionalized data allows us to take into consideration conditions in which treatments are applied and/or acknowledges similar management systems. As a consequence, this improves national estimates' accuracy and support practices that provide greater sustainability for production systems. On the other hand, the results also point out the need to carry out more specific and in-depth studies, to complement and validate the results obtained so far, simulating management scenarios in the different regions of the country which include different fertilizer levels and sources, in order to obtain responses that guarantee sugarcane production sustainability.

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SUGARCANE HARVESTING EFFECTS ON CARBON DYNAMICS AND SOIL PROPERTIES

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The traditional way of harvesting sugarcane in Brazil is characterized by burning cane fields, to facilitate manual operation. However, burning generates environmental problems, such as the production and release of gases into the atmosphere and of ashes deposited onto the surface. Besides, the degradation of plant material (straw) exposes the soil to climatic oscillations, such as rain and excess heat, which accentuate erosive processes and affect the balance of soil organisms. As a result, soil quality is lost. Recently, sugarcane harvest management has been developed without burning cane fields, either due to legal obligations or environmental concerns. Besides minimizing or extinguishing the described problems, this management also improves the sugar cane plantation's productivity.

Therefore, in order to study the aforementioned managements, comparisons were made between two ways of harvesting sugarcane: I. manual harvesting with prior cane field burning (CB); and II. mechanical harvesting without burning (WB), in three cities in the state of São Paulo: Pradópolis, Matão, and Serrana. The cane fields had been under WB management for four years (three harvests), with a fourth site in Matão where WB had been practiced for 12 years. The studied soils (EMBRAPA, 1999) were Dystrophic Red Latosol, in Pradópolis (LV4), Dystrophic Red-Yellow Argisol (PVA4) and Dystrophic Red-Yellow Latosol (LVA12) in Matão and Ortiquezarenic in Serrana (RQo4).

Four years ago, at the three sites that were under WB management, the same experimental design was installed in randomized blocks, with six replicates for each treatment. At the site under WB management for 12 years, four repetitions were performed. Soil samplings and crop residues under WB management (straw) were carried out no more than one week before the fourth or eleventh sugarcane harvest. Soil samples were collected using a Dutch auger, in layers of 0-0.05 m; 0.05-0.1 m; 0.1- 0.2 m; and 0.2-0.4 m in depth in six subsamples for each of the six or four plots of each treatment. The samples were air dried and gently removed to go through a 2 mm sieve.

For apparent density (Ad), two undisturbed subsamples were collected in each plot, at depths 0-0.1 m; 0.1-0.2 m; and 0.2-0.4 m, using a metal ring. The remaining straw on the soil was sampled in the WB plots in LV4 and RQo4

(n = 30), with a delimitation of 0.5 m in length by 0.7 m in width. Total carbon and nitrogen soil and straw contents were determined through dry combustion in a CN 2000 LECO auto-analyzer (LECO Corporation, St. Joseph, MI). The results of Ad and carbon (C) and nitrogen (N) contents were used to calculate their stocks in the soil, according to the considered soil layer. The objective of the study was to compare carbon and nitrogen contents and stocks in the sugarcane plantation soils between harvesting systems, with and without burning.

RESULTS

- The results show that, in terms of storage of carbon (Cest) and nitrogen (Nest), the transition from CB to WB presented significant gains. Considering the global amplitude average of the studied profile (0.0-0.4 m) in the four soils, Cest increased from 59.8 to 64.1 Mg ha⁻¹ and Nest increased from 3.72 to 4.15 Mg ha⁻¹, representing a growth of 7% and 12%, respectively. Under these conditions, the transition from burning to non-burning sugarcane management prior to harvesting resulted in average carbon and nitrogen sequestration rates in the soil of 1.43 and 0.14 Mg ha⁻¹ year⁻¹, respectively;
- The average amounts of dry matter added to the surface were 13.9 and 12.8 Mg ha⁻¹ year⁻¹ in LV4 and RQo4, resulting in remaining quantities determined at 4.5 and 3.6 Mg ha⁻¹ year⁻¹, respectively;
- The remaining amounts of carbon and nitrogen from the straw were 1.36 and 1.61 Mg ha⁻¹ in LV4 and RQo4 and 0.0223 and 0.0209 Mg ha⁻¹ in LV4 and RQo4, respectively;
- The gains in carbon and nitrogen content were both lower the greater the soil's clay content, with the exception of LV4, which had gains higher than LVA12. The variation in the content of these elements in the LV4 surface layer was 18.1 to 22.7 Mg ha⁻¹ (25% gain).

CHALLENGES

- Suppressing burning represents an important and significant agricultural management change in sugarcane cultivation. It provides the sequestration of C and N in the soil, and avoids the emission of gases into the atmosphere;
- Although the benefits in chemical fertility only appeared in some studied soils, exclusively in the superficial layers (0-5 or 0-10 cm), this signals that over time nutrient levels will increase, and this will lead to significant increases in soil fertility;
- In the management without burning, there was a significant recovery of the density and biodiversity of the soil macrofauna, compared to the near extinction observed with burning. In the early years of mechanized harvesting, the use of machines to harvest sugar cane made the superficial layer thicken (0-10 cm) in some studied soils;
- Other studies more directly linked to the subject are needed to assess the consequences of this measured density. The qualitative assessment of sequestered C, through the soil's granulometric fractionation, showed that even a short period of four years of management without burning would result in the sequestration of C in its most labile form, linked to the coarsest fractions (> 50 μm).>

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SOLUTIONS

- We recommend that leaf biomass continues to be maintained in the system and that soil management at the time of replanting the crop is kept to a minimum. If, eventually, management returns to the burning system, sequestered carbon may be lost in a short period of one or two years, as it is an unstable carbon, susceptible to mineralization;
- We believe that maintaining the leaf biomass in the system, associated to reduced soil cultivation, may favor intensively the interactions between soil organic matter, structure, biological activity, and soil fertility in the next years of cultivation.

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BALANCE OF GREENHOUSE GASES FROM THE CONVERSION OF BURNT SUGARCANE CANE HARVESTED AREAS FOR RAW MECHANIZED HARVESTING IN BRAZIL

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There has been a debate on whether sugarcane culture and production of renewable energy derived from sugarcane plantations (CERRI *et al.*, 2009) has contributed to increased concentrations of atmospheric CO₂.

Agricultural production systems have been implementing changes to reduce greenhouse gas emissions in recent years in the country, in which agricultural soils contribute to 9.3% of national emissions. These changes are mainly related to adaptations in management practices that help reduce greenhouse gas emissions, in compliance with national and international laws and good practices protocols, and related to the growing demand for biofuels both in Brazil and other countries of the world.

The present study aims to estimate emissions and the potential for sequestering C in soil and to present an annual emissions balance that considers the main agricultural sources of greenhouse gases (GHG) for one hectare of sugarcane harvested manually with burning, and one hectare of sugarcane harvested mechanically without burning (Figure), in order to present and discuss the impact of different agricultural management practices on the GHG balance. Our approach is based on IPCC emission factors (IPCC, 2006) and the average consumption data from agricultural inputs used for production in Brazil, including soil sequestration of C (carbon) in raw harvested areas and fossil fuel consumption in agricultural operations.

PRELIMINARY RESULTS

- Applying typical cultivation and intensive management practices in sugarcane areas in Brazil, the total GHG emissions estimates for each hectare were 2,793 and 3,104 kg CO₂eq ha⁻¹ year⁻¹ for raw and burnt sugarcane harvesting systems, respectively, without considering soil carbon sequestration. Therefore, the conversion of burnt manual harvesting to raw mechanized harvesting reduces about 310.7 CO₂eq ha⁻¹ year⁻¹. Furthermore, considering the potential soil carbon sequestration

of 320 CO₂eq ha⁻¹ year⁻¹ in raw areas, converting the crop system from burnt harvesting to raw harvesting would avoid emissions equivalent to 1,484.0 kg CO₂eq ha⁻¹ year⁻¹.

CHALLENGES

- Considering the agricultural sector's GHG balance studies for the cultivation of sugar cane, and highlighting the present field research results, we can infer that the cultivation of sugar cane in Brazil must undergo more intense production transformations aiming for the reduction of GHG emissions;
- New production scenarios for the sugarcane agricultural sector must be fostered and studied in order to ensure production sustainability and the promotion of direct and indirect benefits for society, as a result of lower GHG emissions and concomitant higher economic gains.

SOLUTIONS

- Existing strategies to reduce GHG emissions in sugarcane cultivation include conservationist soil management practices such as minimum cultivation, more adapted and productive varieties, and the use of crops that produce food in rotation or intercropped with sugarcane. Such strategies promote direct and indirect economic returns and reduce diesel consumption in field operations, which undoubtedly contribute to sustaining sugarcane production and its derivatives in the long term and promote greater competitiveness of the Brazilian sugar and alcohol sector on the world stage.

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Figure 1: Harvest of raw mechanized sugarcane without burning, at Usina Ipiranga S.A., in Mococa-SP, 2011



Crédit: authors

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CO₂-C EMISSIONS THE SOIL BEFORE REPLANTING SUGARCANE IN SOUTHERN BRAZIL

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This study quantified the impact of sugarcane harvesting systems, soil preparation, and other management practices on C-CO₂ before replantation. We took two agricultural systems into consideration: burnt manual harvesting and raw mechanized harvesting without burning, in plots where the residues were left or removed from the soil surface, in areas without soil preparation and after conventional preparation, with or without applications of lime and agricultural plaster.

PRELIMINARY RESULTS

- Emissions in plots without soil preparation remained lower than all the others throughout the studied period, with fluctuations related to changes in soil moisture associated to the occurrence of precipitation. C-CO₂ emission changes in each of the harvesting systems are clearly observed when soil is prepared with the addition of limestone or plaster;
- Among the studied harvesting and management systems, plots without soil preparation showed the lowest emissions during the entire 25-day measurement period, especially the Raw Sugarcane with Residues without Soil Preparation, with values of 446.4 kg C-CO₂ ha⁻¹. Renewing raw sugarcane harvested areas with residues on the soil surface, applying the usual management practices considered in this work, was responsible for emissions as high as 1,103.8 kg C-CO₂ ha⁻¹ or 4,047.3 kg CO₂ ha⁻¹, during the period of 25 days after soil preparation. In those same management practices, area renovation with burning presented emissions of 568.1 kg C-CO₂ ha⁻¹ or 2,083.0 kg CO₂ ha⁻¹;
- The removal of sugarcane residues from the soil surface resulted in an almost immediate reduction in soil moisture (6% by volume), following an increase in CO₂ emissions in the which represent 925.5 kg of CO₂ ha⁻¹ issued back into the atmosphere in 25 days. This value is comparable to CO₂ losses in the soil resulting from conventional soil preparations in the plots of Burnt Sugarcane and Raw Sugarcane Without Residues, representing 283,4 and 245,7 kg C-CO₂ ha⁻¹, respectively (Figure);
- Reducing the frequency of soil preparation in areas of raw harvested sugarcane reduces CO₂ emissions and promotes an increase in the soil's carbon stock, considering long-term cultivation systems.

CHALLENGES

- Os resultados sugerem que a remoção dos resíduos da cana após a colheita mecanizada crua e o preparo convencional do solo considerado neste estudo anterior ao replantio da cultura, não são opções adequadas para mitigação de gases de efeito de estufa em áreas de cana-de-açúcar;
- Tanto para áreas colhidas queimadas como para áreas colhidas mecanicamente cruas, uma redução na frequência do preparo do solo por ocasião da reforma seria desejável, uma vez que podem causar perdas adicionais de carbono.

SOLUTIONS

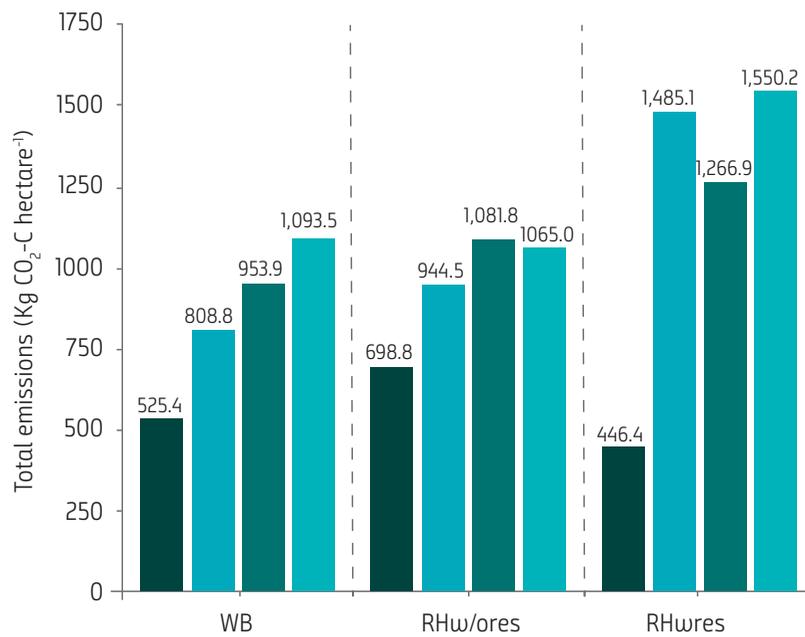
- Reduce soil preparation operations in sugarcane areas;
- Maintain the straw on the soil surface, to ensure lower additional CO₂-C emissions and higher soil moisture.

DATA PUBLISHED IN:

FIGUEIREDO, E. B.; PANOSSO, A. R.; REICOSKY, D. C.; LA SCALA, N. Short-term CO₂-C emissions from soil prior to sugarcane (*Saccharum spp.*) replanting in southern Brazil. *GCB Bioenergy*, v. 7, n. 2, p. 316-327, 2015.



Figure 1: Total carbon emissions, considering burnt sugar cane (WB) harvesting systems, raw harvesting with removed residues (RHw/ores), and raw harvest with residues on the soil surface (RHwres) and their respective managements.



Note: Half of the standard error is shown above the management systems bar. The averages followed by the same capital letters comparing managements between the harvesting systems and the lower case letters comparing the managements within each harvesting system do not differ according to the Tukey test ($p > 0.05$).

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DEVELOPMENT OF INDICATORS TO ANALYZE SUGARCANE CULTIVATION SUSTAINABILITY UNDER IRRIGATION IN TRADITIONAL AND EXPANSION REGIONS OF THE NORTHEAST

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Nitrous oxide (N₂O) is a potent greenhouse gas (GHG). Despite its low concentration in the atmosphere of 324 ppb (IPCC, 2013), it stands out given its length of permanence (approximately 114 years) and high global warming potential (GWP). Estimates in Brazil point out that 93% of N₂O annually released into the atmosphere comes from agricultural activity (MCTI, 2013).

The emissions from N₂O from using nitrogen fertilizers, according to the IPCC estimate (2006), is 1% of the applied N (range of 0.03 to 3%). However, in practice, different amounts of N₂O are issued depending on the fertilizer, management adopted, soil type and environmental conditions.

The study aimed to compare N₂O emissions resulting from the application of N doses in sugarcane cultivations with subsurface drip fertigation, comparing them to emissions from conventional fertilization (via soil). N₂O emissions were studied in an area of sugarcane cultivation in the sugarcane plant harvested without burning phase in the experimental area of Embrapa Mid-North, in Teresina – PI.

The treatments consisted of the combination of two doses of N and K₂O (respectively, 60-120 and 120-180 Kg ha⁻¹), two forms of application (via soil and fertigation) and a control. All treatment plots were irrigated, regardless of the type of fertilizer application.

Fertilization with other nutrients was uniform in all plots. Phosphorus (P2O5) was applied in the amount of 100 kg ha⁻¹, as follows: 30% at the foundation (TSP-triple superphosphate) and 70% via fertigation (monoammonium phosphate) through monthly applications. In soil fertilization treatments, P was all applied to the foundation, in the form of TSP. The micronutrients B, Zn, Mn, Cu, and Mo were applied via fertigation and were split through six applications in all treatments, on a monthly basis.

In the fertigated treatments, the applications of N and K₂O were divided into 24 stages during the six-month culture cycle, with an interval of seven days between applications, the first performed 60 days after planting (DAP). For the treatments with fertilization via soil, the doses of N and K₂O were conventionally applied in two stages: 50% at 68 DAP; and 50% at 144 DAP.

The irrigation depth was uniform and applied based on the reference evapotranspiration (ET₀) estimated by the Penman-Monteith method and by the region's sugarcane cultivation coefficients (K_c) (ANDRADE JÚNIOR *et al.*, 2017), on a daily time scale.

N₂O fluxes were quantified using the closed static chamber method (Figure). For the quantification of fluxes on the day of collection, three samples of N₂O were collected per chamber: immediately after closing the chamber (zero time); after 10 minutes (time 10); and after 30 minutes (time 30). The samples were collected early in the morning (between 7:30 am and 10:00 am) and were stored in hermetically sealed bottles and sent for analysis. The concentration of N₂O was determined by gas chromatography, using a Trace 1310 GC model equipment, with an ECD1 detector, at 350 °C (nitrogen at 20 mL min⁻¹ as make-up gas), and helium as carrier gas.

The evaluations of N₂O emissions in the fertigated treatments were carried out at 83, 104, 146, 186, and 230 DAP, one day after fertigation, totaling five evaluations. In conventional fertilization treatments, collections were performed at 69, 70, 73 and 145, 146 and 147 DAP, to quantify the emissions resulting from the 1st and 2nd cover fertilization, respectively, totaling six evaluations. With the daily N₂O fluxes, the accumulated emissions in the period were obtained through the trapezoidal integration of the daily fluxes as a function of time. The accumulated N₂O emissions enabled the calculation of emission factors (EF) for each dose of N applied, following the IPCC (2006) proposed methodology.

PRELIMINARY RESULTS

- In fertigated treatments with 60 and 120 N ha⁻¹, the accumulated N₂O emissions revealed a reduction of 40.6 and 50.2%, respectively, along the cycle period when compared to their conventional fertilizers via soil;
- The application of 120 kg Nha-lua irrigation presented a lower emission factor (1.69%), closer to the IPCC (2006) established factor, which is 1%;
- The conventional application of 60 kg Nha-l presented an EF of 4.26%, a value above the IPCC established factor.

CHALLENGES

- The results obtained through this research pointed out the need for further studies to be carried out in other sugarcane-producing regions.

SOLUTIONS

- The findings from this study revealed that sugarcane production systems under subsurface drip irrigation promotes fewer GHG emissions into the atmosphere when compared to the system that adopts conventional fertilization via soil.

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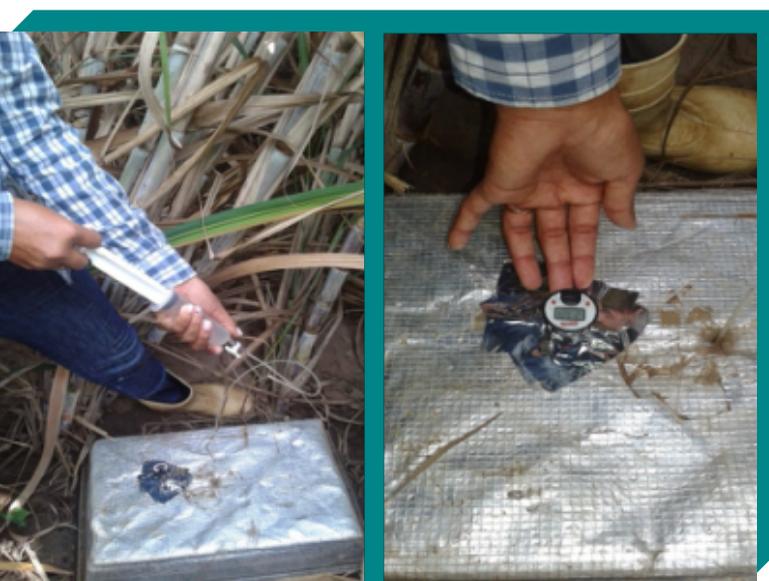


Figure 1: N₂O fluxes measurement using the closed static chamber method.

Crédit: the authors.

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REMOVAL OF SUGARCANE STRAW AND ITS IMPLICATIONS FOR GREENHOUSE GAS EMISSIONS FROM THE SOIL IN THE STATE OF SÃO PAULO, BRAZIL

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Using agro-industrial residues such as sugarcane straw has become a promising option to increase bioenergy production. However, the implications of straw removal on greenhouse gas (GHG) emissions from the soil are still poorly understood due to the scarcity of field studies conducted in Brazil's edaphoclimatic conditions. Life cycle assessments that use the emission factors proposed by the IPCC (IPCC, 2006, p. 68) point out that nitrous oxide (N₂O) emissions derived from synthetic nitrogen fertilizers and sugarcane straw correspond to approximately 49% of total GHG emissions associated with sugarcane production (CHAGAS *et al.*; 2016). This study has the aim of determining N₂O emission factors from the application of nitrogen fertilizers in sugarcane areas under different amounts of straw.

In order to represent the specific regional conditions of the sugarcane production areas in the state of São Paulo under different straw removal scenarios, direct emissions N₂O (in kg CO₂eq ha⁻¹) were estimated based on the standard emission factor (1%) proposed by the IPCC (Tier 1) and the specific regional emission factors (Tier 2) obtained in this study and compiled from a literature review (Table).

Four field experiments were designed to evaluate the soil's N₂O emissions after nitrogen fertilization under different scenarios of sugarcane straw removal in the state of São Paulo. The experiment sites are located in the municipalities of Campinas, Paulínia, Quatá, and Sales Oliveira, and were chosen strategically in order to represent different soil conditions, climate, and harvest seasons. In each location, four rates of straw removal (without removal - WR; low removal - LR with removal of 5 Mgha⁻¹; high removal - HR with removal of 10 Mgha⁻¹; and total removal - TR with removal of 15 Mgha⁻¹) were established in a randomized block design, with four replications. The evaluations were carried out during the 2016/2017 harvest in all locations and in the 2017/2018 harvest only in Quatá and Sales de Oliveira. For GHG measurements, static chambers were installed in the soil on and in between sugarcane lines. Collections started after the nitrogen fertilizer application and were extended until harvest. The application of fertilizer in each site was carried out approximately 30 days after harvest, with 120 kg ha⁻¹ year⁻¹ of nitrogen and 120 kg ha⁻¹ year⁻¹ of potassium.

PRELIMINARY RESULTS

- Cumulative N₂O emissions ranged from 0.20 to 4.09 kg ha⁻¹ year⁻¹ and were significantly affected by straw removal at evaluated sites, indicating that straw removal reduces N₂O emissions.
- The N₂O emission factors obtained in this study (n = 22), along with those compiled from the literature (n = 9), were 0.28; 0.44; 0.70; and 0.56% for the TR, HR, LR, WR scenarios, respectively, consistently lower than the 1% emission factor proposed by the IPCC (Table). It is important to note that the IPCC establishes the emission factor of 1% of the N applied in the form of synthetic fertilizer in addition to 1% of the N present in the cultural residues (that is, in the straw). Data from this study data reflect emissions already taking into account the contribution of fertilizer and straw, and even then, the emission factors were lower, when compared to the IPCC proposed standards.

CHALLENGES

- Although the results indicate that the removal of straw reduces N₂O emissions, the implications of removal on soil organic carbon stocks were not considered in this study. The main objective was to assess the greenhouse gases (N₂O e CH₄) emissions, therefore recommending that future research take these aspects into consideration, especially in the quantification the balance of GHG emissions induced by straw removal for the production of bioenergy.

SOLUTIONS

- Based on specific regional factors (Tier 2), direct N₂O emissions from nitrogen fertilization in straw were 50% lower in relation to the standard emission factor proposed by the IPCC. The present research is an initial step towards providing specific regional data to reduce the high level of uncertainty associated with N₂O emissions estimates for sugarcane ethanol in Brazil. Life cycle analysis studies for sugarcane production using regional emission factors will certainly

result in decreased use of synthetic nitrogen fertilizer when straw is present, on the total GHG emissions associated to sugarcane production, whose contribution has been estimated at 49% of total emissions.

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Table: N_2O emission factors (% of applied N) obtained from experimental areas cultivated with sugarcane under different straw removal scenarios in the state of São Paulo, Brazil.

Site	Location	Harvest/year	Straw removal rates			
			TR	HR	LR	WR
1	Campinas, SP	2016/17	0.14 c	0.57 b	0.47 b	0.81 a
2	Paulínia, SP	2016/17	0.12 d	0.52 c	1.44 a	0.91 b
3	Quatá, SP	2016/17	0.58 a	0.42 a	0.68 a	0.69 a
		2017/18	0.28 a	0.24 a	0.38 a	0.23 a
4	Sales Oliveira, SP	2016/17	0.05 a	0.09 a	-	0.13 a
		2017/18	0.07 b	0.13 ab	-	0.16 a
Literature Data #						
Carmo et al.	Piracicaba, SP	2010/11	0.68	0.96	--	0.76
Pitombo et al.	Piracicaba, SP	2012/13	0.21	--	1.06	--
Pitombo et al.	Araras, SP	2011/12	0.41	0.56	0.19	0.79
Average			0.28	0.44	0.70	0.56

Averages followed by the same letter on the line do not differ statistically according to the Tukey test ($p < 0.05$). Sugarcane straw removal rates: total removal (TR), high removal (HR), low removal (LR) and without removal (WR). # The primary data obtained from the literature were not available to perform the statistical analysis.

N₂O EMISSIONS DUE TO THE APPLICATION OF NITROGEN FERTILIZERS IN SUGARCANE CULTIVATION IN MID-SOUTHERN REGION OF BRAZIL

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This study was developed to determine the effects of nitrogen fertilization (sources and doses) on N₂O emissions in sugarcane cultivation in the Mid-Southern region of Brazil. Two experiments were conducted, one in Piracicaba-SP and one in Goianésia-GO. The evaluated fertilizers were urea and ammonium nitrate, applied at doses of 0, 60, 90, 120 and 180 kg ha⁻¹. Static cameras (STEUDLER et al., 1995) were used for the evaluations.

PRELIMINARY RESULTS

- In Piracicaba-SP, N₂O emissions increased exponentially with the increase of the N dose, and were similar between urea and ammonium nitrate up to a dose of 107.9 kg ha⁻¹. From that point on, emissions increased exponentially for treatments that received ammonium nitrate, while for urea treatments, emissions stabilized after that dose;
- In Goianésia-GO, N₂O emissions were lower than those observed in Piracicaba-SP, although treatments have been similar, with emissions increasing linearly as a function of the dose of N for ammonium nitrate. For the treatments receiving urea addition, the emissions increased in a quadratically as a function of the N dose, with a maximum point of 113.9 kg N ha⁻¹;
- The N₂O emission factors varied depending on both the sources of N and the experiment location.
- Conducted In Piracicaba-SP, the emission factors of N₂O ranged from 0.80 ± 1.0 to 12.94 ± 2.95% of the N applied via ammonium nitrate and from 2.85 ± 1.90 to 6.67 ± 1.59% of the N applied via urea (Table);
- In Goianésia-GO, N₂O emission factors for ammonium nitrate were similar between the tested doses. For urea, the higher the applied dose of N, the lower the emission factors;
- N₂O emissions induced by nitrogen fertilizers are dependent on the applied N dose and also on the type of fertilizer applied;

- Emissions induced by the application of ammonium nitrate increase rapidly as a function of the N dose, while those induced by the use of urea have a maximum point that occurs around 114 kg ha⁻¹.

CHALLENGES

- Differentiated and specific emission factors are necessary for different nitrogen sources;
- The large variation N proportions issued into the atmosphere in the form of N₂O confirms that using a pre-established emission factor value for all situations is problematic.

SOLUTIONS

- Studies must be carried out for the crops representative of the national agricultural scenario, considering the main management practices, sources, and doses of applied fertilizers, in order to generate emission factors to be used in national inventories that are closer to the country's reality.

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Table: Measurement of N₂O fluxes through the closed static chamber method.

Dose de N (kg ha ⁻¹)	Fatores de Emissão (FE)	
	Nitrato de Amônio	Ureia
Piracicaba-SP		
60	0,80 ± 1,00	2,85 ± 1,90
90	1,33 ± 0,62	3,59 ± 1,39
120	6,21 ± 2,11	6,67 ± 1,59
180	12,95 ± 2,95	4,31 ± 0,94
Goianésia-GO		
60	1,22 ± 0,27	1,10 ± 0,22
120	1,53 ± 0,07	0,63 ± 0,12
180	1,22 ± 0,12	0,31 ± 0,09

Source: Authors.

Figure 1: Chambers during the collection of GHGs in a sugarcane area.

Credit: Magnus D. Deon.

Figure 2: Experimento para determinação de fatores de emissão de N₂O no cultivo de cana-de-açúcar.

Credit: Magnus D. Deon.

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EXPANDING SUGARCANE CULTIVATION: TRANSFORMING DEGRADED PASTURES INTO SUGARCANE PLANTATIONS AND CHANGES IN GREENHOUSE GAS EMISSIONS

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In Brazil, the growing cultivation of sugar cane in tropical regions and the increase in the global demand for renewable energy in recent years has led to sugarcane expansion and intensification. Extensive pasture areas are being converted into sugarcane cultivation areas, and, consequently, remaining pasture management is becoming more intensive through the adoption of management practices such as soil preparation and fertilizers application. In the last decade alone, the area harvested with sugar cane in the country has increased by about 60% (FAOSTAT, 2016), mainly towards natural or extensive pastures (MARIN; NASSIF, 2013; OLIVEIRA *et al.*, 2016, 2017).

The growing use of nitrogen fertilizers in pastures and sugarcane can result in greater N₂O e CH₄ emissions and alter the GHG balance of sugarcane ethanol produced in the country. On the other hand, adding nitrogen to the soil can compensate for CO₂ losses and may reduce GHG emissions by promoting carbon sequestration and storage in the soil. Whether the final GHG emissions balance will be positive or negative will depend on a number of factors, including the management adopted during land use changes and how environmental conditions will affect soil biogeochemical processes.

In this context, the objective of this study was to quantify the GHG emissions associated with the conversion of extensive pastures into intensive pastures and into areas of sugarcane production, through experiments conducted in Sorocaba, in the state of São Paulo, as well as to determine how environmental conditions and how adopted management practices affect emissions. Our hypothesis considered that GHG emissions would increase, due to the use of fertilizers, with the conversion of extensive pastures into sugarcane plantations, as well as with the intensification of remaining pastures.

Taking into account the above scenario, this experiment was designed to assess changes in GHG emissions in an extensive pasture area (treatment 1 - without fertilizer application), in an intensified extensive pasture area (treatment 2 - pasture only with the application of inorganic fertilizers), in a reformed pasture area (treatment 3 - extensive land pasture that received only soil preparation), in an area of fertilized reformed

pasture (treatment 4 - extensive pasture that received soil preparation and application of inorganic fertilizers), and in extensive pasture converted into sugarcane cultivation (treatment 5 - conventional soil preparation for planting sugar cane without fertilizer application; treatment 6 conventional soil preparation and application of fertilizers).

The first step in the implantation of conventional sugarcane and reformed pasture was conventional soil preparation. Towards this end, recommended procedures for pasture and sugar cane in the region were carried out, which include double plowing, harrowing, and leveling. Fertilization was carried out according to the recommended rates for pastures and sugarcane in the state of São Paulo (RAIJ *et al.*, 1997). Pasture was fertilized with 60 kg of N ha⁻¹ in the form of ammonium nitrate (NH₄NO₃), 40 kg of P₂O₅ ha⁻¹ of superphosphate and 40 kg K₂O ha⁻¹ of potassium chloride (KCl). Sugarcane was fertilized with 60 kg N ha⁻¹ of ammonium nitrate (NH₄NO₃), 140 kg of P₂O₅ ha⁻¹ of superphosphate and 120 kg of K₂O ha⁻¹ potassium chloride (KCl).

The gas samples were obtained through cylindrical PVC chambers (30 cm in diameter, 28 cm in height) installed in the field and quantified by gas chromatography. From the results obtained, fluxes (Figure), annual emissions, and N₂O e CO₂eq. emission factors were calculated.

PRELIMINARY RESULTS

- During climatic conditions in the studied period, the study observed that CH₄ fluxes alternate between negative and positive values, generally close to zero; CO₂ and N₂O fluxes increased mainly in treatments involving soil preparation and fertilizer application, and were influenced by climatic variables such as pluviometric indexes;
- The highest CO₂ e N₂O peaks occurred between 40 and 110 days after the application of fertilizers;
- Statistical analyzes suggest that soil preparation can better explain the GHG fluxes in the experiment;

- The emission factor (of N_2O) estimated for the intensified extensive pasture (treatment 2) was 0.41%;
- The emission factor (of N_2O) estimated for the reformed pasture (treatment 4) was 3.36%;
- The emission factor (of N_2O) estimated for the cultivation of sugarcane (treatment 6) in the first year of cultivation, when conventional soil preparation is carried out and using only inorganic fertilizers, was 0.46%;
- The intensity of the increase in GHG emissions, according to the experimental results, depends on the environmental conditions and the adopted management practices.

CHALLENGES

- The results from the first year of sugarcane cultivation show that the intensification of pastures and the conversion of pastures into conventional sugarcane can increase GHG emissions;
- The emission factor estimated for reformed pastures in this study was three times higher than the value estimated by the IPCC for reformed pastures in Brazil;
- The emission factor estimated for conventional sugarcane in this experiment may likely be higher, considering the routine use of vinasse and urea as nitrogen fertilizer, as well as a complete crop cycle that can vary from three to five years;
- The emission factor of 1% estimated by the IPCC for sugarcane may be an underestimation given the growing use rates of fertilizer application in the country and based on the results observed in this study.

SOLUTIONS

- Converting pasture into sugarcane plantations in Brazil is associated with a negative GHG balance. This negative balance is generated when taking into account the decrease of deforestation in native areas and the use of inputs that improve livestock production in Brazil;
- Sugarcane expansion methods towards pasture areas must adopt the best and most sustainable management practices available in order to mitigate GHG emissions;

- It is crucial that the expansion of the sugarcane crops in Brazil undergo research considering an accurate quantification of a complete crop cycle.

DATA PUBLISHED IN:

BENTO, C. B. et al. Impacts of sugarcane agriculture expansion over low-intensity cattle ranch pasture in Brazil on greenhouse gases. *Journal of Environmental Management*, v. 206, p. 980-988, 2018.

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OBSERVATION AND MODELING OF GREENHOUSE GASES CO₂, CH₄ AND N₂O EMISSIONS IN A SUGARCANE PLANTATION

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Continuous measurements of water vapor and greenhouse gas (GHG) fluxes of methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂) were carried out in a commercial sugarcane plantation in a harvest area without burning (Figure) in Pirassununga-SP, for two consecutive years, using the vortex covariance method (eddy covariance), under high temporal resolution (30 minutes) and spatial integration in the order of hectares around the observation site. The molar fractions of CH₄ and N₂O gases were measured by a closed-path laser absorption spectrometer (QCLAS); the CO₂ water vapor by an absorption sensor in the open infrared path, both with fast response (10 Hz) in addition to a three-dimensional sonic anemometer. The obtained data set was used to determine net exchanges (NEE: Net Ecosystem Exchange) of CO₂, CH₄, and N₂O between the sugarcane plantation and the atmosphere, and underwent regular verifications overtime to determine if the agrisystem behaved towards the atmosphere as source or a sink.

PRELIMINARY RESULTS

- The first nitrogen fertilization (a liquid mixture of NH₄, 80 kg N ha⁻¹) was carried out after the sugarcane harvest (November 2016); the N₂O fluxes increased exponentially and the total integrated values over 70 days (duration of the effect) was 129.0 ± 4.4 mg N₂O-N m⁻², representing approximately 1.6% of the applied N. In the second application (granulated NH₄NO₃, 100 kg N ha⁻¹) that occurred in September 2017 (first ratooning), the increase in fluxes was only observed after 15 days because of precipitation. The fertilization effect duration was also 70 days, and the total emissions was 70.3 ± 3.1 mg N₂O-N m⁻², representing 0.7% of the N applied, lower than the observed value in the previous year due to the difference between fertilizers;
- Regarding CH₄ fluxes, the daily totals were small and highly variable, on average 330.9 ± 37.6 mg CH₄-CO₂eq m⁻² day⁻¹, in addition to occasional negative values, which indicate oxidation;

- The total emissions observed in the sugarcane plantation throughout each year for N₂O was 62.4 ± 1.3 e 52.3 ± 1.8 g N₂O-CO₂eq m⁻² and for CH₄ was 12.1 ± 1.7 e 10.4 ± 2.3 g CH₄-CO₂eq m⁻²;
- The obtained CO₂ balances (-7643.0 ± 129.0 and -4615.0 ± 124.0 g CO₂ m⁻²) indicated that the plantation's carbon fixation was able to neutralize emissions, even when taking into consideration the removal of stalks in the harvests (4923 ± 459 and 3929 ± 352 g CO₂ m⁻²), in addition to the partial decomposition of deposited straw after the first harvest (1581 ± 301 g CO₂ m⁻²).

CHALLENGES

- The determination of CO₂ balances proved to be essential for verifying GHG N₂O e CH₄ emissions neutralization in the sugarcane plantation.

SOLUTIONS

- The employed methodology (eddy covariance) proved to integrate different parts of the agrisystem (soil-plant-atmosphere), providing the balances between fixation via photosynthesis and soil and plant respiration.

DATA PUBLISHED IN:

CABRAL, O. M. R. et al. The sustainability of a sugarcane plantation in Brazil assessed by the eddy covariance fluxes of greenhouse gases. *Agricultural and Forest Meteorology*, 2020. <https://doi.org/10.1016/j.agrformet.2019.107864>

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Figure: Fluxes tower installed at the sugarcane plantation.

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GREENHOUSE GASES EMISSIONS FROM SUGARCANE CULTIVATION SOILS IN BRAZIL: EFFECTS OF THE APPLICATION OF SYNTHETIC AND ORGANIC FERTILIZERS WITH STRAW ACCUMULATION

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The objective of the study was to carry out in situ experiments to evaluate the emission rates of three greenhouse gases (GHG), CO₂, N₂O e CH₄, in sugarcane cultivation in Brazil under different fertilizer application practices normally used in the main stages of the crop, with straw on the soil surface, resulting from mechanized harvesting. The study sought to determine whether GHG emissions responded to I. the fertilization method used in the first part of the sugarcane cycle (cane plant); and II. the accumulation of cane straw on the soil surface during the subsequent cycle of sugarcane harvest (cane ratooning), with and without the application of liquid residues (vinasse) in the field.

The experiment in Jaú-SP was conducted to determine whether GHG emissions from sugarcane vary with the different fertilization methods most commonly used in Brazil. The study used randomized blocks composed of five treatments and four blocks, totaling 20 plots, in an area greater than 1,100 m². Each plot measured 7m x 8m and contained five 8m long rows planted with sugar cane, spaced 1.4 m apart. The experiment included the treatments: T1- mineral fertilizer containing N, P and K; T2- mineral fertilizer containing N and K; filter cake added as a source of P; T3- mineral fertilizer containing N and P, and vinasse added as a source of K; T4- mineral fertilizer containing N, filter cake and vinasse added as sources of P and K; C - control, without fertilizer (organic or mineral).

The experiment in Piracicaba-SP was carried out to determine the accumulation of agricultural straw resulting from the mechanized harvesting of sugarcane without the practice of pre-burning. The effects of using vinasse in sugarcane on GHG emissions were also evaluated. The experiment was conducted using a randomized block design with a 4 x 2 factorial treatment, containing four replications, totaling 32 plots in five 10m long sugarcane rows at intervals of 1.4 m. The factors corresponded to the application or not of vinasse in plots with four different levels of straw on the soil surface (0, 7, 14 or 21 Mg ha⁻¹, dry material).

Overall, two plots were used as the control to account for emissions, while the other plots were treated with mineral

fertilizers, following common practices used in cane ratooning.

In the sugarcane experiment (Piracicaba) gas samples were collected during a period of 335 days after fertilizer application. The samples were collected using PVC chambers installed in the experimental plots, according to Davidson and Schimel (1995) and Allen et al. (2010). All samples were analyzed at the Federal University of São Carlos, in Sorocaba-SP, Brazil, using the Shimadzu GC-2014 gas chromatograph (Shimadzu Co., Columbia, MD, USA). GHG flows were calculated according to Jantalia et al. (2008).

The emission rate for each experiment was calculated using linear regression based on the curve generated from the gas values measured over the intervals of 30 minutes. N₂O emission factors were calculated by subtracting cumulative emission rates from N fertilizer treated plots. The calculations followed the IPCC (2006) and Allen et al. (2010) methods.

PRELIMINARY RESULTS

- In general, N₂O and CO₂ fluxes in sugarcane plants treated with organic and mineral fertilizers (T2, T3, T4) were higher than those treated only with mineral fertilizers (T1) and higher than those of control treatment plants (C) (figures a-c);
- Unlike N₂O and CO₂, the daily fluxes of CH₄ did not differ significantly between the treatments. We observed that only the vinasse and mineral fertilizer (T3) treatment presented outstanding changes in daily emissions by the end of the experiment. However, the variation in daily fluxes between the sampling dates was greater than the variation between treatments, which didn't result in significant differences;

- Cane-plant Experiment (Jaú-SP) - After observing the daily flux data, we estimate that the use of organic fertilizer combined with mineral fertilizer (T2, T3 and T4) resulted in higher cumulative N₂O emissions annually than if the mineral fertilizer was used on its own (Figure a). Even when N₂O emissions are taken into account, it is evident that only mineral fertilizer (T1) presented lower cumulative emissions annually compared to treatments that used organic fertilizers;
- First sugarcane ratooning Experiment (Piracicaba-SP) - Unlike the cane-plant experiments, accumulated N₂O emissions generally increased after the application of mineral fertilizer and with the amount of straw covering the soil, regardless of the presence of vinasse. However, as the emissions in the experiment using vinasse increased not only in the cultivation lines, but also in the medium, the accumulated emission values were about twice as high in the experiment with vinasse (Figure g);
- For CO₂, accumulated emissions were practically the same in treatments with and without vinasse. In both experiments, however, straw accumulation increased CO₂ far beyond the values observed in the control treatment (Figure h / e);
- In both cane-plant and cane-ratooning, the highest CO₂eq was related to the use of vinasse;
- In cane-plant, the maximum emission value in CO₂eq was about 1380 ha⁻¹ year⁻¹ in T4, while in cane-ratooning, the emissions exceeded 3000 CO₂eq ha⁻¹ year⁻¹. The minimum emission values were similar for cane-plant and cane-ratooning, respectively, with CO₂eq in T1 and 382 CO₂eq in T0, V-;
- Higher values in the N₂O emission factors were observed amongst all experiments and treatments for sugarcane (Piracicaba-SP) that were treated with vinasse and the highest amount of agricultural straw on the soil surface (21 mg ha⁻¹);
- The emission factor of mineral fertilizer (*ammonium nitrate*) applied to sugarcane without vinasse ranged from 0.68 to 2.03% of applied fertilizer, the maximum value associated with the larger volume of agricultural straw on the soil surface;
- When vinasse was applied, the emission factor ranged from 0.59% to 3.03%, and the highest value was linked to a larger amount of agricultural straw.
- In addition, although the emission factors were relatively low for all treatments (below 21 mg ha⁻¹) of agricultural straw in the absence of vinasse (V-), when vinasse was used, the factors

increased according to the amount of straw in the soil;

- With cane-plant, the plots treated with vinasse and mineral fertilizer had the highest emission factor (2.65% of N applied as urea fertilizer). Without vinasse, the value was 1.1%. The filter cake, which added 62 kg Nha⁻¹, presented an emission factor similar to urea.

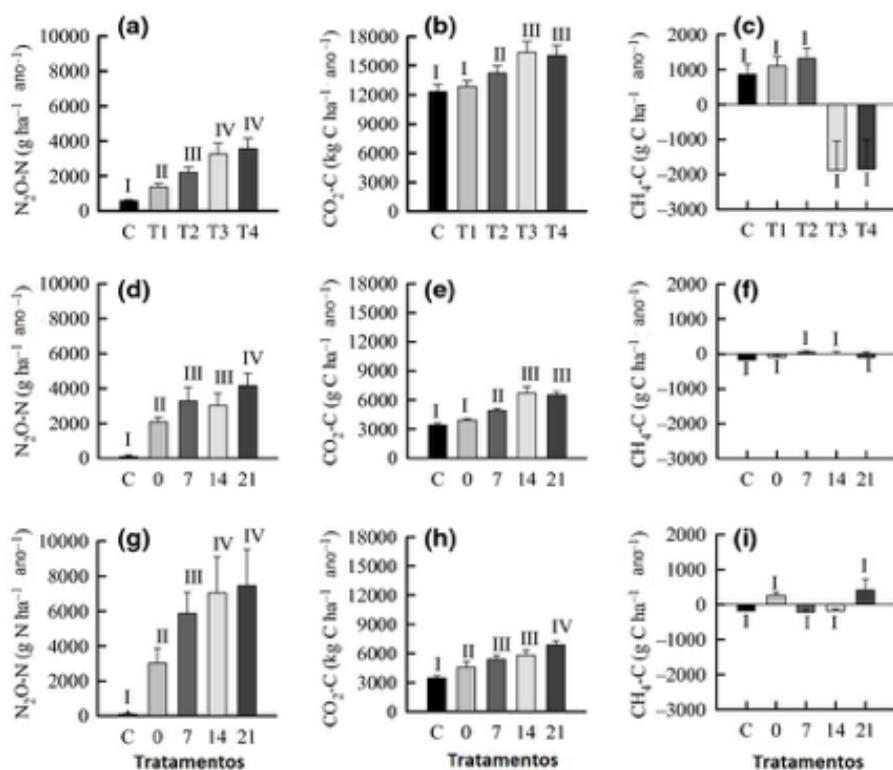
CHALLENGES

- This study provides in situ data on GHG emissions from sugarcane soils in Brazil, with a comprehensive characterization of emissions associated with different fertilizer application practices that are commonly used in the country and with the changes in harvesting practices. Since the study includes data collected throughout the growing season for two of the main harvest stages, as well as data collected intensely in the first two weeks after fertilizer preparation and application, it provides important information on the seasonal variation of emissions;
- However, similar to many of the conditions that affected GHG emissions in our study, they are probably inherent to the region or period studied (for example, soil characteristics, climatic conditions, and fertilizer nutrient concentrations). Thus, the results are not necessarily applicable to other regions of Brazil or anywhere else.

SOLUTIONS

- The results of this study should help both to validate the available GHG emissions estimates in Brazilian sugarcane production, and to better assess the net carbon saving capacity of ethanol in Brazil. Sugarcane production systems are diverse and understanding how emissions change across regions and other management scenarios should be a research priority for future studies on GHG emissions from sugarcane systems and ethanol production.

Figure : Cumulative fluxes of N_2O , CO_2 and CH_4 in cane-plant (Jaú-SP) and cane-ratooning (Piracicaba-SP)



DATA PUBLISHED IN:

CARMO, J. B. et al. Infield greenhouse gas emissions from sugarcane soils in Brazil: effects from synthetic and organic fertilizer application and crop trash accumulation. *GCB-Bioenergy*, v. 5, n. 3, p. 267-280, 2013. DOI: 10.1111/j.1757-1707.2012.01199.x.

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Source: Authors.

Observation: The top three panels (1a to 1c) show cane-plant fluxes; the three intermediate panels (1d to 1f) show fluxes of the sugarcane without vinasse (V-); and the three lower panels (1g to 1i) show fluxes of cane-ratooning with vinasse (V+).

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N₂O EMISSIONS IN SUGARCANE WITH THE APPLICATION OF NITROGEN AND VINHASSE FERTILIZER IN THE CERRADO

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Nitrogen (N) added to agricultural soils, be it in the form of synthetic or organic fertilizers, is responsible for most existing nitrous oxide N₂O emissions and about 1% of N applied in the form of these sources is converted into N₂O. This “emission factor” can vary depending on the soil, how it’s managed, and other agricultural practices. Generally, it’s less than 1% in the well-drained agricultural soils in the Cerrado (Silva *et al.*, 2017), but it increases proportionally according to the applied dose of N. Brazil meets about 16% of its energy needs with bioethanol and other sugarcane products and is a world leader in the production of energy from biofuels. However, sugarcane cultivation raises several environmental concerns, associated to its high N₂O emissions, with a global warming potential about 298 times higher than carbon dioxide (CO₂) and remains in the atmosphere for more than 120 years. This study aimed to quantify sugarcane cultivation N₂O fluxes in the Cerrado during one year, comparing the magnitude of the response to different treatments: mineral nitrogen (N), vinasse (V) and a combination of both (NV), in irrigated and non-irrigated plots. N₂O fluxes in the soil under NV treatment are, on average, at least three times greater than those undergoing other treatments, resulting in four times the intensity of emissions per yield in comparison to when mineral N or vinasse were applied separately. Irrigation has a positive effect, both by increasing N₂O emissions in the first two weeks after adding water, and by increasing the annual productivity of sugarcane. Emission factors varied from 0.05 to 4.6% depending on the applied treatment. Sugarcane production in the Cerrado is a significant source of N₂O, due to the synergistic effect of mineral N and vinasse. Therefore, vinasse as the main fertilizer or the application of N and vinasse at well-spaced intervals are effective strategies for mitigating N₂O, as well as for plant nutrition, waste management, and economically and environmentally sustainable production.

PRELIMINARY RESULTS

- Accumulated N₂O emissions varied in the evaluated treatments, from 0.1 to 7.4 kg N-N₂O ha⁻¹ (Table1).
- Emission factors are between 0.05–4.59%, (average 1.34 ±

- Ammonium and nitrate in the soil were the main covariables to explain N₂O fluxes. The dominant N₂O product after the addition of fertilizers is denitrification, due to the entry of N, which provides a substrate for microorganisms in the soil.
- Irrigation increases N₂O fluxes due to responses from microbial activity to high humidity, resulting in high rates of mineralization.
- The combination of vinasse and mineral N promotes N₂O emissions that are on average at least three times higher than if applied separately.
- Concomitant irrigation with mineral N and vinasse will result in higher amounts of labile carbon, potassium, and N, which explains the higher peaks of N₂O when irrigated with vinasse and N fertilizer.
- Applications of vinasse and nitrogen fertilizer must be carried out separately, with the space of at least one month between applications, to avoid the synergistic effect of the joint application of these two types of fertilizers on N₂O emissions.

CHALLENGES

- Adding mineral N and vinasse simultaneously may trigger significant increases in N₂O fluxes in contrast to each fertilizer being separately applied in sugarcane cultivation in the Cerrado. There is a need to identify how these sources can be best combined, including doses and application intervals.

SOLUTIONS

- Using vinasse as the main fertilizer or applying N and vinasse in well-spaced intervals are effective strategies for mitigating N₂O emissions.

Table: Total mineral nitrogen applied as fertilizer per year (in Kg Nha⁻¹), yield (in Mg fresh stalk mass ha⁻¹), annual cumulative N₂O emissions (in Kg N-N₂O ha⁻¹) and factor emissions (FE, in%) in sugarcane production in the Cerrado.

Treatment	Applied N	Harvest Yield	Cumulative N-N ₂ O	Emission Factor (%)
Control	-	-	0.47 (0.0005)	-
N0	200	90 (15)	0.57 (0.02)	0.05 (0.002)
N75	200	132 (9)	0.78 (0.03)	0.16 (0.002)
NV0	202.7	92 (16)	2.34 (0.16)	0.92 (0.035)
NV75	202.7	138 (8)	2.91 (0.20)	1.20 (0.006)
V0	2.7	106 (4)	0.59 (0.03)	4.59 (0.18)
V75	2.7	127 (9)	0.50 (0.03)	1.11 (0.27)
Média		114 (8)	1.29 (0.43)	1.34 (0.68)
Cerrado	-	-	0.11 (0.003)	-

Average (\pm a standard error). Median (\pm mean absolute dispersion deviation).

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PARADIGMS IN SUGARCANE STRAW MANAGEMENT: CONSERVATIONIST AGRICULTURE X ENERGY COGENERATION?

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Keeping sugarcane straw on the soil after mechanical harvesting without burning has modified the crop management system in recent decades, and is changing varieties, fertilization, pest control, among other aspects. Partial or total removal of straw from the field is driven by the industry's interest in energy cogeneration, while the total or partial maintenance of straw in the field is linked to agronomic and environmental interests of conservationist agriculture, which reconciles agricultural production with natural resource preservation. Sugarcane is a bioenergetic culture and interested parties motivating the exploration of this resource must take into consideration the system's carbon balance. For this reason, knowing how keeping straw on the soil affects greenhouse gases (GHG) emissions is essential, mainly through N_2O from nitrogen fertilization.

With this in mind, N_2O emission factors (EF) we obtained for nitrogen fertilizer applied in doses from 0 to 120 kg ha⁻¹ of N, in the form of ammonium nitrate (ratoon fertilizer), in the absence or presence of straw, up to 12 Mg ha⁻¹. The experiments were carried out in Araras-SP (ARA) and Itacemópolis-SP (IRA) in the 2012/2013 harvest, and in Guairá-SP (GUA) in the 2014/2015 harvest, during the 1st ratooning in Guairá-SP and Itacemópolis-SP, and 3rd ratooning in Araras-SP. After fertilization N_2O emissions were quantified over the period of 250 days using the static chamber methodology, installed within the fertilization range.

In the absence of N, N_2O -N emissions varied from 15.7 to 40.0 mg m⁻² in soils without straw, increasing to 29.2 to 41.8 mgm⁻² with around 12 Mgha⁻¹ of dry straw mass. With the application of nitrogen fertilizer, N_2O -N emissions increased and were positively related to the amounts of straw on the soil. The values varied between 45 and 124 mgm⁻² in plots without straw and between 371 to 429 mg m⁻² when there was 12 Mg ha⁻¹ of straw. The nitrogen fertilizer EF was quite low in the absence of straw, varying from 0.03 to 0.10% of the applied N, but these values increased from 0.48 to 0.54% in plots containing 12 Mgha⁻¹ of straw. In the presence of intermediate amounts of straw on the soil (4.3 and 7.7 Mg ha⁻¹ of dry mass) the EF values were between 0.13 and 0.17% of the applied N, similar to the soil without straw emissions in Araras-SP and Guairá-SP.

It is important to highlight that, in all treatments with nitrogen fertilization, either in the absence or in the presence

of straw, the EF values obtained (Table) were significantly lower than the IPCC default value of 1% of applied N.

In terms of stalk production, the maintenance of straw provided increased productivity in the experiments in Araras-SP and Guairá-SP. An aspect frequently associated with the presence of straw in the field and consequent gains in productivity is the effect that straw has in maintaining soil moisture. In the 2014/2015 harvest in Guairá-SP, this effect was especially important since the rains came below expectations, resulting in a 10% drop in productivity. In Itacemópolis-SP, there was no gain in productivity with the maintenance of cane straw. This may be due to the type of clayey textured soil in the experimental area.

By weighting N_2O -N emissions per stem productivity (Table), we obtained the emission intensity, which is a fundamental parameter in measuring the impact of maintaining different amounts of straw on the soil. The issue is that if 100% of the straw was kept on the soil, from around 2 Mg ha⁻¹ of straw, the emission of N_2O per product unit differs from the value obtained when there is no maintenance of straw on the soil, suggesting a larger negative impact on the sugarcane C balance. However, the intensity of N_2O -N emissions for intermediate amounts of straw (4.3 and 7.7 Mg ha⁻¹ of dry mass) does not differ from the value found in soils without straw.

We may therefore conclude that partial harvesting of sugarcane straw for energy purposes in the industry can be aligned with the agronomic and environmental interests of maintaining part of the straw in the field since maintaining proportions below 100 % of straw (<8 Mg ha⁻¹) in the field yields productivity gains, without additional N_2O -N emissions per agricultural product unit.

PRELIMINARY RESULTS

- The nitrogen fertilizer EF was quite low in the absence of straw (0.03 to 0.10% of applied N), but this value increased from 0.48 up to 0.54% when 12 Mg ha⁻¹ of straw was maintained on the soil. The values obtained for nitrogen fertilizer EFs are lower than the IPCC default of 1%;
- The maintenance of straw on the soil provided gains in productivity of sugarcane stalks;

- N_2O -N emissions per product unit (stalk mass) in treatments with intermediate levels of straw (4.3 and 7.7 Mg ha⁻¹ of dry mass) are similar to those of soil without straw, however with gains of crop productivity.

CHALLENGES

- The methodology for monitoring emissions with static chambers involves intense use of human and material resources, making it costly, as it is necessary to provide sufficient staff and resources for the quantification of gases for prolonged periods of time;
- The dependence on N_2O emissions in relation to the distribution of rainfall in the experimental period and the interaction with the type of soil demand a large volume of results for the appropriate positioning of research bodies vis-à-vis the productive sector and international standardization bodies.

SOLUTIONS

- The sustainability of bioenergy production lies in reducing GHG emissions from agricultural production of raw material. Emissions Soil N_2O emissions are strongly influenced by the use of nitrogen fertilizers. However, contributions from tropical countries with information on possible N_2O soil emissions with the presence of straw residues and application of fertilizers are scarce in scientific literature;
- The application of ammonium nitrate without the presence of a large amount of straw in the

fertilization line (for example, the application of fertilizer after the straw has been lined up) is a strategy for mitigating greenhouse gases.

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Sistema de produção	Local ¹	Níveis de palha (Mg ha ⁻¹)	Produção (Mg ha ⁻¹)	Intensidade de emissão N_2O (kg CO_2 eq Mg ⁻¹ cana)	FE- N_2O (%)
OST + N	ARA	0	99,4 ± 21,8 a	2,85 ± 0,65 a	0,08 a
100ST + N	ARA	12	131,8 ± 15,1 b	14,6 ± 3,11 b	0,54 b
OST + N	IRA	0	95,6 ± 8,1 a	1,23 ± 0,54 a	0,03 a
50ST + N	IRA	6	85,1 ± 16,1 a	5,20 ± 1,74 a	0,13 a
100ST + N	IRA	12,3	91,3 ± 19,1 a	19,4 ± 4,41 b	0,48 b
OST + N	GUA	0	87,6 ± 9,6 a	4,60 ± 1,76 a	0,11 a
36ST + N	GUA	3,6	103,6 ± 12,2 ab	5,55 ± 1,26 a	0,16 a
64ST + N	GUA	7,2	109,1 ± 15,0 b	5,41 ± 0,65 a	0,17 a
100ST + N	GUA	11,5	102,3 ± 12,8 ab	15,9 ± 5,43 b	0,45 b

Key: 1 Experiments carried out in the following municipalities in the state of São Paulo: ARA = Araras, IRA = Iracemópolis, and GUA = Guaira. Observation: Averages followed by the same letter do not differ statistically from each other according to the Tukey test at 5% probability (n = 4).

2

EMISSION AND REMOVAL FACTORS FOR GRAINS



Grain production: strategies to mitigate GHG emissions and maintain crop productivity

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Brazil is one of the world's largest producers of grains. In the last 48 years, Brazil's production increased by 703%, without expanding its planted area by the same proportion (172%) (EMBRAPA, 2019). This continued growth is reflected in the record production estimate for the 2019/2020 harvest, which is expected to reach 251.9 million tons of grain. This estimate points to an increase of 9.9 million tons compared to the 2018/2019 harvest, which was 242.1 million tons (CONAB, 2019a; 2020). This strength is associated with increased efficiency in the use of agricultural inputs and land use, resulting in significant gains in productivity during the last ten years. Currently, average this vigor per area is 3.83 tons ha⁻¹. The planted area in 2018/2019 was 63.2 million hectares, signaling an increase of 2.4% when compared to 2017/2018 (CONAB, 2019a). Soybeans, corn, and rice were the most cultivated grains in the country in the 2018/2019 harvest (CONAB, 2019b).

The cultivation of flood-irrigated rice is economically relevant in the south of Brazil, specifically in the state of Rio Grande do Sul, with cultivated areas that exceed one million hectares all year. In 2018, the state's production represented about 80% of Brazil's total production (CONAB, 2019a). However, flooded soil intensifies methane (CH₄) emissions into the atmosphere.

CH₄ is a greenhouse gas (GHG) with high global warming potential (GWP) that has a heat absorption capacity (infrared radiation) 28 times higher (GWP AR5 of the IPCC) than carbon dioxide (CO₂). Rice cultivation can also produce nitrous oxide (N₂O). Its GWP is approximately 10 times greater (GWP AR5 of the IPCC) than the GWP of CH₄, but its emissions are lower in systems of soils saturated with water.

Methane emissions in flood-irrigated rice cultivation are caused by the anaerobic decomposition of the soil's organic matter, which generates gases, including methane. Rice plants that are adapted to flooded soils have an aerated tissue, the aerenchyma, which is the main route that gas fluxes take from the plant into the air. (AULAKH *et al.*, 2000). Residues left by rice cultivation alter the soil's organic redox reaction conditions, with different effects on atmospheric CH₄ and N₂O emissions. Organic material added to the soil can enhance CH₄ emissions, by making labile carbon (C) available for methanogenic microorganisms (KIM *et al.*, 2012, 2013). On the other hand, the suppression of irrigation water entering rice paddies can significantly mitigate CH₄ emissions. By suppressing irrigation and promoting the spread of oxygen into the soil, an environment favorable to the production of N₂O is created in the oxidation process from ammonium to nitrate (nitrification). N₂O is also created if the availability of O₂ is reduced again, in the denitrification process - when the final electron acceptor becomes nitrate and not oxygen anymore (ZOU *et al.*, 2007).

The Intergovernmental Panel on Climate Change (IPCC), through its methodological guidelines for preparing greenhouse gas emission inventories, has highlighted the different impacts of waste management and irrigation water practices. In Brazil, research has been mobilized to study and understand the possible effects of irrigation water management (continuous or intermittent, for example) and different agricultural waste management and planting systems, on GHG emissions and crop productivity.

In Brazil, soybeans occupy a prominent place in the national scenario of grain crops, as they account for 35.9% of all agricultural crops and 24.5% of the country's agricultural production (GASQUES, 2018). Because it is a legume, soy does not need nitrogen fertilization via synthetic fertilizers. Biological nitrogen fixation (BNF) is enough to provide for the plant's physiological needs and can supply between 72% and 94% of its required N (ALVES *et al.*, 2003; HUNGRIA *et al.*, 2005). Therefore, the N made available after the mineralization of soybean crop residues can be used, especially when succession systems with grasses are used (eg soybean/corn) (OLIVEIRA *et al.*, 2013).

The area destined for soy production in the country has been growing since 2004, always being above, of which 80% are located in the South and Midwest regions of Brazil (CONAB, 2017). Productivity has also been growing in recent years, going from 2,000 to 2,400 kg ha⁻¹, in the 2003/2004 to 2005/2006 harvests, to 3,385 kg ha⁻¹, in 2017/2018. Production, on the other hand, went from 49.8 million tons in the 2003/2004 harvest to 119 million tons in the 2017/2018 harvest, corresponding to an increase of 139% (EMBRAPA, 2018).

N₂O emissions in soybean cultivation are generally more associated with the decomposition of plant residues, especially in the final phase of the cycle in two situations: when leaf senescence occurs, and for legumes, in green manure in rotation with soybeans, which incorporate quantities of N to the soil (ALVES *et al.*, 2014). Currently, NBF is not considered as a source of N₂O emissions in the GHG National Inventory (IN), as there is no evidence that the emissions resulting from this biological process are significant for the overall amount of agricultural activity (IPCC, 2006; ALVES *et al.*, 2014; BRASIL, 2016).

On the other hand, Maize is the second most planted crop in the country, with an area of approximately 18.5 million hectares in the 2019/2020 harvest and a production of 102 million tons (first, second and third harvests) and productivity of 5.5 tonha⁻¹ (CONAB, 2020c). The use of nitrogen fertilizers has been instrumental in achieving high corn yields. For this reason, urea has been one of the most used sources of nitrogen for corn cultivation, despite being a source susceptible to large N losses due to ammonia volatilization, in addition to indirectly contributing to N₂O emissions (MOTA *et al.*, 2015).

Producers that have adopted the consortium of soybeans or second-harvest maize, in combination with crotalaria (legume) or brachiaria (forage grass), have reaped various benefits. In addition to the agronomic and environmental aspect that the vegetation cover represents for the soil, the benefits also include the decrease of nematodes and nutrient stock maximization. This consortium has also shown itself to be economically interesting, since, if well managed, it guarantees excellent grain and meat crop productivity (EMBRAPA, 2013). Currently, second-harvest maize represents almost 50% of Brazilian production, with a yield of 5.1 tons ha⁻¹, which is very similar to the average yield of second-harvest maize (CONAB, 2018).

According to the 3rd NI on GHG emissions in 2010, Brazilian CH₄ emissions from rice crops irrigated by continuous flooding were 455.3 Gg CH₄, representing 98.1% of total methane emissions (464.2 Gg CH₄) associated with culture. Emissions from rice grown in floodplains (subject to flooding) represented only 1.9% of total methane emissions. Due to the lack of more in-depth studies on rice production in different flood regimes and on other factors that interfere with CH₄ emissions, IPCC default factors (FEp) were used in the 3rd NI for the calculation of emissions, except for rice produced in Rio Grande do Sul, which had their own emission factors.

In the IPCC methodological guidelines (2006) for calculating CH₄ emissions from Tier 1 rice crops, a base default EF_p of 1.3 kg of CH₄ ha⁻¹ day⁻¹ was established (with an uncertainty interval of 0.80 -2.20) for fields that were unflooded for less than 180 days prior to rice cultivation and for fields continuously flooded during the rice-growing period without additions of organic C sources. For conditions related to the water regime, the guidelines provide a value of 0.78 for default EF_p and an uncertainty interval of 0.62-0.98 for water during the cultivation period (SFw), and a value of 1.22 with an uncertainty range of 1.07-1.40 for water before the cultivation period (SFp). There are also defined default EF_p for organic additions in rice cultivation.

N₂O emissions from the production of maize, soybeans, and rice are accounted for in the NI as direct emissions, both from crop residues that are incorporated into the soil and from the application of synthetic fertilizers in the production process. N₂O emissions associated with crop residues were 27.1Gg N₂O, corresponding to 6% of the total N₂O issued from agricultural soils in 2010. Direct N₂O emissions from synthetic fertilizers were slightly higher and represented 7.9% of the N₂O emissions. However, the 3rd NI still does not report N₂O emissions detailed per type of crop and EF_p is used to calculate emissions.

For the calculation of direct N₂O emissions from managed soils, which relate to the amount of N₂O emissions from applying synthetic and organic N to soils, including crop residues and soil organic C mineralization, the IPCC (2006) establishes the emission factor EF₁, which a value of 0.01, and an uncertainty range of 0.003-0.03. This value corresponds to a percentage of 1% of N applied to soils or released through activities that result in the mineralization of organic matter in mineral soils.

The contributions received in this compilation were mainly from results obtained for the production of soybeans, maize, and rice. Specifically, it is important to highlight the research results contributed by the AGROGASES and FLUXUS Projects, which studied the dynamics of greenhouse gases (CO₂, N₂O e CH₄) and the country's carbon balance in grain production systems in different biomes. We do know, however, that this compilation does not represent 100% of existing research on the topic. Nonetheless, these contributions reveal how much knowledge has advanced in management practices in the cultivation of soy, maize, and rice and in the identification of gaps that must be filled in order to enable the sustainability of these crops. On the other hand, despite the small number of contributions regarding grains for this compilation, there is a noteworthy institutional effort in researching rice cultivation, in topics related to the evaluation of management practices to mitigate N₂O and CH₄ emissions in irrigated rice production systems, especially in the state of Rio Grande do Sul.

In the following section, we will briefly describe some of the results from the studies covered in this chapter, which highlight the efforts made and achieved progress.

In order to verify the adequacy of the default EF_p being used in the country for estimating N₂O emissions from the application of nitrogen fertilizers and other N sources, Jantalia et al. (p. 80) performed the evaluation of N₂O fluxes over two years in different crop rotations (eg soybean/wheat, corn/wheat, soybean/vetch) in conventional tillage (CT) and no-tillage (NT) in an 18-year experiment carried out in Latosol, at a location close to the city of Passo Fundo-

RS. N₂O emissions were not influenced by the CT or crop rotation system. Although emissions measured for crop rotation treatments that received high rates of nitrogen fertilizer in the second year are significantly underestimated by the IPCC emission factor FE₁, for the other treatments, the emissions were within the FE₁ uncertainty range. However, such emissions always are considerably lower than the IPCC FE₁ estimate, suggesting that EF_p overestimates correct N₂O values found in the evaluated soil.

Camargo and Bayer (p. 77), who evaluated the mitigation potential of CH₄ and N₂O emissions in rice cultivated with intermittent irrigation in the state of Rio Grande do Sul, found that adopting intermittent systems of irrigation reduced CH₄ emissions, and that the process of soil drying out favored the processes responsible for the production of N₂O, regardless of the edaphoclimatic conditions, while, in the periods when the water covered the soil surface, in all treatments, locations, and crops, the values of N₂O emissions remained close to zero, or even negative. Seasonal emissions ranged from 117 to 745 kg CH₄ ha⁻¹, with an estimated regional average emission factor of 368 kg CH₄ ha⁻¹, which is 18% higher than the FE_p of 300 kg CH₄ ha⁻¹.

In a similar study carried out by Lima *et al.* (p. 84) in the cities of Pindamonhangaba-SP, Tremembé-SP, and Itajaí-SC, the generated emission factors were expressed in kg CH₄ ha⁻¹ d⁻¹, for the following management systems: I. Continuous and intermittent irrigation systems through a transplant system, in the harvests of 2002/2003, 2003/2004, 2004/2005 in Pindamonhangaba-SP; II. Continuous irrigation system through a transplant system in the 2005/2006 crop in Pindamonhangaba-SP; III. Continuous irrigation system in a pre-germinated system in the 2006/2007 and 2007/2008 harvests, in Itajaí-SC. The results showed that the intermittent irrigation system showed no significant difference in CH₄ emissions when compared to continuous irrigation, mainly due to climatic factors of annual occurrence (LIMA *et al.*, 2014). However, the different pattern of emissions between both treatments over the growth seasons points towards possible mitigation strategies. However, in the 2004/2005 harvest, there was a 37% reduction in emissions given the use of an intermittent management system. Lima *et al.* (2019) also observed that the pre-germinated system practiced in some areas of the country tends to generate high methane emission rates, but that sowing on dry soil, when the flooding period subsides, is an indicated mitigation measure for this type of system (LIMA *et al.*, 2007; EBERHARDT *et al.*, 2009).

Jantalia *et al.* 2008 (p. 80) evaluated the effect of fertilizing maize with pasted urea at a dose of 150 kg N ha⁻¹ in a conventional soil tillage system in the experimental area of Embrapa Tabuleiros Costeiros (Aracaju-SE), in soil classified as Red Dystrophic Yellow Argisols, and measured N₂O fluxes measured over two years. No relationship between N₂O fluxes and water-saturated porous space (% WSPS) or mineral N was observed. The emission factors (EF) for N₂O varied according to the accumulated precipitation in the agricultural year and remain above FE_p (<1%) in 2015 and below FE_p in 2016. These results point towards the need to continue fertilization studies with pasted urea and to increase the amount and frequency of gas flux assessments in other locations and sampling points.

Oliveira *et al.* (p. 86) measured N₂O fluxes and their interactive effects with rainfall seasonality and crop rotation in the Cerrado biome in a long-term experiment (19 years) in various agricultural systems: I. no-tillage with soybean-sorghum rotation (PDR1); II. no-tillage with maize-pigeon rotation (PDR2); III. conventional till with soybean without second-harvest corn. The native Cerrado (CE) vegetation was used as a reference. The study also observed the relationship between organic matter and N₂O emissions under different management systems. The results indicated that the no-tillage systems with crop rotation, when compared to the conventional planting system with soybeans and without rotation, contribute to mitigating N₂O emissions. The definition of a no-till system with mitigating potential depends on the species used in the rotation.

Carvalho *et al.* (p. 88) evaluated the effects of cover crops and nitrogen fertilizer on soil N_2O fluxes in corn cultivation under a no-tillage system in the Cerrado, at the experimental station of Embrapa Cerrados (Planaltina-DF), in the period between 01/11/2013 and 03/01/2016, in Red Latosol. The treatments were distributed into plots represented by six cover plants sown in succession to corn. The reference treatment was the native Cerrado vegetation. For all evaluated cover crops, adding N on the corn coverage resulted in higher accumulated N- N_2O emissions ($p < 0.005$), in both crop cycles. In treatments without N added to the cover, no significant difference of accumulated emissions of N- N_2O was observed between the cover plants and in both the corn cycles.

In a literature review, Madari *et al.* (p. 90) extracted patterns of direct N_2O emissions in soils from different Brazilian ecosystems. The findings were that N_2O from natural ecosystems exhibited a wide range of values. Average annual flux rates were the highest in the Amazon and Atlantic Forest rainforests (respectively 2.42 and 0.88 kg N- N_2O ha⁻¹) while emissions from Cerrado soils were close to zero. Pasture emissions decreased the more time passed after conversion, and this was associated to pasture degradation. In cultivated areas, relatively low fluxes of N_2O -N (-0.07 to 4.26 kg N- N_2O ha⁻¹ year⁻¹, mean 0.80 kg N- N_2O ha⁻¹ year⁻¹) were reported along with low responses to fertilization.

Campaign *et al.* (p. 100) evaluated the effect of the management system, with and without nitrogen fertilization, on N_2O emissions and the nitrous oxide emission factors in Latosol with maize cultivated under rainfed in the Cerrado region. The study was carried out over the course of one year (2014–2015), and studied monoculture maize plantations under conventional tillage (CT) and no-tillage (NT), with (1) and without (0) application of nitrogen fertilizer (0 and 257 kg N ha⁻¹), at Embrapa Milho and Sorghum in Sete Lagoas-MG. In conventional tillage (CT), residues were incorporated with a heavy harrow, followed by a leveling harrow, and for no-tillage (NT), the soil was not overturned over the straw. The results revealed that under nitrogen fertilization, the no-tillage system (NT1) emitted 30% less N_2O than the conventional cultivation system (CT1), during the period in which the crop was in the field. The emission factors were 0.96% for the conventional planting system (CT1) and 0.79% for the no-tillage system (NT1), which is lower, although within the range of uncertainty, as suggested by the IPCC standard of 1% (0.3 to 3%).

Marchão *et al.* (p. 88) quantified carbon stocks and GHG emissions in maize/brachiaria systems in the Cerrado biome. The studies were carried out primarily through long-term experiments. The stocks of C and N in the soil and straw/soil coverage were characterized. N_2O soil fluxes and edaphoclimatic variables were surveyed (for example, biomass, mineral nitrogen, gravimetric water content, soil and air temperature, rainfall, among others). The soil organic matter was evaluated in relation to quantity and quality. The data on chemical and microbiological attributes of the soil and organic matter were related to N_2O emissions, in order to understand the relationship between these factors, taking into account soil management. The findings pointed towards a crop-livestock integration that issues less N_2O compared to crops in a conventional tillage system, due to forage grasses, which developed the full potential of their root system (by deepening their roots in the soil and depositing organic matter that is more difficult to be degraded), with an important physical effect on the soil, protecting and stabilizing the soil's organic matter, and mitigating emissions.

Over the course of four agricultural harvests (2013/2014 to 2016/2017), Scivittaro *et al.* (p. 97) evaluated the GHG emissions associated with the use of increased efficiency nitrogen fertilizers in the cultivation of irrigated rice and compared it to traditional soluble fertilizer (urea), in order to establish ammonia (NH_3) and N_2O emission factors from different sources of nitrogen,

at Embrapa Clima Temperado, in Pelotas-RS. According to the findings, sources of soluble or increased efficiency nitrogen fertilization optimizes the agronomic and productive performance of irrigated rice crops. CH₄ contributes more than 90% to the partial global warming potential of irrigated rice, regardless of the nitrogen fertilization source. Volatilization of NH₃ is a minor source of N loss for irrigated rice. The N₂O emissions are the main route for the loss of nitrogen in irrigated rice cultivation. All nitrogen sources evaluated presented an N₂O emission factor that was higher than the IPCC reference value of 1%.

Gonzatto *et al.* (p. 68) evaluated N lost to the atmosphere by NH₃ volatilization and by N₂O emissions after the application of liquid pig manure (LSM) in maize, with and without the presence of black oat crop residues (*Avena strigosa* Schreb.) on the soil surface. The study was carried out in the field, on arsenic Red Dystrophic Agrisol, at the experimental area from the Irrigation and Drainage sector, at the Federal University of Santa Maria (UFSM). The results are related solely to N₂O emission rates, which were evaluated for 90 days between January and April 2011, in four treatments: T1 - Soil (Control); T2 - Soil + LSM (LSM); T3 - Soil + Black Oat Straw (Straw); T4 - Soil + Straw + LSM (Straw + LSM). To evaluate NH₃ volatilization, only the "Straw", "LSM" and "Straw + LSM" treatments were used. The main results highlighted in the study were that N-N₂O emissions increased right after the application of SLM, mainly when they were applied on black oat crop residues. The highest peaks of N₂O emissions occurred after irrigation and/or rainfall.

The EFs determined in national studies that are summarized in these contributions show the importance of deepening and expanding the time horizon and scope of research, in order to validate currently obtained results and to improve these values through tests in different management scenarios, environmental conditions, and regions of the country. For N₂O emissions, most EF values were reported within the FE1 uncertainty range (0.3%-3%), but most values were less than 1%. This suggests that using default EF may be an overestimation of national estimates of direct N₂O emissions for the cultivation of grains in Brazil.

According to the authors who contributed to this compilation, the challenges for doing research range from financial challenges, related to the availability of more resources to continue and extend the period of evaluations in different locations and sampling points, to specific research aspects, related to practical combinations and management inputs, and qualified human resources for the collection and analysis of gas samples.

Regarding rice cultivation, more financial resources would allow researchers to monitor seasonal CH₄ in irrigated rice areas for longer periods of time, which would enable them to evaluate different growing seasons, different possibilities for water management, and rice varieties, taken also in consideration various various cultivation systems' responses to climatic conditions.

The compilation of EFs of this chapter and the comparison with default EF, show how important is the definition of local EFs are, and also emphasize the need to carry out more GHG emission studies in different grain crops. The definition of EFs for tropical conditions enables more accurate estimates of emissions from grain cultivation to be reported in the NI and is a more adequate reflection of Brazilian efforts for more sustainable production.

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THE POTENTIAL OF INTERMITTENT IRRIGATION TO MITIGATE THE EMISSION OF CH₄ AND N₂O IN RICE FIELDS IN THE STATE OF RIO GRANDE DO SUL

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The state of Rio Grande do Sul (RS), in southern Brazil, concentrates 80% of the country's irrigated rice production area (CONAB, 2015), although rice fields potentially issue CH₄, given that its cultivation occurs predominantly under flooded systems. In then Brazilian inventory for CH₄ in irrigated rice cultivation has an emission factor of 300 kg CH₄ ha⁻¹, a value that is based on international indexes. However, it is important to take into consideration the regional representation of soil and climate in order to establish reliable estimates.

Another important aspect of greenhouse gas emissions in irrigated rice fields is the identification and quantification of the emission mitigation potential of agricultural practices. At the international level, the use of intermittent irrigation systems stands out as one of the most efficient practices in the mitigation of CH₄ emissions in soils cultivated with irrigated rice (TOWPRAYOON *et al.*, 2005; TYAGI *et al.*, 2010; ITOH *et al.*, 2011; KIM *et al.*, 2014). This occurs due to changes in soil properties, especially those related to the reduction of moisture and the level of oxygen in the soil, which is caused by a potential increase in redox and the differentiation of microbial activity. In in the state of RS in Brazil, information related to the management of CH₄ e N₂O in irrigation water is still scarce, especially in different edaphoclimatic conditions.

Although the emission potential of CH₄ has been reduced by 45 to 90% in intermittent irrigation systems compared to continuous irrigation systems (ITOH *et al.*, 2011; ZHANG *et al.*, 2012; HOU *et al.*, 2012; IRR1, 2015), an increase in N₂O been observed simultaneously. However, even when taking the respective warming potential of these gases (expressed by CO₂eq) into consideration, the reductions in CH₄ emissions have still been greater than the increase in N₂O emissions.

Given this context, this study aimed to assess the potential of intermittent irrigation systems in the mitigation of CH₄ and N₂O emissions in different soils from various locations in RS, considering different soil and climate conditions; as well as to determine a regional CH₄ emission factor for rice production systems

under continuous irrigation in RS, taking these different conditions into consideration. This study was conducted during two harvests (2011/2012 and 2012/2013) in five municipalities from the state's rice-producing region.

Three irrigation water management treatments were evaluated at each location and type of cultivation: I. continuous flooding irrigation (permanent water throughout the growing period); II. moderate intermittent (flood irrigation with a suppression period from stage V6 to V8); and III. severe intermittent irrigation system (flood irrigation with a suppression period from stage V6 to V8 and from V8 to V10). Air samples were collected according to the closed static chamber method (MOSIER, 1989) during the rice harvest in RS.

The concentrations of CH₄ and N₂O in the air samples were determined through gas chromatography, and the emissions were presumed as equivalent to the daily average emissions calculated from the integration of the accumulated daily emission fluxes of CH₄ and N₂O from the soil (GOMES *et al.*, 2009). The partial global heating potential (GHPp) was calculated by converting the CH₄ e and N₂O emissions to their2 equivalent (kg CO₂eq ha⁻¹) and then adding both of the values. The GHPp index was also calculated according to a yield scale, where the GHPp ratio was considered per unit of rice grains produced.

PRELIMINARY RESULTS

- CH₄ emissions were reduced by adopting intermittent irrigation systems instead of continuous irrigation cultivation systems;
- The process of soil drying out favored the processes responsible for the production of N₂O regardless of the edaphoclimatic conditions, while during the periods where the water irrigation depth was maintained, in all treatments, locations, and cultivations, N₂O emissions remained close to zero, or even negative;

- Differences in GHPp were verified according to the adopted irrigation system, in both the evaluated harvests;
- The GHPp was higher in all locations that adopted continuous irrigation in relation to treatments that adopted intermittent irrigation periods;
- Severe intermittent treatment was more efficient in mitigating GHPp, given lower CH₄ emissions per kilogram of grains produced, in relation to the continuous irrigation treatment;
- GHPp can be reduced by up to 50% through adopting intermittent irrigation systems, without decreasing crop productivity. This is because rice yields were not significantly different between irrigation systems. The GHPp per rice grain yield for intermittent irrigation treatments reduced this index (GHPp / yield.) by 45%, in relation to continuous irrigation. This decrease is probably due to the adoption of intermittent irrigation systems, that do not affect rice productivity and at the same time, lower CH₄ emissions, and consequently, the GHPp during the growing season. In other words, the lowest CH₄ emission per kilogram of grain produced was achieved in intermittent irrigation systems, when compared to continuous irrigation;
- Seasonal emissions verified in different locations in RS showed variations that ranged from 117 a 745 kg CH₄ ha⁻¹, with an estimated average regional emission factor of 368 kg CH₄ ha⁻¹ (Table), which is 18% higher than the IPCC emission factor (200 kg CH₄ ha⁻¹);
- This data is relevant given the fact that national GHG emission inventories for the cultivation of irrigated rice adopt emission factors based on international indexes, due to the lack of research data available in Brazil. The IPCC emission factor used for these agroecosystems is 20 g m⁻² (200 kg CH₄ ha⁻¹). Considering the average addition of organic waste 1-2 t ha⁻¹, the emission factor reaches 300kg CH₄ha⁻¹, after the application of a scale factor of 1.5 (EMBRAPA, 2010);
- Given the emission factors and the area of irrigated rice production in the years of evaluation of this study, and after extrapolating this index for the whole state, the CH₄ emission value for irrigated rice crops in Rio Grande do Sul was defined at 0.35 Tg CH₄ harvest⁻¹.

CHALLENGES

- Efficient research projects aiming to cover extensive geographic spaces that encompass different locations require a network of partners and supporters. Therefore, this research project was only possible through the commitment and partnership of funding agencies, research institutions, experimental stations, graduate programs, researchers, and students who were involved and who made it possible for these results to be achieved.

SOLUTIONS

- The adoption of intermittent irrigation is an efficient strategy to reduce the GHPp for irrigated rice production systems in Rio Grande do Sul, regardless of soil and climate conditions;
- Intermittent irrigation systems in irrigated rice fields in southern Brazil have the capacity to sustain rice crop productivity levels and to reduce the GHPp / Yield index;
- The effect of intermittent irrigation in irrigated rice production systems on reducing CH₄ emissions is greater than its effect on the increase of N₂O emissions;
- Different edaphoclimatic conditions cause differences in CH₄ emissions in irrigated rice crops and, consequently, on their emission factors.

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Continuação no Anexo

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Table 1: Regional emission factors for CH₄ in rice production systems in different locations in Rio Grande do Sul

Locais	Ano	Fatores de Emissão (FE) kg CH ₄ ha ⁻¹	Média	Fonte
Uruguaiana	2011/2012	486##	615	Este estudo
	2012/2013	745##		
Cachoeirinha	2002/2003	490#	486	Bayer et al. (2014)
	2003/2004	590#		
	2007/2008	262##		
	2009/2010	520##		Este estudo
	2011/2012	431##		
	2012/2013	623##		
Pelotas	2009/2010	117#	135	Wesz (2012)
	2010/2011	159#		Buss (2012)
	2011/2012	128#		Este estudo
	2012/2013	138##		
Restinga Seca	2012/2013	465##	465	Este estudo
Camaquã	2012/2013	127##	127	Este estudo
Santa Maria	2007/2008	423#	381	Moterle et al. (2013)
	2009/2010	340##		
Média Regional (FE)			368	
IPCC (FE) ###			300	

Source: Authors.

Caption: # Assessments under conventional tillage; ## Assessments under minimum soil tillage; ### 200 kg ha⁻¹ + 50% for additions of 1-2 t ha⁻¹ of dry matter (MCT, 2010).

FLUXES OF NITROUS OXIDE FROM THE SOIL UNDER DIFFERENT CROP ROTATION AND SOIL TILLAGE SYSTEMS IN SOUTHERN BRAZIL

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Tropical and subtropical regions compose 51% of the world's agricultural area. The use of nitrogen fertilizers to sustain increased food production is expected, however it is also responsible for most of the world's emissions of gases such as nitrous oxide (N₂O). In Brazil, as in other countries in this region, the amount of information on N₂O emission factors that come from N doses and sources in agricultural systems under crop rotation with conventional tillage and no-tillage is still scarce, pointing towards the need for more studies in this area that take into consideration different agricultural production systems. The no-till system (NT) is a soil management system that can contribute to C sequestration, but studies in other countries have registered higher nitrous oxide emissions under NT when compared to conventional tillage (CT), which could reduce its greenhouse gas mitigating benefits.

The objective of this study was to estimate the nitrous oxide emission factor from cultivation systems under NT and CT, in an 18-year experiment, carried out in Latosol in an experimental area of Embrapa Trigo, located near the city of Passo Fundo-RS. N₂O fluxes were measured over two years using static chambers validated according to protocols from the Agricultural Research Service (ARS-USDA) group. Evaluations were made concomitantly in both planting systems with three crop rotations. The rotation treatments evaluated were: I. soy-soy;

II. wheat-soy; and III. vetch-corn. The study monitored the soil's water-saturated porous space (% WSPS) and the mineral N, along with precipitation and air temperature. Estimates of N₂O emissions were obtained by integrating fluxes with time and by applying the direct IPCC emission factor (EF1 = 1%) for N quantities added as fertilizers and returned as crop residues.

PRELIMINARY RESULTS

In this study, data were obtained that determined the emission factors for the grain regions of the south of the country, both for fertilizers and for other sources of N, such as green manures. The purpose was to verify the adequacy of IPCC proposed factors that are being used in inventories in the country.

N₂O fluxes were relatively low, with higher emissions during a short period, when the first crop measurements were being taken (Table);

- No relationship between N₂O fluxes and % WSPS or mineral N was observed;
- N₂O emissions were not influenced by the no-tillage system or crop rotation;
- In the crop rotation that received high levels of nitrogen fertilizer in the second year, the N₂O emissions measured in the field were significantly underestimated by the IPCC emission factor EF1;
- For the other treatments, N₂O emissions were within the EF1 uncertainty range, but always considerably lower than the IPCC EF1 estimate, suggesting that using the IPCC emission factor would be an overestimation of the correct amount of N₂O emissions in the assessed soil.

CHALLENGES

- Developing a chamber that enabled the adequate collection of the samples was a challenge, along with sending the samples from Rio Grande do Sul to the laboratory in Rio de Janeiro;
- Developing an N₂O chromatographic analysis protocol, which aimed both to establish the columns and use of more appropriate standards for determinations in N₂O concentrations in parts per billion (ppb) was another challenge. An effort was made to reduce the analysis time from 20 minutes to 3 minutes, in order to optimize the laboratory sample processing time.

SOLUTIONS

- The no-tillage system under wheat-soybean succession or under crop rotations in the conditions of the Southern Region of Brazil did not demonstrate any increase of nitrous oxide emission potential in relation to conventional tillage, contrary to observations made in other countries with

temperate climate conditions. The observations made in this study did not confirm claims made based on theoretical models, which state that in higher temperatures, such as under Brazilian conditions, nitrous oxide emissions would increase under no-tillage;

- The study also sought to evaluate how the edaphoclimatic variables, including soil's hydraulic properties under different management systems, are related to the processes that originate N₂O fluxes into the atmosphere under Brazilian subtropical conditions.

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JANTALIA, C. P.; DOS SANTOS, H. P.; URQUYAGA, S.; BODDEY, R. M.; ALVES, B. J. R. Fluxes of nitrous oxide from soil under different crop rotations and tillage systems in the south of Brasil. *Nutrient Cycling in Agroecosystems*, v, 82, p. 161-173, 2008.

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Table 1: N₂O emissions obtained from field measurements and estimates using IPCC factors (EF1 = direct emissions from the soil) of 1.25%-1%, applied to the total nitrogen fertilizer added by crops. Amount of N derived from biological N fixation and N amounts in crop residues after harvest (Nrcc), in three different crop rotations (R1, R2A and R2B) under no-tillage (NT) and conventional tillage (CT), for two consecutive years.

Período avaliado Rotações de cultura	Dados de campo (% IPCC total)	IPCC (EF1 = 1.25%; incertezas de 20% até 180% do valor calculado)			
		Fertilizantes	Nrcc	N no residuo	Total
		kg N-N ₂ O ha ⁻¹ ano ⁻¹			
Inverno					
2003					
R1 PD (Soja-trigo)	0.67 (16)	0.56	2.63	0.93	4.12
R1 PC	0.94 (24)	0.56	2.50	0.89	3.95
R2A PD (Soja-ervilhaca)	0.76 (12)	0	3.82	2.44	6.26
R2A PC	0.69 (13)	0	3.24	2.14	5.38
R2B PD (Milho-trigo)	0.67 (33)	0.56	0	1.46	2.02
R2B PC	0.98 (56)	0.56	0	1.20	1.76
2004					
R1 PD (Soja-trigo)	0.60 (21)	0.56	1.32	1.02	2.90
R1 PC	0.69 (23)	0.56	1.34	1.09	2.99
R2A PD (Soja-ervilhaca)	0.61 (19)	1.30	0	1.85	3.15
R2A PC	0.72 (23)	1.30	0	1.85	3.15
R2B PD (Milho-trigo)	0.74 (22)	0	2.25	1.18	3.43
R2B PC	0.62 (22)	0	1.85	0.98	2.83

Source: Authors.

NITROUS OXIDE FLOWS DERIVED FROM PASTED UREA FERTILIZATION IN THE PRODUCTION OF CORN GROWN IN A CONVENTIONAL TILLAGE SYSTEM IN THE STATE OF SERGIPE

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In most Brazilian soils, the natural availability of nitrogen is insufficient to guarantee high yields. This makes fertilizer additives of N in adequate quantities crucial to ensure the growth, development, and production of corn. In the state of Sergipe, the erratic distribution of rainfall during the grain production period, which takes place from April to September, is an additional challenge. This happens mainly because, in addition to edaphoclimatic conditions, corn is a crop that demands high amounts of nitrogen. When not adequately supplied, this nutrient (along with water supply) is the most limiting factor for production. In Brazilian agriculture, urea is the most utilized source of nitrogen, followed by ammonium sulfate. The advantage of urea is its high concentration of N ($\pm 45\%$), which reduces transportation and application costs. On the other hand, its potential for gaseous losses of N is equally high. In this sense, there is a lack of studies on the application of urea as a source of nitrogen and its impacts on the environmental losses of N in the region that includes the states of Sergipe (SE), Alagoas (AL) and Bahia (BA) (the three acronyms combined: SEALBA).

The aim of this study was to estimate the emission factor of nitrous oxide (N_2O) from the fertilization of pasted urea at a dose of 150 kg of N per hectare in corn production grown in a conventional tillage system, at the experimental area of Embrapa Tabuleiros Costeiros, located near the city of Nossa Senhora das Dores-SE. The soil in the area was classified as Dystrophic Red-Yellow Argisol.

N_2O fluxes were measured over two years using static chambers validated according to protocols from the Agricultural Research Service (ARS-USDA) group.

The evaluations were concomitant in an area with and without pasted urea application (44.9% N) at a dose of 150 kg of N per hectare. The study monitored the soil's water-saturated porous space (% WSPS) and the mineral N, along with precipitation and air temperature. N_2O emission estimates were obtained by integrating fluxes over time and also by directly applying the IPCC emission factor ($EF1 = 1\%$) for N amounts added as fertilizers.

PRELIMINARY RESULTS

- No relationship between N_2O fluxes and % WSPS or mineral N was observed;
- The emission factors (FE) for N_2O changed according to the accumulated rainfall in the agricultural year and remain above the IPCC indexes 2015, while in 2016, the N_2O indexes were below ($< 1\%$) (Table).

CHALLENGES

- Disponibilidade de recursos financeiros para a continuidade e a ampliação das avaliações em maior quantidade de locais e pontos de amostragens;
- Disponibilidade de recursos humanos treinados para a coleta de campo.

SOLUTIONS

- Improving new technologies on nitrogen sources based on urea is essential to improve the efficiency of the use of N and to reduce losses through gas, mainly in areas with hot climates and with potential for grain production, such as the region within the states of Sergipe (SE), Alagoas (AL) and Bahia (BA) (SEALBA). This is a way to improve knowledge and decision-making and can contribute to the development of this new Brazilian agricultural frontier and its economy.

DATA PUBLISHED IN:

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Table 1: Cumulative N₂O emissions and pasted urea (PU) emission factors applied at a dose of 150 kg ha⁻¹ of N as coverage and in a control area without N application in corn crops

Year	2015			2016		
	N ₂ O-N loses (g N ₂ O-N ha ⁻¹)		EF (%)	N ₂ O-N loses (g N ₂ O-N ha ⁻¹)		EF (%)
Treatment	N ₂ O-N accumulated	N ₂ O-N fertilizer		N ₂ O-N accumulated	N ₂ O-N fertilizer	
UP	2433 a	2293	1.53	861 a	701	0.47
Control	140 b	-	-	160 b	-	-

Source: Authors.

EVALUATION OF METHANE EMISSIONS IN FLOOD IRRIGATED RICE CULTIVATION

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Flood irrigated rice cultivation produces methane (CH₄), an important greenhouse gas that has a strong influence on the photochemistry of the atmosphere. CH₄ has a global warming potential 28 times greater than carbon dioxide (CO₂), spanning a time horizon of 100 years (MYHRE *et al.*, 2013). The methane emissions from flood irrigated rice cultivation in Brazil (BRASIL, 2016) were estimated at 8.3 Tg CH₄ in 2014.

Rice cultivation represents 2.38% of the total planted area of the country. The total area of planted rice in the country was estimated at 1.88 million hectares in 2018 (IBGE, 2019), with average national productivity at 6.28 tons / ha, with Rio Grande do Sul being the largest producing state, responsible for 71.6% of total production in 2018, followed by the state of Santa Catarina.

Much of the flood-irrigated rice cultivation uses continuous water management. Local studies that measure CH₄ in irrigated rice cultivation in different climatic regions and distinct soils is essential to improve national and global greenhouse gas emission estimates, as well as to support the development of emission factors and the evaluation of simulation models based on biogeochemical processes.

The general objective of this project was to estimate methane emission rates in irrigated rice fields, under different soil, water management, and climate conditions, as well as to evaluate the influence of environmental variables and irrigated rice production systems in the south and southeast of the country.

The method used to measure methane emission was the static chamber (IAEA, 1992), which consists of using aluminum chambers, with a temperature indicator device and internal fans. Methane collections were performed once or twice a week, using 60 ml syringes, and then analyzed using gas chromatography, equipped with a flame ionization detector (FID). The areas studied are located: I. at the Experimental Station of the São Paulo Agribusiness Technologies Agency – APTA Regional Polo of Vale do Paraíba, in Pindamonhangaba-SP; II. at the Instituto Rio Grandense de Arroz (IRGA), in the municipality of Cachoeirinha-RS (harvests 2003/2004 and 2004/2005); and III. at Epagri Experimental Station, in Itajaí-SC (2006/2007 and 2007/2008 harvests), all that have meteorological stations.

An experiment was also carried out at a farm in the municipality of Tremembé-SP, during the 2008/2009 harvest. The data corresponding to the temperature from the air, water, and soil, along with the soil's pH and Eh were taken on the same day of methane collection, in addition to the plant height and irrigated water depth measurements. The seasonal methane fluxes were calculated in Excel spreadsheets, using the average temperature data from inside the box, the height of the chamber, and methane concentrations, in ppm. The accumulated emissions were the calculation basis for the emission factors of each growing season, and were expressed in CH₄ ha⁻¹ d⁻¹.

The CH₄ emission factor results that are presented in the Table refer only to the experiments carried out in Vale do Paraíba-SP and in Itajaí-SC. CH₄ emission factor data were generated for: I. continuous and intermittent with transplanting irrigation systems, in the 2002/2003, 2003/2004 and 2004/2005 harvests, in Pindamonhangaba-SP; II. continuous irrigation system in a transplant system in the 2005/2006 harvest, in Pindamonhangaba-SP; and III. continuous irrigation system in a pre-germinated system in the 2006/2007 and 2007/2008 harvest, in Itajaí-SC.

Other experiments were carried out between 2010 and 2017, and are in the process of being published, including a study on the measurement of methane emissions in a pre-germinated system in the 2008/2009 harvest at Fazenda Regina, in Tremembé-SP, and another in a pre-germinated system in the 2010/2011 harvest, in Pindamonhangaba-SP. The data are contained in a work submitted to and approved by *Ciência Rural* magazine, to be published in 2019 or 2020.

PRELIMINARY RESULTS

- Seasonal fluxes of methane were obtained, in g CH₄ m⁻² per growing season, from which emission factors were calculated (Table), expressed in kg CH₄ ha⁻¹ d⁻¹ for flood irrigated rice cultivation under a continuous and intermittent irrigation system, in Pindamonhangaba-SP, and under a pre-germinated system in Itajaí-SC, in Pindamonhangaba-SP and in Tremembé-SP.

CHALLENGES

- We highlight the need to monitor seasonal flows of methane in irrigated rice areas for a longer period, evaluating various growing seasons, soil tillage systems, different water management possibilities, rice varieties, considering the different responses of farming systems to climatic conditions;
- Experiments accounting for N₂O fluxes have been carried out by the team in recent years, providing a more complete assessment of the balance of greenhouse gas emissions in irrigated rice production systems, and consequently, improving the calculation of the global warming potential (GWP) for each system.

SOLUTIONS

- Regarding water management in a transplanted system: the intermittent irrigation system showed no average difference in emissions of CH₄, in relation to continuous irrigation on the studied crops, although each treatment portrayed different emission patterns, pointing towards possible mitigation strategies.
- For the pre-germinated system, we recommend avoiding prolonged flooding in the production of irrigated rice, along with the recommendation of using rice varieties with a lower CH₄ emission potential. Sowing on dry soil, that reduces the flooding period, is an indicated mitigation measure.

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CARBON BALANCE AND GREENHOUSE GAS DYNAMICS IN SOY / CORN, SOY / SORGHUM, SOY / MILLET IN THE CERRADO BIOME

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Study 1. In its natural state, the Cerrado biome is a mitigator of nitrous oxide (N₂O) emissions. However, as this biome becomes integrated with agricultural activities, changes in nitrogen (N) dynamics are induced, consequently increasing N₂O emissions into the atmosphere. Thus, yearly N₂O fluxes and their interactive effects with rainfall seasonality and cultural rotation were measured in a long-term experiment (19 years). The agricultural systems were (Figure): I. no-tillage with soy-sorghum rotation (PDR1); II. no-tillage with pigeon pea rotation (PDR2); and III. conventional tillage in soybeans without interim harvest (PC) and as a reference to the native vegetation of the Cerrado (CE). The average fluxes ranged from zero to 266 mg m⁻² h⁻¹. The accumulated values for the annual period for PC, PDR1 and PDR2 were: 1.36; 1.00; and 0.70 kg N₂O ha⁻¹, respectively. For CE, the annual accumulated values were 0.27 kg N₂O ha⁻¹.

Study 2. The relationship between organic matter and N₂O emissions under different management systems were evaluated. Study objects were: I. C and N pools and the labile and stable fractions of organic matter; II. accumulated emissions; and III. The relationship between fractions of organic matter and N₂O emissions. The agricultural systems were: I. no-tillage with soy-sorghum rotation (PDR1); II. no-tillage with pigeon pea rotation (PDR2); and III. conventional tillage for soy without interim harvest (PC) and as reference to the native vegetation of the Cerrado (CE). After 18 years, the carbon stock for PC in the 0-20 cm layer, was reduced by 0.64 ha⁻¹ year⁻¹. No-tillage systems were more efficient at accumulating carbon in labile and stable fractions and were related directly with low N₂O emissions in the ground. The cumulative pattern of N₂O was inversed for the following organic matter fractions: carbon from microbial biomass; oxidizable carbon in permanganate; particulate organic carbon; inert carbon; and humic substances. Based on the analysis of the main components, PC was separated from the other systems. This separation can be influenced by the low content of C in the different fractions of organic matter and high N₂O emissions in PC.

PRELIMINARY RESULTS

The objective of the study was not to obtain emission factors; however, this research generated the following results presented below:

- The results indicate that the Cerrado (native vegetation), under natural conditions, is conservative with regard to the N cycle (biomass has a high C: N ratio and, consequently, decomposes slowly, with the predominant form of mineral N being ammonium).
- N₂O emissions tend to increase in the wetting and rewetting cycles (Birch effect), which occur throughout the growing season;
- In the agroecosystems studied, the accumulated N₂O emissions were influenced by rainfall seasonality (dry and rainy season), by the management system, by crop rotation, as well as by the interaction of edaphoclimatic factors;
- No-tillage systems with crop rotation, when compared to conventional soybean and no-tillage systems, contribute to N₂O emissions mitigation. The definition of a no-till system with mitigating potential depends on the species used in rotation. In this case, pigeon pea rotation was more efficient, with lower emission peaks, compared to soy- sorghum;
- Results from long-term experiments indicate that there are short and long term results that work on N₂O emissions in synergy. From this perspective, soil organic matter is a key factor that helps elucidate the effects of different systems cultivated in the long term;
- In comparison with the Cerrado, C levels were lower in conventional tillage, indicated by the labile fractions of organic matter and the C content of macro and micro aggregates. The decrease in C in the no-tillage system was correlated with N₂O emissions;

- Agroecosystems altered the stocks of C and N and the accumulation of C in different fractions of soil organic matter (SOM). In relation to the native Cerrado, the greatest reductions in C levels were promoted by the conventional system of land use, verified mainly in the most labile fractions of SOM and in the soil aggregates. In addition, land use under a conventional system in the Cerrado also promoted higher soil N₂O emissions. Systems under no-tillage showed closer C accumulation and N₂O emission values that were closer to those of the native area, representing an important strategy for soil management in tropical regions. The results of this study indicate that soil management systems that increase C in a balanced way between labile and stable fractions, in addition to protection mechanisms of C in aggregates, present low N₂O emissions from the soil.

CHALLENGES

- Several demands for information were brought to light upon defining the scope of this project, such as chemical and biological indicators needed to complement the research, but it was not possible to insert them. The nature of the data was another important aspect; in tropical conditions, important variations were observed in some studies, and sometimes the evaluated factors could not be disaggregated. Most of the long-term experiments did not allow us to obtain the emission factors, since such studies were not designed for this purpose.

SOLUTIONS

- From this research, it was identified that the Cerrado, in its natural form, is conservative in terms of nitrogen, and practically has zero emissions;
- Nitrous oxide emissions are present in every agricultural system, however, the no-tillage with rotation system is better than conventional tillage without rotation. The fallow period in the conventional system can account for up to 75% of emissions;
- The intensity of emissions per product in conventional tillage without rotation was 1.5 and 6.4 times higher when compared to no-tillage

systems in soy-sorghum and pigeon pea (with rotation), respectively. These results reinforce the importance of adopting no-tillage with rotation for grain production, improving the system and intensive soil use in the Cerrado;

- New perspectives: I. quantifying important losses, such as ammonia volatilization, which, although it is not a greenhouse gas, represents a significant loss of N in the system; II. improving management techniques that use the soil more intensively, but with principles of good practices and sustainability; and III. encouraging the continuity of greenhouse gas measurements in representative systems associated with adaptation and climate vulnerability actions.

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CARBON BALANCE AND GREENHOUSE GAS DYNAMICS IN CORN SYSTEMS / COVER PLANTS IN THE CERRADO BIOME

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N₂O is the most relevant greenhouse gas (GHG) in the agricultural sector, since 70% of its emissions originate from nitrogen (N) dynamics, including N from the mineralization of biological fixation of nitrogen (BFN). The concentration of N, as well as the chemical composition of plant residues, are factors that determine the mineralization or immobilization of this nutrient in the soil. The use of cover crops in association with annual crops is a strategy that should be taken into consideration, due to the increase of N levels in the soil, as well as the partial substitution of N-fertilizer in the corn crop from BFN. This process results in a gradual release of N and the reduction of N₂O emissions depending on the production and chemical composition of the biomass of these plants (CARVALHO *et al.*, 2016).

The objective of this study was to evaluate the effects of cover crops and nitrogen fertilizer on nitrous oxide fluxes (N₂O) of the soil with corn cultivation under a no-tillage system in the Cerrado. The experiment was conducted at the Embrapa Cerrados experimental station (Planaltina-DF), in the period between 11/01/2013 and 01/03/2016, in Red Latosol. The treatments were distributed in plots represented by the following cover crops (Figure) sown in succession to corn: brachiaria ruziziensis (*Urochloa ruziziensis*); feijão-bravo-do ceará (*Canavalia brasiliensis*); millet (*Pennisetum glaucum*); pigeon pea 'BRS Mandarin' [*Cajanus cajan* (L.) Millsp.]; sunn hemp (*Crotalaria juncea* L.); black mucuna (*Mucuna atterima* Merr.); and fodder radish (*Raphanus sativus* L.). The reference treatment was the native Cerrado vegetation. For all evaluated cover crops, the addition of N in the cover of the corn crop resulted in higher accumulated N-N₂O ($p < 0.005$) emissions, in both studied crop cycles. In the treatments without the addition of N in the cover crops, there were no significant differences between cover plants in relation to the accumulated emissions of N-N₂O, for both of the corn cycles. However, in the first evaluated cycle with the application of N in the cover, the soil cultivated with corn in succession to brachiaria ruziziensis (1.20 kg N-N₂O ha⁻¹) and feijão-bravo-do-ceará bean (0.86 kg N-N₂O ha⁻¹) resulted in higher accumulated emissions of N-N₂O, at about 42.5 and 19.8%, respectively, when compared to millet (0.69 kg N-N₂O ha⁻¹) (VERAS *et al.*, 2016). In the second period, during the 199 evaluation days after harvest of corn, the soil cultivated with wild beans from ceará and brachiaria ruziziensis showed significant differences ($p <$

0.05) between treatments with (1.16 kg N-N₂O ha⁻¹ and 1.00 kg N-N₂O ha⁻¹, respectively) and without (0.63 kg N-N₂O ha⁻¹ and 0.24 kg N-N₂O ha⁻¹, respectively). On the other hand, millet presented the lowest emissions of 0.36 kg N-N₂O ha⁻¹ when evaluated on the soil that had corn cultivated with N coverage and 0.60 kg N-N₂O ha⁻¹ on the soil where the corn was cultivated without nitrogen fertilization on the cover, with no significant differences between emissions with and without N applied to the cover ($p < 0.05$). In the second evaluation cycle of corn in succession to other cover crops treated with nitrogen application, both black velvet bean (118.49 $\mu\text{g N-N}_2\text{O m}^{-2} \text{h}^{-1}$) and fodder radish (108 $\mu\text{g N-N}_2\text{O m}^{-2} \text{h}^{-1}$) resulted in higher daily fluxes of N₂O in the first fertilization added to the corn cover. The highest N₂O fluxes were observed after the second fertilizer was added to the cover, in succession to fodder radish (174.12 $\mu\text{g N-N}_2\text{O m}^{-2} \text{h}^{-1}$) and brown hemp (153.30 $\mu\text{g N-N}_2\text{O m}^{-2} \text{h}^{-1}$). During the evaluated period, the mineralization process of pigeon pea vegetable residues accelerated, which along with black velvet bean and fodder radish, present the highest ariel N contents; consequently, the highest cumulative N₂O emission values ($p < 0.005$) were observed during corn cultivation: 0.98; 0.86; and 0.82 kg N-N₂O ha⁻¹, respectively. The accumulated N₂O value observed in the Cerrado was close to zero (0.078 Kg N-N₂O ha⁻¹) Due to nitrogen fertilization, the system that used millet followed by corn had the lowest accumulated N-N₂O emission.

PRELIMINARY RESULTS

- The Cerrado has the lowest N-N₂O fluxes, in general close to zero. These values are correlated with the low levels of nitrate and low soil temperatures;
- Soil cultivated with millet (*Pennisetum glaucum*) has the lowest peaks and the lowest accumulated emission value N-N₂O;
- The soils cultivated with feijão-bravo-do-ceará (*Canavalia brasiliensis*) and brachiaria ruziziensis (*Urochloa ruziziensis*) presented the highest accumulated nitrous oxide fluxes and the highest peaks during the experiment period;
- In general, the results indicate a relationship between production and the chemical composition

of the cover plant biomass, in addition to the N applied via fertilizer, and N_2O fluxes in the soil cultivated with corn in succession to cover crops, under no-tillage systems in the Cerrado.

CHALLENGES

- The findings of this research reveal that during the implementation of this project, new and important variables were correlated with the N_2O emissions and the accumulation of carbon (C) in the soil. This increase was only possible due to the support of external partnerships such as the Graduate Program from the University of Brasilia and approved resources from external sources such as FAPDF and CNPq. Most of our long-term experiments did not allow us to obtain the emission factor, since they were not designed for that purpose. However, this corn experiment in succession to cover plants, which is the pilot experiment of this action plan, was redesigned with the application of N and without application of N in the corn cover crop, which led us to calculate the emission factor. These calculations are being processed.

SOLUTIONS

- This study identified that the Cerrado presents low $N-N_2O$ fluxes, which are close to zero, due to unfavorable conditions for nitrification such as low pH. This favors the predominance of nitrogen in its ammoniacal form and consequently, it does not favor the production of N_2O in the soil and its emissions into the atmosphere;
- In addition to the N applied via fertilizer, the production and chemical composition of the cover plant biomass has a strong influence on nitrous oxide fluxes from the soil cultivated with corn in succession to cover plants, under no-tillage systems in the Cerrado;
- New perspectives: I. quantification of other important losses such as ammonia volatilization, which, although is not a greenhouse gas, which represents significant losses of N in the system, in addition to also negatively impacting the atmosphere, such as atmospheric deposition, acid rain and indirect greenhouse effect; II. estimate of carbon stocks in soil and conversion to CO_2eq to determine low carbon agricultural production systems to mitigate GHG, which should contribute to public policies on climate change at national and global levels, such as the Low Carbon Agriculture Program (ABC Plan) and the IPCC report; III. Brazil is a signatory to greenhouse gas (GHG) mitigation measures and global climate change, with high expectations from research, farmers and society, regarding its role in sustainable soil management and, consequently, in GHG mitigation. In this context, the results of these surveys, conducted at different scales (experimental

fields, farm-scale agricultural production systems, areas of native vegetation), have contributed relevant and consistent information to sectors that demand data for reports on climate change and in N_2O emission indexes that are directly impacted by the agricultural sector, such as the Ministry of Science and Technology (MCT) and the IPCC, respectively;

- IV. One of the main perspectives of the execution of this project, that takes the form of new arrangements / production systems or new technologies that generate lower GHG emissions, is in the indication of agricultural production systems with greater adaptive capacity / resilience and low GHG emissions.

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Continued in Annex

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NITROUS OXIDE (N₂O) FLUXES IN SOIL UNDER VARIOUS SOIL USE SYSTEMS IN BRAZIL

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Changes in land use, such as the conversion of natural vegetation into pastures and cultivation areas, are always associated with changes in the nutrient cycle and result in changes in greenhouse gas fluxes from the soil into the atmosphere. In this study, we analyzed extraction patterns of direct nitrous oxide emission values found in scientific literature (N₂O) in soils from different ecosystems in Brazil. There was a wide range of flux values in natural ecosystems: while average annual flux rates were the highest in the Amazon and Atlantic rainforests (respectively 2.42 and 0.88 kg N ha⁻¹), emissions from Cerrado soils were close to zero. Pasture emissions decreased the more time passed after conversion, associated to pasture degradation. Relatively low N₂O-N (-0.07 to 4.26 kg N ha⁻¹ year⁻¹, median 0.80 kg N ha⁻¹ year⁻¹) values and low fertilization responses were reported in cultivation areas. Contrary to the premises, soil parameters, such as pH, organic carbon and clay content, were poor N₂O fluxes predictors. This may be the result of the formation of micro-aggregates, which strongly affect the hydraulic properties of the soil, and consequently, define the potential for nitrification and denitrification. Data on cultivated areas was derived mainly from areas that were originally under the natural Cerrado vegetation, a possible justification for the low emissions in agriculture. In order to better represent all relevant agricultural regions, future and more frequent measurements are needed to enable more robust national estimates.

PRELIMINARY RESULTS

- Land use types resulted in different direct N₂O fluxes from the ground, but emissions were generally low;
- Soil parameters, such as pH, organic carbon and clay content were not considered adequate indicators for N₂O fluxes.
- The annual N₂O-N fluxes from cultivated soil in Brazil ranged from -0.07 to 4.26 kg N ha⁻¹, with a median of 0.80 kg N ha⁻¹. This value is much lower than the emissions reported by Roelandt et al.

(2005) from cultivated areas in Canada (2.27 kg N₂O-N ha⁻¹ year⁻¹), in Europe (2.47 kg N₂O-N ha⁻¹ year⁻¹) and the United States (3.35 kg N₂O-N ha⁻¹ year⁻¹).

CHALLENGES

- We observed a few information gaps in certain biomes. We did not find any reported N₂O emissions for the Caatinga and Pantanal biomes;
- Except for one location, the data on cultivation areas was derived from established areas in the Cerrado region, which presented extremely low emissions under natural vegetation. The lack of information on crop emissions outside the Cerrado is probably due to the importance of this biome for the country's agriculture. However, the lack of data from other biomes makes it difficult to explain the low emissions of cultivated soils, even after the application of fertilizers, and points to the need for additional assessments from other biomes. We believe this compilation is an important contribution as it should provide more information on agricultural N₂O emissions in other biomes;
- As N₂O emissions usually occur during peaks caused by events such as precipitation or N applications, measurements with a higher temporal resolution are needed to capture all important emissions and explain their mechanisms. Most projects before the Fluxus, Pecus and Saltus networks did not follow an adequate protocol for logistical issues. Automated measurements enable continuous data acquisition (MADARI *et al.*, 2018), but the establishment of such studies requires a relatively high investment and is restricted to locations with a power supply and, for certain approaches, demand flat topography. Perhaps, with the development and improvement of N₂O field sensors, in the future this might become more feasible. Furthermore, in order to obtain a spatially adequate and representative distribution of measurements in a continental country like Brazil, we still need to rely on manual measurements that also take into account

environmental changes (drought / humidity cycles) and human-induced changes (conversion land). Biweekly measurements throughout the year, as made by most authors, are no longer adequate to increase our understanding of biogeochemical processes;

- In addition, there is a lack of exact knowledge of how N₂O-N emissions change during land conversion, which would be very necessary as this period of time can probably be responsible for large emission pulses that should be accounted for. Improving the existing understanding of underlying processes, especially during land conversion, is only possible through consistent monitoring and frequent measurements. Monitoring data can provide the basis for improved model refinement and enables spatial and temporal extrapolations.

SOLUTIONS

- The objective is to develop regional solutions to improve national inventories, preferably generating Tier 2 and 3 data. Currently, however, most models that work via biophysical process simulations were developed temperate climate and non-tropical soils, and applying them in tropical conditions is a challenge. The varied hydraulic conditions caused by micro-aggregates in kaolinitic soils typically present in tropical regions need to be considered, since an adequate description of soil moisture is a prerequisite for modeling N₂O-N fluxes from soils. Adapting or developing models for tropical climate conditions is essential.

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IMPACT OF NITROGEN FERTILIZATION MANAGEMENT ON GREENHOUSE GAS NITROUS OXIDE EMISSIONS AND PRODUCTIVITY OF IRRIGATED RICE (*ORYZA SATIVA L.*) IN THE CERRADO

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Although most of Brazil's irrigated rice is produced in the south, irrigated rice (*Oryza sativa L.*) produced in tropical floodplains, for example, in the valley of the Araguaia and Tocantins rivers, is of great importance in the local economy. The state of Tocantins is third largest rice producer in the country. The lack of synchronicity between the time of nitrogen (N) application and the time of greatest demand from the plant results in irrigated rice's low recovery of N efficiency, given the losses of this element. The aim of this study was to estimate the loss of N in the form of nitrous oxide (N₂O) and ammonia (NH₃) in an irrigated rice production system in a tropical floodplain, in the Cerrado. The experiment was conducted in gley soil, during the 2011/2012 (S1), 2012/2013 (S2) summer harvests and in the period between harvests. The cultivar used was BRS Tropical. The experiment consisted of three treatments: (T0) control (without N); (T1) application of the recommended dose of 90 kg ha⁻¹ of N spread in coverage; and (T2) application of 75 kg ha⁻¹ of N spread in coverage, based on data from the Minolta SPAD-502 chlorophyllometer. In addition to the coverage, 20 kg ha⁻¹ of N were applied in the planting furrow in T1 and T2. The fluxes of N₂O and NH₃ were quantified using manual static chambers throughout the harvests and between the harvest season. Most of the total gaseous N (N-N₂O+N-NH₃) losses occurred during the period prior to the flooding of the production system. Using a chlorophyllometer to manage N was the most efficient in reducing losses of NH₃, keeping grain productivity stable. In general, the N₂O emission factor from nitrogen fertilization was low (0.3%), compared to the average recommended IPCC value (1%).

PRELIMINARY RESULTS

- Nitrogen fertilization management enabled the reduction of the amount of applied N by 15 kg ha⁻¹, without decreasing rice yield (Table 1);
- Large gaseous losses of nitrogen (N-N₂O+ N-NH₃) occur during a short period of time, one month before flooding;

- Two-thirds of nitrogen was lost as ammonia (NH₃) and one-third as nitrous oxide (N₂O);
- The management of nitrogen fertilization based on monitoring plant chlorophyll levels resulted in lower intensities of volatilization, in other words, reduced NH₃ losses for each kg of rice grain produced;
- The N₂O emission factor for nitrogen fertilization found in this study was not affected by N management, but its value was low (0.2%-0.3%) in all treatments, compared to the average emission factor recommended by the IPCC (1%).

CHALLENGES

- We still lack information regarding the effect of green manure (with legumes and non-legumes) on the dynamics of N fluxes in a tropical flood-irrigated rice production system;
- There is also a lack of information on N losses due to leaching and its effect on groundwater or river water;
- Collecting data in remote areas was difficult due to the lack of manpower and difficulties of sending samples to the laboratory for analysis;
- In general, there are few laboratories that perform these analyses since most are located in university research centers, making it harder to get information;
- Currently, there is no quality control program in Brazil for the analysis of total organic carbon and total nitrogen in soil samples via combustion (elemental analysis) NH₃, N₂O, CO₂ and CH₄. Such a program, if organized, would greatly increase the credibility of data obtained by the research networks

SOLUTIONS

- In order to avoid gaseous nitrogen losses, we suggest that nitrogen fertilizer be applied on the cover when the irrigated water layer is established and adjusted according to the plants' needs, using the chlorophyll meter reference index.

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Table: Yield of irrigated rice grains in tropical floodplains for treatments with different doses and management of N in crops S1 and S2.

Treatment	Productivity (kg ha ⁻¹)		
	S1	S2	Average
T0	6.361 b	6.323 b	6.342
T1	8.984 a	8.014 a	8.499
T2	10.006 a	8.134 a	9.070
Average	8.451	7.490	8.119

Averages followed by the same letter in the column do not differ by Tukey's test at 1% probability. T0: 0 kg N ha⁻¹; T1: 110 kg N ha⁻¹; T2: 95 kg N ha⁻¹ (N management through chlorophyllometer)

ASSESSMENT OF MINERAL N SOURCES CAPACITY IN MITIGATING NH₃ VOLATILIZATION AND N₂O EMISSION FROM AN OXISOL CULTIVATED WITH IRRIGATED COMMON BEANS UNDER NO-TILL

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Between May and June, the production of common beans (*Phaseolus vulgaris* L.) via central pivot irrigation in Brazilian savanna (Cerrado) is responsible for about 36% of the bean's supply in Brazil. Under this system, bean is cultivated intensively, and therefore yields are high and can reach 3,500 kg ha⁻¹. However, the use of mineral fertilizers and irrigation makes it financially and energetically costly since N and water supply are key factors for productivity maintenance (CARMO et al., 2016).

The adoption of no-till under tropical conditions, especially in Cerrado, is important for soil and water conservation because it keeps crop residues on soil surface protecting soil from temperature extremes. However, amongst the technologies indicated for a cropping system under no-till, nitrogen fertilization is the one that has raised more questions. Questions are related to mechanisms that control nitrogen availability to plants and reactions of different sources of nitrogen application in soil.

The objective of this study was to evaluate the effect of sources of mineral N, ammonium sulfate, urea, urease with urease inhibitor (NBPT), biochar and biological nitrogen fixation (BNF) on N losses through volatilization and emission in latosol from Cerrado, cultivated with common beans irrigated in no-tillage over brachiaria straw.

Experiment 1. Effects of mineral fertilization (NPK) and mulch of *Brachiaria* straw (*Urochloa ruziziensis*) on N₂O and NH₃ fluxes from an Oxisol cultivated with irrigated common beans under no-till were assessed from May to September 2008. The treatments were composed of: I. common beans cultivated under no-till over mulch of brachiaria straw with mineral fertilization; II. common beans cultivated under no-till over mulch of brachiaria straw without mineral fertilization; III. common beans cultivated under no-till without mulch of brachiaria straw with mineral fertilization; and IV. common beans cultivated under no-tillage without mulch of brachiaria straw and without mineral fertilization. Amounts of mineral fertilization applied on treatments were 400 kg ha⁻¹ of NPK (5-30-15) at sowing, and 200 kg ha⁻¹ of urea (45% N) via sprinkler irrigation. Manual static chambers were used to measure N₂O and NH₃ fluxes from soil throughout entire growing season of common beans.

Experiment 2. An irrigated common bean cropping system under no-till on an Oxisol of the Cerrado was assessed throughout two growing seasons (from May to August) in 2010 and 2011. On June 2011, the biomass of plant residues, mulch mainly of millet (*Pennisetum glaucum*), on the soil surface weighed on average 6 t ha⁻¹. The experimental design was randomized blocks with four replications. The treatments were: without application of mineral N (CONTROL) and five different sources of mineral N applied at sowing (20 kg ha⁻¹ of N) and throughout growing seasons as topdressing (80 kg ha⁻¹ of N). The different sources of mineral N were: I. common urea - 44% N (UREA); II. urea with urease inhibitor - 45% N (UR + NBPT); III. polymer-coated urea - 41% N + 1% calcium (Ca) (UR + POL); IV. ammonium sulfate - 20% N + 22% sulfur (S) (SULFATE); and V. ammonium nitrate - 32% N (NITRATE). Losses of N from soil to atmosphere was monitored on a weekly basis throughout growing seasons, using manual static chambers.

PRELIMINARY RESULTS

- **Experiment 1.** Highest N₂O emissions occurred in treatments with mulch of brachiaria straw, regardless mineral fertilization. However, carbon in microbial biomass of soil was significantly higher in treatments with mulch of brachiaria straw. Emission factors for N₂O and NH₃ related to the mineral N applied under the conditions of this study was below to that preconized by IPCC (data "Publication 1", in Table 1);
- **Experiment 2.** NH₃ volatilization represented about 96% of N gas losses in the irrigated common beans production system. The NH₃ volatilization factor ranged between 1% for ammonium nitrate and 17% for urea. The use of the urease inhibitor NBPT reduced the loss of N from volatilization of NH₃ from the urea by 47%. On the other hand, the polymer-coated urea favored the reduction of N₂O emissions, compared to common urea. The N₂O emission factor for nitrogen fertilizer was between 0.01%

CHALLENGES

- Most significant N losses to atmosphere due to mineral N fertilization applied in a no-till system occurred via NH₃ volatilization.
- Total losses of N to atmosphere from a crop system need to be analyzed considering gains as soil C sequestration and crop grain yield.

SOLUTIONS

- Treated urea mitigates losses of N₂O and NH₃ compared to common urea;
- Under a no-till system with mulch of brachiaria straw N₂O emissions are low and related to an increment in soil carbon.

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Table 1: Emission factors for N₂O emission (EF1) and NH₃ volatilization (FracGASF) from mineral nitrogen fertilizer applied in irrigated common beans cropping systems under no-till on an Oxisol of the Brazilian savanna (Cerrado).

Reference	Sources and management	Quantidade de N aplicado	EF1 %	FracGASF %
Publicação 1 (CARVALHO <i>et al.</i> ,2013)	N-P-K formula applied at sowing and urea via sprinkler irrigation	110 kg/ha	0,2	0,6
Publicação 5 (CARVALHO <i>et al.</i> ,2018)	N aplicado no plantio e em cobertura a lanço	100 kg/ha	0,2	11
Publicação 7 (MADARI <i>et al.</i> , 2007)	N aplicado no plantio e em cobertura a lanço	80 kg/ha	0,1	-
IPCC (2006)*			0,3-3	3-30

*KLEIN, C. de; NOVOA, R. S. A.; OGLE, S.; SMITH, K. A.; ROCHETTE, P.; WIRTH, T. C.; McCONKEY, B. G.; MOSIER, A.; RYPDAL, K. N₂O emissions from managed soils, and CO₂ emissions from lime and urea application. In: 2006 IPCC Guidelines for National Greenhouse Gas Inventories: agriculture, forestry and other land use. [Geneva]: IPCC National Greenhouse Gas Inventories Programme; [Hayama]: Institute for Global Environmental Strategies, 2006. v. 4, cap. 11, p. 11.1-11.54.

WATER MANAGEMENT PRACTICES AND IRRIGATION SYSTEMS AS GREENHOUSE GAS EMISSION MITIGATORS IN RICE CULTIVATION

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Irrigated rice cultivation is socially and economically relevant in Rio Grande do Sul, and contributes to national food security. However, the state's predominant irrigation system- continuous flooding- creates anaerobic conditions in the soil, which favor the production and emission of methane (CH₄), a potent greenhouse gas (GHG). The adoption of irrigation systems that have soil drainage during practically the entire growing period for rice (sprinkler irrigation) or intermittent irrigation during the rice growing period (intermittent flood irrigation), as well as water management practices that restrict the irrigation period or the irrigated water layer (saturated soil), significantly reduce CH₄ emissions and global warming potential (GWP) compared to continuous flooding, since soil aeration promotes aerobic soil conditions, which is unfavorable to methanogenesis. However, these irrigation and water management systems favor nitrogen losses (N) through ammonia (NH₃) and nitrous oxide (N₂O) volatilization in rice cultivation, as they promote alternations in soil oxidation-reduction conditions, which are favorable to nitrification and denitrification, resulting in a substantial increase in N₂O emissions (HOU et al., 2000; LIU et al., 2010). Studies were carried out to assess potential strategies to mitigate greenhouse gas emissions associated with intermittent flooding and sprinkling irrigation systems and to evaluate alternative water management systems (reducing the height of the water depth or the irrigation period) for rice cultivation as alternatives to continuous flood irrigation.

The studies were carried out over four harvests (2010/2011 to 2013/2014) in haplasic planossol, at Embrapa Clima Temperado, in Pelotas-RS. In one experiment, the continuous flood irrigation system [soil flooded between the four-leaf stages (V₄) and harvest maturity (R₉)] was compared with the intermittent flood irrigation system [soil flooded between the four to seven leaf stages (V₄ to V₇) and panicle differentiation (R₁) and milky grains (R₆)] and with a saturated soil maintenance system (between V₄ to R₉). In another experiment, continuous flooding system was compared with a sprinkler irrigation system, as well as with a reference area (natural area of the same soil, with no recent history of cultivation).

In both experiments, rice crop management was carried out in accordance with the technical indications for the

crop (REUNIÃO, 2010; 2012). Air samples for CH₄ and N₂O were performed on weekly basis throughout the rice irrigation period, using the closed static chamber method adapted from Mosier (1989). The concentrations of GHG in the samples were determined by gas chromatography. The total fluxes and soil CH₄ and N₂O emissions were assessed, along with the partial global warming potential (GWPP) associated with irrigation and alternative water management systems for rice. GWPP results were also related to grain productivity (GWPP / GP), by dividing (GWPP) by productivity values. Based on seasonal emissions, calculations were made for the emission factors (EF) of N₂O for urea (source of nitrogen) and daily CH₄ emission factors different irrigation and water management systems in rice cultivation.

PRELIMINARY RESULTS

- The continuous flood irrigation system predominantly issues CH₄, representing a much greater partial global warming potential when compared to irrigation systems with intermittent flooding systems and maintenance of saturated soil. These irrigation systems provided CH₄ emission factors corresponding to 0.92; 0.72 and 0.70 kg CH₄ ha⁻¹ day⁻¹, respectively;
- The intermittent flood irrigation system reduces CH₄ emissions from the soil, although it increases N₂O emissions from rice cultivation, in relation to continuous flooding. The reduction in CH₄ emissions is greater than the increase in N₂O emissions, making intermittent flooding irrigation have a lower impact on partial global warming Potential;
- The irrigation system that maintains saturated soil slows down and reduces soil CH₄ emissions in rice cultivation without stimulating N₂O emissions, lowering the partial global warming potential when compared to continuous and intermittent flood irrigation systems;

- The intermittent flooding and maintenance of saturated soil irrigation systems present greater efficiency in the use of water, in comparison to continuous flooding;
- The intermittent flooding irrigation system with lower height of the irrigation blade (saturated soil) are an efficient strategy to mitigate greenhouse gas emissions from rice cultivation;
- The sprinkler irrigation system virtually eliminates CH₄ emissions from rice cultivation (daily emission factor of 0.002 kg CH₄ ha⁻¹ day⁻¹), making N₂O emissions almost the total global warming potential of this irrigation system (> 99%);
- Sprinkler irrigation intensifies N₂O emissions in rice cultivation, if compared to continuous flooding. However, the sprinkler rice irrigation system contributes considerably to the reduction of the partial global warming potential of this culture, given its lower CH₄ emissions;
- Rice production, whether irrigated through continuous flooding or sprinklers, has less partial global warming potential than the uncultivated natural area (Figure);
- The sprinkler irrigation system, although it reduces the productivity potential of irrigated rice, is still an efficient strategy to mitigate greenhouse gas emissions.
- N₂O potential emissions from intermittent flooding and sprinkler irrigation systems for rice cultivation.

SOLUTIONS

- Studies have identified that intermittent flooding and sprinkler irrigation systems represent promising alternatives to mitigate CH₄ emissions and the global warming potential of rice cultivation compared to traditional continuous flooding irrigation.

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Continued in Annex

CHALLENGES

- Rice cultivation under intermittent flooding or sprinkler irrigation systems have a higher potential to mitigate greenhouse gas emissions, especially for CH₄, when compared to continuous flooding irrigation. However, both systems enhance soil N₂O emissions, as they change the soil's redox conditions and may even reduce the crop's potential yield;
- Risking the loss of rice productivity is a factor that justifies the resistance from farmers to adopt such irrigation strategies, since the environmental gains are not incentives enough for the productive sector. Therefore, it is up to research to adapt crop management systems in order to minimize or even eliminate the potential losses in productivity resulting from the adoption of irrigation systems or alternative water management systems for rice, instead of continuous flooding irrigation. Likewise, research must develop management strategies that reduce

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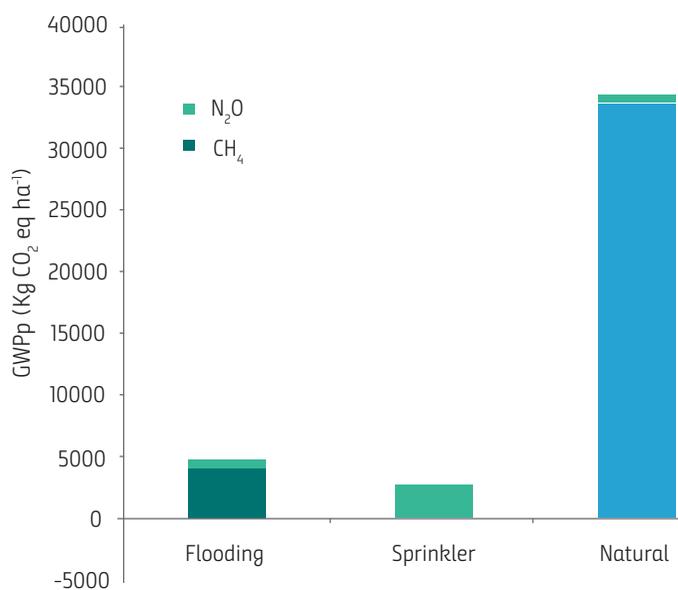
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Figure: Partial Global Warming Potential (GWPP) in planosol cultivated with rice irrigated by flooding, sprinkler and in a natural area, over a year (harvest and between harvest periods)



Source: Scivittaro et al. (2015).

N₂O IN CORN PRODUCTION SYSTEMS UNDER NO-TILL AND CONVENTIONAL TILL IN LATOSOL IN THE CERRADO

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The increase of greenhouse gases (GHG) emissions in the atmosphere produced by human activities is the main source of global climate change. Agriculture is one of the main sources of GHG, responsible for approximately 12% of global anthropogenic GHG emissions (IPCC, 2013).

Among the main GHG (CO₂, N₂O and CH₄) that are in the atmosphere, N₂O has a global warming potential (GWP) 298 times greater than CO₂ over a 100-year time horizon (MYHRE *et al.*, 2013). In the agricultural sector, agricultural soils are the largest source of N₂O emissions, accounting for 76% of global emissions. The agricultural soil management system and the use of nitrogen (N) is a factor that impacts N₂O emissions. There is a consensus that the increase in N₂O emissions in agricultural systems occurs after the application of nitrogen fertilizers (BELL *et al.*, 2016; SANTOS *et al.*, 2016). However, research has not reached a consensus on systems and practices as recommendations for mitigating climate change (BAYER *et al.*, 2015; SANTOS *et al.*, 2016; FENG *et al.*, 2018).

Brazil accounts for 12% of global grain production, and the Cerrado biome plays a significant role in this production, mainly for soybean and corn crops. The growing demand for food creates an increase in demand for nitrogen fertilizers.

In the search for practices to mitigate GHG emissions for the agricultural sector, the objective of this study was to evaluate the effect of the management system, with and without the practice of nitrogen fertilization, in non-irrigated oxisol cultivated with corn in the Cerrado region, on N₂O emissions and on the nitrous oxide emission factor. This study was carried out over one year (2014/2015), at Embrapa Milho e Sorgo, from Sete Lagoas-MG. A monoculture corn plantation was studied under conventional tillage (CT) and no-tillage (NT), with (1) and without (0) the application of nitrogen fertilizer (0 and 257 kg N ha⁻¹). In conventional tillage (CT), residues were incorporated with a heavy harrow, followed by a leveling harrow, and for no-tillage (NT), the soil was not overturned over the straw. AG 8088 VT PRO maize was planted spaced by 0.70 m, stand of 60,000 plants. In the treatments with nitrogen fertilization (CT1 and NT1), 400 kg ha⁻¹ of NPK 08-28-16 + were used + two topdressings with 250 kg ha⁻¹ of urea

each. For treatments without N (CT0 and NT0), 112 kg de P2O5 ha⁻¹ (simple superphosphate) and 64 kg of K₂O ha⁻¹ (KCl) at planting. The corn harvest was on 05/27/2015. The harvest residues were incorporated into the soil in the CT or NT system and were left under the soil. From then on, the area was left to fallow until the next growing season, planted with the next harvest of corn.

Soil N₂O fluxes were measured using a closed static chamber, which were determined by gas chromatography and calculated according to Bayer *et al.* (2015). The study monitored the soil's water-saturated porous space (% WSPS) and the mineral N, along with precipitation (nitrate-NO₃⁻ and ammonium-NO₄⁺), along with precipitation and air temperature.

Estimates of N₂O emissions were obtained by integrating fluxes with time (accumulated N₂O flux), during the growing season (harvest) and during one year (harvest + fallow). The emission factor for unirrigated corn in the Cerrado were calculated, along with the accumulated emissions per grain amount and the GHG emission intensity (GGI, Mg CO₂ eq Mg⁻¹ grain).

PRELIMINARY RESULTS

- For the systems that received nitrogen fertilization, the no-tillage system (NT1) issued 30% less N₂O than the conventional cultivation system (CT1) during the period in which the crop was in the field (growing season – GS). In the GS, the N₂O emissions were: CT1 (4.84 kg ha⁻¹) > NT1 (3.36 kg ha⁻¹) > (NT0 = CT0 = 0.29 kg ha⁻¹);
- The addition of urea increased N₂O emissions at about 10 times when compared to systems that were not fertilized with N. For the accumulated total N₂O (crop + fallow), in a period of one year, the emissions were: CT1 = NT1 (5.06 and 4.06 kg ha⁻¹, respectively) > CT0 = NT0 (0.50 kg ha⁻¹ and 0.31 kg ha⁻¹, respectively);
- N₂O emissions did not occur right after N fertilization; the combined effect of the presence of mineral N,

- especially nitrate and soil moisture, expressed by WFPS, was observed;
- The emission factors for dry corn in the Cerrado were 0.96% in the conventional tillage system (CT1) and 0.79% for the no-tillage system (NT1). Although the values were lower, they will still be within the range of uncertainty, as IPCC standard recommendations of 1% (0.3 to 3%);
- The no-tillage system with N fertilization emitted less N₂O and was more efficient in converting N₂O per kg of grain produced, when compared to conventional nitrogen fertilization. The accumulated N₂O emissions were 769 mg N-N₂O and 391 mg N-N₂O per kg of grain produced, for the no-tillage and conventional planting systems, with N, respectively;
- The emission intensity (GGI) showed a tendency towards a lower global warming potential when under no-tillage system, with values of 0.00021 Mg CO₂e q ha⁻¹ year⁻¹ and 0.00011 Mg CO₂e q ha⁻¹ year⁻¹ for CT1 e NT1, respectively.

CHALLENGES

- Availability of financial resources for the continuity and expansion of assessments in different locations and different management systems;
- Availability of trained human resources for field collections.
- Accurate estimation of annual nitrous oxide emissions, due to the great spatial and temporal variability in these emissions;
- Evaluation of different types and formulations of nitrogen fertilizers in grain production areas;
- Evaluation of grain production management systems.

SOLUTIONS

- The emission factors for dry-land corn in the Cerrado were 0.96% in the conventional tillage system and 0.79% for the no-tillage system, lower, although within the range of uncertainty, than the IPCC standard of 1%;
- The no-tillage system with N fertilization emitted less N₂O and was more efficient in the conversion of N₂O emissions per kg of grain produced, when compared to conventional tillage, for dry-land corn cultivation in the Cerrado;

- The presence of mineral N and sufficient moisture in the soil favored nitrous oxide emissions in this study;
- There was a synergy of factors given by soil tillage and nitrogen fertilization, affecting emissions of corn nitrous oxide. The study of different formulations and dosages of nitrogen fertilizers, as well as management systems for grain production in the country, could result in a potential strategy for mitigating the emission of greenhouse gases in agriculture.

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Continued in Annex

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CARBON BALANCE AND GREENHOUSE GAS DYNAMICS IN -LIVESTOCK INTEGRATION SYSTEMS IN THE CERRADO

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The cultivation of corn in consortium with forage grasses is expressive in the Cerrado and considered as an efficient alternative of agricultural exploration with more sustainability. Forage can be used for both animal feed and straw formation for no-tillage, bringing several benefits to the system, such as improving soil quality, breaking cycles of pests, diseases and invasive plants, among others. To increase carbon and nitrogen stocks in the soil, vast quantities of biomass must be produced and plant residue accumulation on the soil surface is also necessary. The carbon stock in the soil is directly related to the increase of nitrogen coming from systems that associate crops and cover crops such as brachiaria, that have been increasingly used through intercropping with corn, a greenhouse gas (GHG) emission mitigating practice. Given the lower levels of lignin, most modern brachiaria cultivars have been shown to be quite efficient in supplying nutrients and cycling them to the corn crop, either in consortium or in succession. These grasses have a high potential to protect the soil, store carbon and nitrogen and also provide nutrients, such as N. Thus, this action plan aims to quantify the carbon stock and greenhouse gas emissions in corn / brachiaria systems in the Cerrado biome. The studies were carried out primarily through long-term experiments. Activities were carried out to characterize the carbon and nitrogen stocks in the soil and in the straw / cover; The N₂O fluxes in the soil and the edaphoclimatic variables (biomass, mineral nitrogen, gravimetric water content, apparent density, porous space filled with water, soil and air temperature, rainfall, relative humidity, among others) were surveyed. The soil organic matter was evaluated in terms of quantity and quality. The data on the chemical and microbiological attributes of the soil and organic matter were related to nitrous oxide emissions, in order to understand the existing relationships taking into account soil management.

PRELIMINARY RESULTS

- Integration systems based on pasture-crop rotation associated with the no-tillage system, have been important in the sustainable intensification of land use in Brazil. They are more efficient in nutrient cycling, improving soil quality and increasing biodiversity. Furthermore, as research demonstrates, it promotes carbon sequestration, contributing to the mitigation of GHG emissions;
- Previous research has shown that N₂O in agricultural systems are influenced by edaphoclimatic conditions (soil, climate, vegetation, among others), and that the availability of soil organic matter (SOM) is a key factor in the process. The study improves knowledge on how the accumulation of fractions of stable and labile SOM (less stable) occurs in soils under crop-livestock integration (ICL) and possible relationships with N₂O emissions. ICL systems emit less nitrous oxide (N₂O), an important greenhouse gas, when compared to crops in conventional tillage. Using forage grasses, which provide organic matter and deepen roots in the soil profile, influences this process, as well as the presence of larger diameter aggregates. Some explanations for this for is the fact that forage grasses deposit organic matter that is less easily degraded, besides the fact that ICL provides soil with larger aggregates. With more carbon and nitrogen accumulated in these particles, the organic matter present is protected from decomposition by the microbiota, the microorganisms that inhabit the soil;
- The highest accumulated emissions, after 146 days of evaluation during the intercropped sorghum cycle, were observed in the area with conventionally planted crops with 1.8 kg / ha of N-N N₂O, while emissions from continuous crops under no-till accounted for half of this emission (0.9 kg/ha). Among cultivated areas, the ICL system was the one with the lowest accumulated N₂O emissions, with 0.79 kg/ha. In the Cerrado area, considered the positive reference of the study and where daily emissions are always close to zero, the cumulative emissions for the period represented only 11% of the crop emission in conventional tillage, which is considered the negative reference;
- In areas with ILP, there is a greater mobilization of nitrogen by pastures in the gain off-season, which reduces the availability of this chemical element to the microbial biomass responsible for the nitrification and denitrification processes;

- The findings include that crop residue decomposition during the succession of crops in the first and second harvests (soy and sorghum) in the presence of forage grass with and without grazing in both systems under no-tillage explain the differences in N_2O fluxes in the different management systems analyzed;
- One of the conclusions was that tropical forage grasses, especially brachiaria, when they find soils of built fertility, as is the case of this study, are able to express the full development potential of their root system, which has an important physical effect on the soil, protecting and stabilizing SOM and mitigating GHG emissions.

CHALLENGES

- Despite found in much smaller proportions than carbon dioxide (CO_2), N_2O has about 300 times more capacity than CO_2 in retaining heat in the atmosphere. Furthermore, N_2O remains in the atmosphere for over 100 years;
- Brazil is responsible for most of N_2O emissions in Latin America. Gas emissions are influenced by a number of factors, such as: management; the high amount of water in the soil, which reduces aeration and promotes anaerobiosis; the acidity of the soil; the use of nitrogen fertilizers; conventional planting, which interferes with aeration, the decomposition of plant residues and flora; and animal excrements, which are sources of nitrogen and organic carbon, which favor microbial activity;
- Studies conducted in other regions of the world with *Brachiaria humidicola* indicate that the lower emissions of nitrous oxide by these systems can be explained by the ability of the roots to release biological inhibitors of nitrification, which block the enzymatic pathways of bacteria of the genus *Nitrosomonas*, which are responsible for oxidation of ammonia to nitrite. Nitrite undergoes nitrification by bacteria of the *Nitrobacter* genus, to become nitrate. The nitrate is then reduced to nitrogen gases, including N_2O , in the denitrification promoted by heterotrophic bacteria;
- Future research that understands the relationships between communities of microorganisms present in the soil and their interactions with the rhizosphere in more complex agricultural systems, such as ICL are fundamental to progress this line of research. The impact of the presence of other types of microorganisms that are being studied and recommended by Embrapa may also help to understand how to make the environment more conducive to the development of plants with greater productivity and less environmental impact.

SOLUTIONS

- These and other results are being used to support a major strategy for adopting sustainable (or low-carbon) technologies. Based on research of this nature, the Sectorial Plan for Mitigation and Adaptation to Climate Change originated for the Consolidation of a Low Carbon Emission Economy in Agriculture (ABC Plan), which, among other technologies, provided for the implementation of four million hectares of ICL / CFI in Brazil, between 2010 and 2020. In 2015, Brazil made new commitments in the Paris Agreement, with the intention of implementing an additional 20 million hectares of ICLF and recovering degraded pastures between 2021 and 2030.

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POTENTIAL OF SOIL MANAGEMENT AND PLANT COVERAGE PRACTICES IN MITIGATING GREENHOUSE GAS EMISSIONS IN LOWLANDS

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The cultivation of irrigated rice is an activity with a high potential for greenhouse gas (GHG) emissions, particularly methane (CH₄), that is produced through the microbial decomposition of organic materials in anoxic environments, and nitrous oxide (N₂O), a product of the microbial transformation of nitrogen (N) native to the soil and present in organic waste (REDDY; DeLAUNE, 2008).

The season, soil preparation operations and the management of vegetation cover determine different potentials for incorporating carbon (C) and nitrogen (N) into the soil and GHG emissions in rice cultivation (YAO et al., 2010).

This study aimed to assess the potential of soil and vegetation management practices in mitigate CH₄ and N₂O in lowland areas cultivated with rice paddies. The study was carried out in a haploid planossol, at Embrapa Clima Temperado, in Pelotas- RS

The evaluations lasted for two years, including two off-season periods (autumn / winter) and harvest (spring / summer) periods. The treatments comprised four systems involving associations of soil management in the off-season and spring / summer crops, all of which started with the cultivation of irrigated rice: T1- rice / soy / rice (irrigated rice harvested in dry soil, with maintenance of the bark on the surface during the fall / winter period; direct sowing of soybeans in the spring; early soil preparation in the fall; direct sowing of rice in the following spring); T2- rice / rice / rice (irrigated rice harvested in moist soil, with the area kept fallow during the autumn / winter period; conventional soil preparation in the spring and rice sowing, harvested in the presence of water layer; soil preparation with knife-roller in the fall; direct sowing of rice in the spring); T3- rice / rice / soybean (irrigated rice harvested with irrigated water layer, followed by soil preparation with a knife roller; direct sowing of rice in the spring, which was harvested in the presence of a irrigated water layer; soil preparation with a knife roller and direct sowing of soybeans in the spring); and T4- rice / soybeans / prepared rice (irrigated rice harvested on dry soil, followed by early soil preparation in autumn,

sowing direct soybean in the spring and harvest in late summer; advanced soil preparation in autumn and direct sowing of rice in spring).

The technical indications of the research for these crops in the south of Brazil were followed in the cultivation of irrigated rice and soybeans (REUNIÃO, 2014a, 2014b). Since the study involved different summer crops (irrigated rice and soy), the productivity data was converted to gross energy produced.

Air samples for the determination of CH₄ and N₂O emissions from the soil were carried out at regular intervals of approximately seven days, using the closed static chamber method. The concentrations of CH₄ and N₂O in the air samples were determined through gas chromatography.

The fluxes and total emissions of CH₄ and N₂O from the soil were determined. Based on the accumulated emissions of CH₄ and N₂O, the partial global warming potential (GWpp) was calculated, which considers the heating potential of each gas in relation to CO₂.

PRELIMINARY RESULTS

- Early fall tillage reduced CH₄ emissions during the off-season, compared to conventional spring tillage and autumn/winter tillage with roller knife;
- During the off-season, in succession to irrigated rice cultivation, the CH₄ emission factors corresponded to: 0.807 kg CH₄ ha⁻¹ day⁻¹, for the area prepared with a roller-knife; 0.307 kg CH₄ ha⁻¹ day⁻¹, for the area under conventional spring tillage; 0.044 kg CH₄ ha⁻¹ day⁻¹, under early preparation; and 0.041 kg CH₄ ha⁻¹ day⁻¹, with no tillage;
- Regardless of soil management, CH₄ emissions in the off-season are lower than those measured during irrigated rice cultivation, ranging from 408 kg CH₄ ha⁻¹, in the area under conventional tillage, to 438 kg CH₄ ha⁻¹, in the area prepared with a roller knife. On the other hand, in the soybean cultivated areas, due

to the maintenance oxidized soil, practically no CH₄ emissions were found (1.8 to 2.3 kg CH₄ ha⁻¹);

- Early soil tillage (dry) and with a knife roller (with irrigated water layer) generated, respectively, daily CH₄ emission factors for rice cultivation corresponding to 1.76 and 2.34 to 2.78 kg CH₄ ha⁻¹ day⁻¹. On the other hand, conventional tillage in spring generated 2.18 kg CH₄ ha⁻¹ day⁻¹. In addition to the preparation operations, CH₄ emissions from rice cultivation are associated to the previous crop, and are minimized by rotation with dry-land crops, such as soybeans, in relation to irrigated rice monocultures;
- Maintaining the land to lie fallow soil in the autumn/winter period eliminates N₂O emissions during the off-season, in relation to early tillage management. Even in these managements, N₂O emissions during the off-season were not expressive, concentrated more during the summer crop;
- Growing soybeans in rotation with irrigated rice markedly reduces CH₄ emissions but boosts N₂O emissions in lowlands. Even then, rotating soybean crops considerably minimizes the potential for partial global warming in lowlands, representing a promising alternative for mitigating greenhouse gas emissions in this environment.

CHALLENGES

- The data are representative for production systems involving rotated irrigated rice / soybean, however further studies are needed that contemplate other production systems developed in the lowlands of Rio Grande do Sul, particularly those that include irrigated rice rotated with extensive livestock and irrigated rice rotated with other grain crops..

SOLUTIONS

- This research identifies that the inclusion of irrigated crops in rotation to irrigated rice markedly reduces CH₄ emissions and the partial global warming potential of the lowlands of Rio Grande do Sul, making it a promising alternative in mitigating greenhouse gas emissions into the atmosphere. Likewise, anticipating tillage in the autumn-winter period also minimizes emission potential.

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AMMONIA (NH₃) VOLATILIZATION AND NITROUS OXIDE (N₂O) EMISSIONS FOLLOWING SOIL APPLICATION OF PIG SLURRY IN CORN”

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Brazil is amongst the largest pork producers and exporters in the world. Brazil's current pork production system generates large volumes of manure, which are normally handled in their liquid form. The high nitrogen content (N) in liquid pig slurry (PS) can be used as an alternative to synthetic nitrogen fertilizers. Another way of disposing the waste is through distributing it into the soil.

Most of the mineral N present in the PS is in its ammoniacal form, which is quickly oxidized to nitrate by nitrifying bacteria. When PS is applied on the soil surface in a no-tillage system (NT), significant amounts of N in its gaseous forms of ammonia (NH₃) and nitrous oxide (N₂O) may be lost, reducing its fertilizing potential and negatively impacting the environment. With this scenario in mind, the scientific community made efforts to study the effects PS applications, in the presence or absence of crop residues on the soil surface, and its gaseous emissions of N.

Soil surfaces applied with PS potentializes N emissions into the atmosphere, especially NH₃. The magnitude of the emissions depend on the method, time and rate of manure applied, in addition to the manure composition, soil type and environmental conditions.

The availability of carbon (C) increases when PS is applied and when crop residues are present, and can influence the emission of these gases since the heterotrophic bacteria, responsible for the immobilization of N and denitrification, depend on sources of C and energy. Therefore, understanding how different ways of applying PS into the soil may interfere in the magnitude of NH₃ and N₂O emissions is fundamental for the development of more adequate management strategies for this organic material.

The purpose of this study was to evaluate the NH₃ and N₂O emissions after the application of PS in a corn plantation, with and without the presence of black oat crop residues (*Avena strigosa* Schreb.) on the soil surface. This compilation will focus solely on N₂O emissions.

The study was carried out in the field in Red Dystrophic arenic Argissol from the Federal University of Santa

Maria (UFSM), located at 29° 41' 24" S, 53° 48' 42" W and an altitude of 106 m. N₂O emissions were evaluated for 90 days, between January and April 2011, in plots with dimensions of 1m x 1.6 m under the following treatments: T1 - Soil (Control); T2 - Soil + PS (PS); T3 - Soil + Black oat straw (Straw); T4 - Soil + Straw + PS (Straw + PS).

Manure was applied manually, on 01/19/2011, at a dose of 60 m³ ha⁻¹, two days before the corn sowing (hybrid Pioneer P3646). In the T3 and T4 treatments, black oat straw was added to the soil at a rate of 4.0 Mg ha⁻¹, collected at the physiological maturation stage. Since the N₂O fluxes evaluations were performed according to the procedures described by Rochette & Bertrand (2008). The collections were carried out from three to four times a week, during the first 30 days, and once the treatment emissions neared T1 levels, the collections were spaced between once to twice every 15 days. Air sample N₂O concentrations were determined by gas chromatography.

PRELIMINARY RESULTS

- N₂O emissions increased right after the application of PS, mainly when the waste was applied on black oat crop residues;
- The highest peaks of N₂O emissions occurred after irrigation and/or rainfall. On the seventh day of evaluation, after a precipitation of 40 mm, the emission of N-N₂O in the Straw + PS treatment exceeded the treatment with PS alone by 200% (> 844 µg of N-N₂O m⁻² h⁻¹).
- Approximately 90% of the total N-N₂O emissions occurred in the first 36 days after manure application.;
- Cumulative N-N₂O emissions ranged from 1.1 to 3.2 kg N-N₂O ha⁻¹ with the highest value obtained when black oat straw was on the soil surface and PS was applied (Table);
- The straw + PS treatment presented an emission factor of 1.3% (above the IPCC recommended value of 1%) while in the treatment with PS alone, the emission factor was only 0.1% (Table).

CHALLENGES

- The lack of control over environmental conditions in field studies (for example, precipitation, temperature, wind, among others) may incur variations in assessments;
- The wide variety of cover plants and the variation in the quality / biochemical composition of their crop residues may add new variables to future studies on the effect of straw associated with the application of animal waste;

SOLUTIONS

- The application of Pig Slurry (PS) on black oat crop residues may contribute to increased nitrous oxide emissions to the atmosphere.

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Table: Total amount of nitrogen (N) added to manure, accumulated emissions of N₂O and emission factors of N₂O after applying liquid pig slurry (PS) on the soil surface, with and without straw

Tratamentos	N adicionado com os DLS	Emissão acumulada de N ₂ O	Fator de emissão
	kg N ha ⁻¹	kg de N-N ₂ O ha ⁻¹	% do N adicionado
Testemunha		1,1 b*	
DLS	160	1,3 b	0,1 b
Palha		1,1 b	
Palha + DLS	160	3,2 a	1,3 a

Note: Averages followed by the same letter in the same column do not differ statistically from each other according to the Tukey test at 5%.

3

EMISSION AND REMOVAL FACTORS FOR INTEGRATED PRODUCTION SYSTEMS AND PLANTED FORESTS



Integrated production systems as an effective strategy for agricultural sustainability

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Agriculture has vital importance for the Brazilian economy and is present in all municipalities in the country (OLIVEIRA *et al.*, 2017). The development of cutting-edge technologies for tropical agriculture and the large availability of land for agricultural use has gained the country a prominent position in worldwide food production, that is central to national economy and essential to promote food security. Although the Brazilian agricultural sector and other productive activities contribute to global Greenhouse Gas (GHG) emissions, it only represents 0.83% of total global emissions. In relation to national emissions, agriculture represents approximately 34% of anthropic origin GHG emissions, with the largest amount of emissions from the subsectors Enteric Fermentation and Agricultural Soils with a contribution of 56.5% and 36.0%, respectively (BRAZIL, 2019).

According to projections by the Ministry of Agriculture, Livestock and Supply (MAPA), Brazilian agribusiness is expected to continue to grow over a 10-year time horizon (2017/2018 – 2027/2028), both in meat (1.9% annually) and milk production (2.5% annually) (BRASIL, 2018). An increase in the sector's GHG emissions is also projected given the sector's growth, generating concerns not only at the national but also at the international level (OLIVEIRA *et al.*, 2015). However, existing knowledge already point out that it is possible to, depending on the management applied to the production systems, create a balance between the sources and sinks of GHG that make up these systems.

Adopting sustainable agricultural systems that integrates knowledge from other disciplines and management practices from other production systems that improve current productivity levels without harming the environment or compromising resources in the long run, are a viable alternative not only to control GHG fluxes from the soil to the atmosphere and maintain a positive carbon balance (C), but also to improve local economies and positively impact the national economy (OLIVEIRA *et al.*, 2017).

According to a survey of agriculture data, in the 2015/2016 harvest, where Brazil had approximately 11.5 million hectares of integrated production systems, of which 83% were occupied with agropastoral systems (ICL), 9% with agrosilvopastoral systems (ICLF) and 7% with silvopastoral systems (ILF) (EMBRAPA, 2016a).

Crop-livestock integration (ICL) and crop-livestock-forest (ICLF) integration systems have the potential to sequester C. The incorporation of other components into the agricultural systems such as trees, especially fast-growing ones, such as eucalyptus, improve atmospheric removal of CO₂ and mitigate the gases produced by cattle and even provide greater thermal comfort to the animals (CARVALHO, 2014). These results supported the concept of Carbon Neutral Brazilian Beef. According to Embrapa researchers, the results from implementing these integrated systems indicate a positive C balance of 1.3 and 23.0 CO₂eq ha⁻¹ year⁻¹ for ICL and ICLF, respectively, while low productivity pasture has a negative balance of -0.4CO₂eq ha⁻¹ year⁻¹ (EMBRAPA, 2016b).

ABC Plan promotes Integrated production systems (IPS) through financial and development instruments, especially training and technical assistance. Therefore, increasing an area under this system also contributes to the Brazilian commitment of reducing GHG emissions, especially in controlling emissions from the agricultural sector (BRIANEZI *et al.*, 2014). The IPSs are a central element of the actions in the ABC Plan since they emphasize productive and environmental gains and highlight the potential for sequestration of CO₂eq. According to the preliminary estimate, integrated systems were responsible for the sequestration of 21.8 million tons of CO₂eq between 2010 and 2015, achieving and exceeding expectations established by the ABC Plan for that period, which was estimated to be between 18 at 22 million tons of CO₂eq (EMBRAPA, 2016a).

The different contributions of this compilation reveal that knowledge on IPS has made important advances. The results contributed by the Pecus¹ Project is a special example of this, which evaluated the emissions and removals of N₂O and CO₂ in production systems in the Amazon, Atlantic Forest and Pampa biomes, focusing on the evaluation of the crop (L) and forest (F) components. However, the studies also show that there are still information gaps that need to be filled in order to ensure the sustainability of IPS.

The results from research presented in this chapter are briefly described below, which underscore the efforts and progress achieved.

Lima *et al.* (p. 116) evaluated N₂O emissions from soil under *Brachiaria brizantha* pasture, under two grazing methods – rotational pasture (RP) and continuous pasture (CP) in an experiment carried out in the municipality of Pirassununga-SP, from January 24 to October 11, 2014. In the RP method, cattle from the Nelore breed occupied pasture area of 0.315 ha for seven days, followed by rest period of 28 days, completing a 35-day cycle, for two cycles. 60 kg of N ha⁻¹ of ammonium nitrate was applied in February. Part of the area was isolated with a tarp, protecting it from the same addition of fertilizer. In the CP method, the animals remained in the paddock for the entire study period and no fertilizer was applied. In RP, the difference between treatments with and without fertilization was 13.14 N-N₂O m⁻² day⁻¹, while in CP the emissions totaled 5.6 N-N₂O m⁻² day⁻¹ during the period. Based on this value, a nitrous oxide emission factor of 0.0022 (22% of the recommended IPCC EF– 0.01) was estimated for direct N₂O emissions from the addition of nitrogen fertilizers.

Costa *et al.* (p. 118) used the Denitrification-Decomposition (DNDC) model to estimate nitrous oxide (N₂O) emissions in the following systems: I. *Brachiaria humidicola* (Rendle) Scheick pure grass pasture. (G); II. *B. humidicola* grass intercropped with forage peanut *Arachis pintoi* Krapov. & WC Greg cv. BRS Mandobi (GL), both without fertilization; and III. in native forest (FN), classified as open/dense bamboo, which was the reference to assess the change of land use from native forest to pasture. All systems had the same type of soil, a plinthic Red-Yellow Argisol. The experiment was installed in 2011, at Fazenda Guaxupé in Rio Branco-AC. The native forest was deforested in 1981. The soil collections were carried out from February to December 2014 and from January to July 2015 in the 0-10 cm and 10-20 cm layers. Analysis results and meteorological information were inputs to the DNDC model to predict N₂O emissions. Average N₂O emissions in the following 166 days were: pure pasture (35.8 µg N m⁻² h⁻¹) > native forest (28.2 µg N m⁻² h⁻¹) > intercropped pasture (27.2 µg N m⁻² h⁻¹).

¹ The Pecus project (2011–2016), coordinated by Embrapa Pecuária Sudeste, was structured into twelve component projects and executed through a research network, with the participation of more than 300 researchers in Brazil and abroad, as a result of the joint action from various institutions. Its main objective was to evaluate the dynamics of greenhouse gases (GHG) and the carbon balance (C) in agricultural production systems in the six Brazilian biomes (Atlantic Forest, Caatinga, Pantanal, Pampa, Amazonia and Cerrado), in order to know the current state of GHG emissions and identify alternatives to mitigate emissions and subsidize public policies.

Pilecco *et al.* (p. 122) evaluated the effect of ryegrass overseeding in soybean, in an ILP system, on N_2O emission and forage production. The experiment was conducted during two agricultural years, in two land use systems under no-tillage: I. ICL with soybeans in the spring / summer and annual ryegrass in the fall / winter in overwintering when the soybeans were in stage R7 (ICL-I); and II. ICL with soy in the spring / summer and annual ryegrass in the fall / winter sown after the soybean harvest (ICL-II), in an argisol, in the city of Santa Maria-RS. The results showed that ryegrass overseeding over soybean at the grain maturation stage reduces the NO_3 content in the soil and, consequently, the N_2O emissions, making it a practice that mitigates soil N_2O emissions.

Weiler *et al.* (p. 124) conducted a two-year study in the city of Santa Maria-RS to quantify N_2O emissions and determine emission factors after summer cover crops (SCC) management in soils classified as Arenic Dystrophic Red Argisol. The treatments consisted of a fallow treatment and six SCC species cultivated from January to April and managed with a roller-knife at the full flowering of the species, and the area was cultivated with black oat and white oat in the first and in the second year, respectively. The results showed the high capacity of biomass production and biological N fixation in the case of leguminous SCC in a short period (78 and 88 days), making it possible to cultivate it in the summer during the period between each crop. Most species, with the exception of millet and *Crotalaria spectabilis*, had emission factors below 1%, EF as recommended by the IPCC. The study demonstrated that the inclusion of SCC in cropping systems results in lower N_2O emissions.

Zanatta *et al.* (p. 100) evaluated the contribution of pine (*Pinus taeda* L.) to soil C, in Rio Negrinho-SC under cambisol. The results showed that, in the first pine rotation (after forest conversion), there was a 22% depletion in soil C stocks, generating a C change factor of 0.81 for the soil 0-30 cm layer and 0.78 in the 0-100 cm layer. In the second rotation, initial C stocks were recovered generating a C emission/removal factor, in relation to native forest, of 0.97 in the 0-30 cm layer and 1.19 in the 0- 100 cm. This demonstrates that well-managed pine plantations in the study region can contribute to the maintenance and recovery of C stocks in the soil.

Jacovine *et al.* (p. 128) evaluated the C balance in different silvopastoral and agroforestry systems in different locations in the state of Minas Gerais, in order to support improve integrated system estimates in reducing emissions and increasing GHG removal. The results showed that the agroforestry systems have a positive carbon balance. Removals (21.78 to 200.14 t CO_2 eq ha^{-1}) were greater than emissions (2.78 to 17.57 t CO_2 eq ha^{-1}), generating a positive C balance, pointing towards the potential of these systems in mitigating GHG in the atmosphere.

In the experimental area of the Research and Extension Farm from Universidade Estadual Paulista, located in the municipality of Selvíria-MS, Panosso *et al.* (p. 110) evaluated the influence of the uses of native cerrado (CE), eucalyptus forest (EU), forest of pine (PI) and silvopastoral system (SI, brachiaria intercropped with red mastic) on the dynamics of CO_2 emissions from the soil, as well as its relationship with the degree of humification of organic matter and the carbon stock of an oxisol in the Cerrado region of Mato Grosso do Sul. Data were collected after 30 years of conversion from the Cerrado for EU, PI and SI. The native cerrado (CE) area presented the highest soil CO_2 emissions, at 4.55 $\mu mol m^{-2} s^{-1}$, while the PI and SI had lower emissions, at 2.98 $\mu mol m^{-2} s^{-1}$ and 3.22 $\mu mol m^{-2} s^{-1}$, respectively. The largest carbon stock, in the 0-10 cm layer, was found in CE with 21.57 Mg ha^{-1} , followed by SI (21.34 Mg ha^{-1}), EU (20,67 Mg ha^{-1}), and PI (13,91 Mg ha^{-1}), respectively. In the other depths, SI exhibited the largest carbon stocks, always followed by CE, EU and PI.

Escanhoela *et al.* (p. 132) carried out a study with orange orchards (*Citrus sinensis*) in a commercial farm located in the municipality of Sorocaba-SP, to verify the capacity of an organic management system and how it can contribute to carbon sequestration in the soil and mitigate GHG emissions (CO_2 , CH_4 e N_2O). Emissions were measured during two consecutive soil applications of organic and inorganic fertilizers. An adjacent seasonal fragment of a semi-deciduous forest was used as a reference for C and N stocks and their stable isotope ratios. The conversion of the forest to the citrus orchard was carried out 42 years before the experiment. The results showed that organic management did not promote C sequestration after six years of management. However, the results from the soil suggest a small positive C balance during the sixth year (1%), which can represent significant C sequestration after a long period of management. In addition, organic management has increased N_2O emissions (EF = 3.14%), and the GHG balance showed better responses to conventional agriculture in determining the relationship between harvest and emissions.

Volk *et al.* (p. 134) conducted a study to characterize the stock of organic carbon and nitrogen and the emission of greenhouse gases (GHG) from the soil, as well as to understand how they relate to vegetation and animal management. Assessments of soil gas emissions were carried out between 2014 and 2015 in a native field area with Hereford steers at three intensification levels: natural pasture (NP), fertilized natural pasture (FNP) and natural fertilized pastures with ryegrass (*Lolium multiflorum*) and red clover (*Trifolium pratense*) (NFP). Among other important results, a positive and significant relationship was found between the C and N stock in the soil and root mass, indicating that if animals' grazing is properly managed, it leads to an increase in the production of roots and an increase in the carbon stock and organic nitrogen. The conclusion was that more botanical composition diversity is positively related to the greater stock of organic carbon in the soil. The findings include that emissions fluctuated throughout the year, showing strong dependence on climatic factors (rain and temperature, mainly).

Chaves *et al.* (p. 122) evaluated the carbon stock in improved pastures in an area destined to the technological reference unit (URT) of Embrapa Amazônia Oriental, located in Fazenda Vitória in the municipality of Paragominas, in the southeast of the state of Pará. The local soil is classified as a Yellow Latosol and has a clayly texture. The following chronosequences were evaluated: I. native vegetation (NV), used as a reference, classified as dense ombrophilous forest (located close to pasture); II. degraded pasture (DP), intended for extensive livestock, made up of *Brachiaria humidicola*, highly infested with weeds, and managed with fire for renewal; III. improved pasture in integration with paricá (*Schizolobium amazonicum*)(PP); and IV. improved pasture, in integration with African mahogany (*Khaya spp.*) (IP). Soil collections were carried out over different years throughout the study (1993-2013). The main results showed that the soil's C stock (0-30 cm) at the NV area was similar to the recovered pasture areas (close to 55 Mg ha^{-1}) and differed from the DP area (42.4 Mg ha^{-1}). Most of the carbon stored in the recovered pasture soils comes from plants with a C3 type photosynthetic route. The greatest contribution from pastures (C4 plants) occurred in the 0-10 cm layer, with 21% in the IP and 23% in the PP, remaining below 15% in the subsurface layers.

Mello *et al.* (p. 90) used different nonlinear mixed models using soil data (f2C.2.0, f2C.2.A, f2C.2.B and f2C.2.C) to explain the dynamics of C and N stocks in the soil in a livestock system with different managements over time at Fazenda Vitória, located in the municipality of Paragominas-PA. Three distinct patterns of land use and soil cover were studied: I. agroforestry system with *B. brizantha* cv. Piatã between cultivation strips of *Schizolobium amazonicum* (paricá); II. agroforestry system with *B. brizantha* cv. Piatã among rows of *Khaya spp.* (African

mahogany); and III. secondary forest. Soil data were collected in 2013 from air-dried fine soil samples (TFSA), with three replicates in each area, in the following layers: 0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-130 and 130-150 cm. The content of C and N (g kg^{-1}) was analyzed in the elemental analyzer Carlo Erba CHN 1110. The study showed that the f2C model.2. A was the one that adjusted the best to the observed soil carbon data, which revealed high variability of C and N levels in the most superficial layers of the soil. This model proved to be efficient capturing the C and N content in the soil, and a valuable tool for monitoring and estimating stocks in the soil.

The research related to the evaluation of integrated systems of production and forest plantations that are presented in this compilation are concentrated in the South and Southeast regions, with an important role from the Federal University of Viçosa (UFV), in Minas Gerais. UFV has generated important results in relation to the potential of agroforestry systems to mitigate GHG emissions, especially related to the sequestration of C in the forest component of agroforestry systems. Regarding research related to emissions/removals in planted forests, most of the efforts are concentrated in the states of the Southern Region (Paraná, Santa Catarina and Rio Grande do Sul). However, this compilation does not reflect the entirety of national research efforts carried out on the topic, and represents a snapshot of the contributions received.

GHG fluxes generated in integrated production systems are more complex to measure due to the different components and particular arrangements of each established production system. Due to the importance that integrated systems have as an effective instrument to promote greater resilience and economic gains for agriculture, in addition to contributing to the mitigation of GHG emissions, the country has been striving to generate EF and technological innovations to increase its adoption throughout national territory. The results show that the EF values generated for the SCC are within the IPCC (2006) EF1 uncertainty range of 1%, while most are lower than 1%. This shows the importance of having specific EF data for each region, so that local emission estimates can benefit from continuous improvements and contribute to better national accounting.

It is also necessary to continue working on the generation of specific EFs for the agricultural and livestock component within the integrated systems, to demonstrate how effective it is as a GHG mitigation tool and as a model of sustainable management in agriculture. In addition, we need deeper studies that assess the arrangements that may have greater productivity and profitability, while at the same time achieving greater emissions reductions and even greater fixation of C in soil and biomass. We highlight that some contributions on integrated production systems with the livestock component are also present in the Compilation of Emission and Removal Factors of Greenhouse Gases from Brazilian Livestock.

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EVALUATING NITROUS OXIDE EMISSIONS IN PASTURES UNDER ROTATIONAL AND CONTINUOUS MANAGEMENT IN THE SOUTHEASTERN REGION OF BRAZIL

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Nitrogen gas loss measurements in the tropical savanna is still scarce in literature, especially regarding nitrous oxide emission factors in soils with the addition of nitrogen fertilizer. Southeastern Brazil is a region with an abundant production of beef cattle, around 5.76 million heads, according to the Department of Agriculture and Supply (GOVERNO DO ESTADO DE SÃO PAULO, 2007/2008).

The grazing methods are commonly classified as continuous or rotational pastures. In the first, the animals have uninterrupted access to the grazing area, during a pre-determined grazing period; in the second, rotational pastures designate periods of grazing and rest between the paddocks.

This study aimed to quantify N₂O emissions from *Brachiaria brizantha* soil pastures under two grazing methods – rotational pasture (RP) and continuous pasture (CP) – at the experimental station from the Faculty of Animal Science and Food Engineering, University of São Paulo, located in the city of Pirassununga-SP. The study was carried out between January 24 and October 11, 2014, and the data presented here refers to the period from January 24 to March 19, 2014, during the summer season (Figure). The region's climate is characterized as subtropical according to the Köppen-Geiger classification, with an annual rainfall of 1,300 mm and an average temperature of 23 °C, with a rainy season in summer and a dry season in winter. The soil is classified as Red Ferralsol (FAO classification), with 31% clay in the upper 20 cm layer.

In the RP method, cattle from the Nelore breed occupied a pasture area of 0.315 ha for seven days, followed by rest period of 28 days, completing a 35-day cycle, for two cycles. The period of this experiment comprised approximately two summer cycles. In the first cycle, nine male animals with an average weight of 279.06 kg were used, and in the second, seven animals with an average weight of 304.29 kg were used. An application of nitrogen fertilizer (ammonium nitrate) was made on February 3, in order to account for 60 kg of N per hectare. Part of the area was isolated with a tarp, protecting it

from the applied fertilizer. In the CP method, the animals remained in the paddock for the entire study period and no fertilizer was applied. Three animals were used at the beginning (with an average weight of 274.4 kg) and at the end (with an average weight of 316.0 kg) of the second cycle.

Gas samples to determine the soil N₂O flux occurred on alternate days, through PVC chambers installed in the experimental plots, following the static camera technique described by Keller & Reinert (1994). The chambers are composed of a 30 cm in diameter and 20 cm in height PVC base, with a 10 cm deep lid, containing a septum for gas collection and a vent. The bases were inserted into the soil at a depth of 3 cm. Twenty chambers were used for 15 sampling events, eight of them for the RP treatment with fertilization, four for RP without fertilization, and eight for the management of continuous pasture (CP) without fertilization. Samples were collected with 60 mL BD plastic syringes and transferred to 12 mL vials (vacutainers) by LABCO Exetainer. At the Biogeochemistry Laboratory of Embrapa Meio Ambiente in Jaguariúna-SP, the gas samples were analyzed in a Shimadzu GC-2014 (Greenhouse) gas chromatograph equipped with an electron capture detector (ECD) and a flame ionization detector (FID). The N₂O soil flux was calculated according to Jantalia et al. (2008).

The data presented here comprise a part of the experiment carried out in the summer. Currently, a study is underway to include the complete data, comprising the entire experiment.

PRELIMINARY RESULTS

- The accumulated emissions for fertilized pasture were estimated at 17.90 mg of N-N₂O m⁻² day⁻¹, while for non-fertilized pasture, it was 4.84 mg of N-N₂O m⁻² day⁻¹. The differences between the treatments with and without fertilization on the rotated pasture was 13.14 mg N-N₂O m⁻², equivalent to 0,13 kg N-N₂O ha⁻¹. In continuous pasture, emissions

totalled 5.16 mg de N-N₂O m⁻² day⁻¹ during the period. This value enabled the estimation of a nitrous oxide emission factor of 0.0022, which represents 22% of the emission factor recommended by the IPCC (0.01) for direct N₂O emissions from the application of nitrogen fertilizers.

CHALLENGES

- Denitrification and nitrification processes which occur through the mediation of microorganisms and that originate nitrous oxide emissions, are influenced by environmental conditions such as precipitation and temperature, as well as management practices such as fertilization, soil preparation, soil compaction, irrigation and drainage. 2014 was a year with low rainfall, which can be a partial explanation for the low N₂O fluxes. These results demonstrate how important it is for measurements to be continued and experiments repeated, so that improved annual N₂O emissions in pastoral systems can be reached. Micrometeorological methods are costly in the country, but it would be important to carry out comparative studies with traditional measurement methods, such as that of the static chamber;
- The study confirmed the spatial and temporal variability in N₂O emissions, making it challenging to reach precise annual estimations of this gas.

SOLUTIONS

- Nitrogen fertilizers are one of the many direct anthropogenic sources of N₂O emissions. The impact of using different types and formulations of nitrogen fertilizers in pasture areas still needs to be studied, and this line of research could result in a potential strategy for mitigating gas emissions.

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MODELING NITROUS OXIDE EMISSIONS FROM PURE GRASS PASTURES AND INTERCROPPED GRASS AND LEGUMES IN THE WESTERN BRAZILIAN AMAZON

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Brazilian agriculture is associated with greenhouse gas (GHG) emissions and the exact contribution of emissions from pastures is not yet known due to their varying quality/ degradation degrees. These emissions may cause extreme events that, in a closed cycle of cause and effect, may affect production systems in the Amazon. Knowing the magnitude of the contribution of livestock systems to GHG emissions in the Amazon Biome identifies variables associated to their processes and emission factors, potentially enhancing technological solutions for a positive balance between carbon inputs and outputs in the production system. The dynamics of mineral nitrogen (N) in the soil and the exchange of its gaseous forms at the soil-atmosphere interface are closely associated with the deposition of animal waste (urine and feces) in pasture. Depending on the content of inorganic N in the soil and the studied site, be it forest or pasture and the pasture age, the contents of N-ammonium and N-nitrate may be similar in the forest or dominated by N-ammonium in the pasture as it ages. Additionally, average annual net nitrification rates on the soil surface in the forest may be higher than in the pasture area, suggesting potential greater losses of N-nitrate, either through leaching or gaseous emissions in preserved forest soils, when compared to soil under consolidated pasture (NEILL *et al.*, 1995). According to Melillo *et al.* (2001) emissions of nitrous oxide (N₂O) from young pastures (5.0 kg N-N₂O ha⁻¹ year⁻¹) were two to one and a half times lower than in the forest (9.0 kg N-N₂O ha⁻¹ year⁻¹) during the first two years of pasture, increasing to one third of these amounts when the pasture was more than three years old (1.4 kg N-N₂O ha⁻¹ year⁻¹). The magnitude of the nitrate content in the soil surface is one of the best indicators for predicting N₂O emissions (VERCHOT *et al.*, 1999, MELILLO *et al.*, 2001). N₂O emissions can be measured through field samples by gas chromatography or estimated by process-based models. The DNDC (Decomposition Denitrification) model simulates biogeochemical cycles of carbon and nitrogen in agricultural systems (GILTRAP *et al.*, 2010). N₂O emissions for pure grass pastures (> 30 years of age) and intercropped with legumes- grass (> from four years after > 30 years of age) from the soil of a native forest in the west of the Brazilian Amazon, estimated by the DNDC model, will be presented here. To enable knowledge regarding the contribution magnitude of livestock system GHG emissions in the Amazon Biome, livestock in pasture systems in Acre, Brazil's western Amazon, were studied.

Nitrous oxide (N₂O) emissions were estimated using the Denitrification-Decomposition (DNDC) model.

The evaluated systems were pure pastures of *Brachiaria humidicola* (Rendle) Scheick (G) and *B. humidicola* grass intercropped with forage peanut *Arachis pintoi* Krapov. & WC Greg cv. BRS Mandobi (GL), both without fertilization. A native forest (NF) classified as open/dense bamboo was the benchmark for assessing land use change from native forest to pasture. Pure pasture was the benchmark for changing pasture management. The evaluated systems have the same type of soil, a plinthic Red-Yellow Argisol (EMBRAPA, 2013). The experiment was installed in 2011 at the Guaxupé farm (68 ° 05 'W, 9 ° 57' S, 200 m above sea level) in Rio Branco, State of Acre, Brazil. The native forest was removed from the soil used in the experiment in 1981.

Soil collections were carried out in G, GL and FN from February to December 2014 and from January to July 2015 in the layers of 0-10 cm and 10-20 cm, the soil sampling followed the Pecus Network protocol.

The results of soil sample analysis and meteorological information were the inputs from the DNDC model for predicting N₂O emissions (LI *et al.*, 1994).

PRELIMINARY RESULTS

- Average N₂O emissions in the 166 days are listed in this order: pure pasture (35,8 µg N m⁻² h⁻¹) > native forest (28,2 µg N m⁻² h⁻¹) > intercropped pasture (27,2 µg N m⁻² h⁻¹). N₂O emissions were lower during the transition from the wet-dry and dry-wet seasons and higher during the usual wet and dry seasons of the Brazilian Amazon;
- N₂O emissions were correlated with the porous space filled with soil water (0-10 cm) and with the soil temperature (0-10 cm) in the FN, G and GL systems (P < 0.05), and showed no correlation with soil N-nitrate content;
- Annual N₂O emissions were 3.13 kg N ha⁻¹ year⁻¹ in G, 2.47 kg N ha⁻¹ year⁻¹ in FN, and 2.38 kg N ha⁻¹ year⁻¹ in GL. The annual emissions predicted in the G, GL and

FN systems are within the range of annual emission tabulated by Verchot et al. (1999) for humid tropical forests (0.3 to 6.7 kg N ha⁻¹ year⁻¹) and according to Meurer et al. (2016) for pastures;

- The total N₂O emissions for the evaluated period was 4.6 kg N ha⁻¹ in G, 3.0 kg N ha⁻¹ in FN and 2.7 kg N ha⁻¹ in GL (Figure), higher than those cited by Melillo et al. (2001) for older pastures, however, still within the range mentioned by Meurer et al. (2016);
- Although the N₂O emissions measured in the Brazilian Amazon were within the range, the emissions predicted by the DNDC in this study should be seen with caution, since the results for emissions measured in the field are still not available for the soil, neither regional meteorological conditions and pasture management on the farm evaluated in this study.

CHALLENGES

- To measure N₂O emissions in field conditions for soil, regional meteorological conditions and pasture management evaluated in this study.

SOLUTIONS

- Integrated groups of well-established researchers in the Brazilian Amazon and national and international groups on the topic of climate change;
- A laboratory in the southwest of the Brazilian Amazon that has continuous operational capacity.

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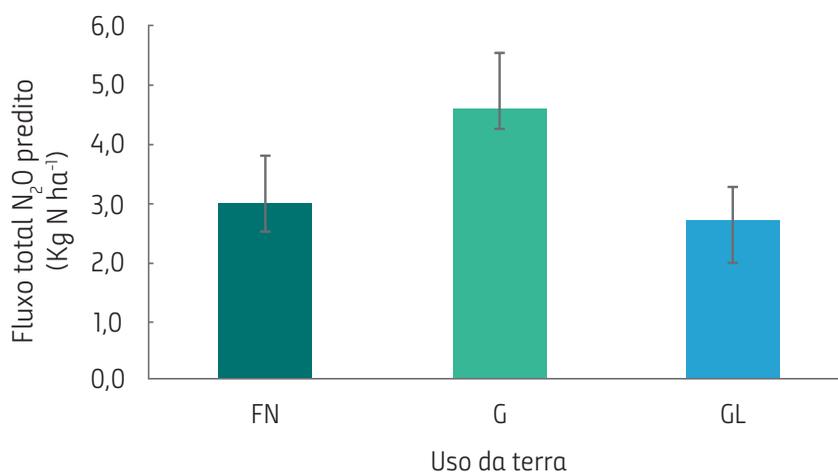
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Continued in Annex

Figure 1: Total NO fluxes predicted at Guaxupé farm, State of Acre, Brazil. FN = native forest. G = pure *Brachiaria humidicola* pasture and GL = intercropped *B. humidicola* with *Arachis pintoi* cv BRS Mandobi pasture. Values are averages from 38 simulations of soil parameters in the DNDC. Bars are the standard deviation of the mean.



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AMMONIA (NH₃) VOLATILIZATION AND NITROUS OXIDE (N₂O) EMISSIONS FOLLOWING SOIL APPLICATION OF PIG SLURRY IN CORN¹

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Brazil is amongst the largest pork producers and exporters in the world. Brazil's current pork production system generates large volumes of manure, which are normally handled in their liquid form. The high nitrogen content (N) in liquid pig slurry (PS) can be used as an alternative to synthetic nitrogen fertilizers. Another way of disposing the waste is through distributing it into the soil.

Most of the mineral N present in the PS is in its ammoniacal form, which is quickly oxidized to nitrate by nitrifying bacteria. When PS is applied on the soil surface in a no-tillage system (NT), significant amounts of N in its gaseous forms of ammonia (NH₃) and nitrous oxide (N₂O) may be lost, reducing its fertilizing potential and negatively impacting the environment. With this scenario in mind, the scientific community made efforts to study the effects PS applications, in the presence or absence of crop residues on the soil surface, and its gaseous emissions of N.

Soil surfaces applied with PS potentializes N emissions into the atmosphere, especially NH₃. The magnitude of the emissions depend on the method, time and rate of manure applied, in addition to the manure composition, soil type and environmental conditions.

The availability of carbon (C) increases when PS is applied and when crop residues are present, and can influence the emission of these gases since the heterotrophic bacteria, responsible for the immobilization of N and denitrification, depend on sources of C and energy. Therefore, understanding how different ways of applying PS into the soil may interfere in the magnitude of NH₃ and N₂O emissions is fundamental for the development of more adequate management strategies for this organic material.

The purpose of this study was to evaluate the NH₃ and N₂O emissions after the application of PS in a corn plantation, with and without the presence of black oat crop residues (*Avena strigosa* Schreb.) on the soil surface. This compilation will focus solely on N₂O emissions.

The study was carried out in the field in Red Dystrophic arenic Agrissol from the Federal University of Santa Maria (UFSM), located at 29 ° 41' 24" S, 53 ° 48' 42" W and an altitude of 106 m. N₂O emissions were evaluated for 90 days, between January and April 2011, in plots with dimensions of 1m x 1.6 m under the following treatments: T1 - Soil (Control); T2 - Soil + PS (PS); T3 - Soil + Black oat straw (Straw); T4 - Soil + Straw + PS (Straw + PS).

Manure was applied manually, on 01/19/2011, at a dose of 60 m³ ha⁻¹, two days before the corn sowing (hybrid Pioneer P3646). In the T3 and T4 treatments, black oat straw was added to the soil at a rate of 4.0 Mg ha⁻¹, collected at the physiological maturation stage. Since the N₂O fluxes evaluations were performed according to the procedures described by Rochette & Bertrand (2008). The collections were carried out from three to four times a week, during the first 30 days, and once the treatment emissions neared T1 levels, the collections were spaced between once to twice every 15 days. Air sample N₂O concentrations were determined by gas chromatography.

PRELIMINARY RESULTS

- N₂O emissions increased right after the application of PS, mainly when the waste was applied on black oat crop residues;
- The highest peaks of N₂O emissions occurred after irrigation and/or rainfall. On the seventh day of evaluation, after a precipitation of 40 mm, the emission of N-N₂O in the Straw + PS treatment exceeded the treatment with PS alone by 200% (> 844 µg of N-N₂O m⁻² h⁻¹);
- Approximately 90% of the total N-N₂O emissions occurred in the first 36 days after manure application. ;
- Cumulative N-N₂O emissions ranged from 1.1 to 3.2 kg N-N₂O ha⁻¹ with the highest value obtained when black oat straw was on the soil surface and PS was applied (Table);

- The straw + PS treatment presented an emission factor of 1.3% (above the IPCC recommended value of 1%) while in the treatment with PS alone, the emission factor was only 0.1% (Table).

CHALLENGES

- The lack of control over environmental conditions in field studies (for example, precipitation, temperature, wind, among others) may incur variations in assessments;
- The wide variety of cover plants and the variation in the quality / biochemical composition of their crop residues may add new variables to future studies on the effect of straw associated with the application of animal waste;

SOLUTIONS

- The application of Pig Slurry (PS) on black oat crop residues may contribute to increased nitrous oxide emissions to the atmosphere.

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GONZATTO, R.; MIOLA, E. C. C.; DONEDA, A.; PUJOL, S. B.; AITA, C.; GIACOMINI, S. J. Volatilização de amônia e emissão de óxido nitroso após aplicação de dejetos líquidos de suínos em solo cultivado com milho. *Ciência Rural*, v. 43, n. 9, p. 1590-1596, 2013.

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Table: Total amount of nitrogen (N) added to manure, accumulated emissions of N₂O and emission factors of N₂O after applying liquid pig slurry (PS) on the soil surface, with and without straw

Tratamentos	N adicionado com os DLS	Emissão acumulada de N ₂ O	Fator de emissão
	kg N ha ⁻¹	kg de N-N ₂ O ha ⁻¹	% do N adicionado
Testemunha		1,1 b*	
DLS	160	1,3 b	0,1 b
Palha		1,1 b	
Palha + DLS	160	3,2 a	1,3 a

Note: Averages followed by the same letter in the same column do not differ statistically from each other according to the Tukey test at 5%.

RYEGRASS OVERWINTERING IN SOYBEANS TO MITIGATE NITROUS OXIDE EMISSIONS IN A CROP-PASTURE SYSTEM IN SOUTHERN BRAZIL

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Integrated crop-livestock systems (ICL) are characterized by the production of grain, milk and meat in the same area over time. ICL systems have been used successfully in a variety of climatic environments. Furthermore, the success of these systems can be associated with a series of agronomic and environmental benefits. In the Southern Region of Brazil, corn or soybeans are commonly grown in the summer in rotation with ryegrass during the winter, which coincides with the low forage production of native pastures. If the summer crop is soybean, anticipating the forage supply can be obtained by the natural reseeding of ryegrass or by the overgrowth of ryegrass, when the soybean is at the beginning of the grain ripening stage (stage R7). Thus, the pasture fully development at the time of the soybean harvest.

The presence of pasture and its gradual development, concomitant with the fall of soybean leaves, should promote efficient nutrient cycling and reduce N gas losses, mainly in the form of nitrous oxide N₂O. This mitigating effect of N₂O emissions can be extended into the post-harvest period of soybean, as the pasture in full vegetative development will absorb mineralized N during the decomposition of legume crop residues.

The aim of this study was to evaluate the effect of ryegrass overwintering in soybeans under ICL system on N₂O emissions and forage production. The study was conducted during two agricultural years in argisol, in the experimental area of the Department of Soils, of the Federal University of Santa Maria (UFSM), located in the city of Santa Maria-RS.

The experiment was conducted during two agricultural years, in two land use systems under no-tillage: I. ICL with soybeans in the spring / summer and annual ryegrass in the fall /winter in overwintering when the soybeans were in stage R7 (ICL-I); and II. ICL with soybeans in spring / summer and annual ryegrass in autumn / winter sown after soybean harvest (ICL-II). Soil N₂O fluxes were measured using the static chamber method over a two-year period.

Cumulative N₂O emissions were obtained by integrating fluxes between consecutive sampling dates. The gravimetric moisture and ammonium (NH₄) and nitrate (NO₃) content of the soil were also evaluated. Grain yield was evaluated in soybean and biomass production for ryegrass, when the pasture reached a height of approximately 0.2 m.

PRELIMINARY RESULTS

- In both years there were few N₂O emission peaks, with the highest fluxes occurring during the strongest leaf fall period after the soybean harvest and after intense or sequential rainfall;
- Overwintering ryegrass (ICL-I) reduced annual N₂O emissions, compared to ryegrass sowing after soybean harvest (ICL-II) in the first year; but the systems did not differ significantly in the second year. However, it is important to note that the P value observed in the second year was relatively low for N₂O data for a field experiment. In the two-year average, the ICL-I reduced N₂O emissions by 18.4%, compared to the ICL-II (Table);
- The gradual fall of soybean leaves over the crop cycle represents a potential source of N₂O emissions, but sowing winter pasture can mitigate these emissions. The results of this study demonstrate that ryegrass overwintering reduces NO₃⁻ content in the soil and consequentially, the N₂O emissions;
- Soybean grain yield was not affected by production systems. Over the two years, ryegrass overwintering resulted in anticipated forage supply and on average, resulted in 1.4 times more biomass, when compared to ryegrass sowing after soybean harvest.

CHALLENGES

- In this study, differences in soil N₂O fluxes between two ICL systems and a grain production system were evaluated. However, the presence of grazing animals and the possible effects of excrement from animals (feces and urine) on N₂O fluxes have not

been tested. The separate quantification of N₂O originating from the soil and animal excrement in the soil is difficult due to the high spatial and quantitative variability of excrement in the soil (SELBIE *et al.*, 2015).

SOLUTIONS

- Ryegrass overwintering at the soybean grain maturation stage reduced N₂O emissions compared to sowing after soybean harvest. It can therefore be considered a practice to mitigate N₂O emissions from the soil.

DATA PUBLISHED IN:

PILECCO, G. E.; WEILER, D. A.; SCHMATZ, C. A.; SCHMATZ, R.; CHAVEZ, B.; GIACOMINI, S. J. Ryegrass early sowing into soybean to mitigate nitrous oxide emissions in a subtropical integrated crop-livestock system. *Agriculture, Ecosystems and Environment*, v. 272, p. 276-284, 2019. DOI: <https://doi.org/10.1016/j.agee.2018.11.006>.

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Tabela: : Soybean grain yield, ryegrass biomass production and accumulated N₂O emissions in integrated crop-pasture systems with ryegrass overwintering (ICL-I) and ryegrass sowing after soybean harvest (ICL-II)

System	Soybean grain yield		Ryegrass forage production		Cumulative N ₂ O emissions	
	2011/12	2012/13	2012	2013	2011/12	2012/13
			Mg ha ⁻¹		g N-N ₂ O ha ⁻¹	
ICL-I	4.65	3.82	5.04	4.89	763.1 (18.3%)*	879.4 (18.5%)
ICL-II	4.35	3.71	2.31	4.85	934.6	1079.7
P-value	0.53	0.85	< 0.05	0.77	< 0.05	0.10

*Caption: *Values in parentheses represent the percentage of N₂O emissions reduced from by the use of ryegrass overwintering.*

NITROUS OXIDE EMISSIONS DURING THE DECOMPOSITION OF CROP RESIDUES FROM COVER PLANTS SUMMER IN SUBTROPICAL CLIMATE

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Summer cover plants (SCP) are an important strategy in meeting basic assumptions of the no-till system. In tropical and subtropical climates, SCP is an alternative for protecting the soil against high intensity rains during the summer. Although they are grown in the same period as commercial species, SCP can also be cultivated between the harvest of summer commercial crops and the sowing of winter crops.

The cultivation of these species adds significant amounts of nitrogen (N) to the soil that partially or totally satisfies the demand for grasses cultivated in succession. However, it may also favor nitrous oxide (N₂O) emissions. This is because the cultural residues of SCPs have a high content of C and N that is soluble in water, which favor the production of N₂O in nitrification and denitrification processes. However, little is known on how SCP residues impact N₂O emissions. Knowledge is also lacking on emission factors under field conditions and mainly, under no-tillage cultivation systems with residues on the soil surface. Thus, the objective of this study was to quantify N₂O emissions and emission factors after SCP management.

The study was conducted during two years at the Federal University of Santa Maria, in southern Brazil. The soil of the experimental area is classified as Arrenic Red Dystrophic Argisol. The treatments consisted of a fallow treatment and six summer cover species: black velvet bean (*Mucuna aterrima*), millet (*Pennisetum americanum*), dwarf pigeon pea (*Cajanus cajan*), sunn hemp-spectabilis (*Crotalaria spectabilis*), sunn hemp-juncea (*Crotalaria juncea*) and jack beans (*Canavalia ensiformis*). SCPs were cultivated from January to April and managed with a full-blooming worm-roller, and the area was cultivated with black oat and white oat in the first and second year, respectively. Cultural residues were characterized in terms of total and soluble C and N levels in water, cellulose, hemicellulose and lignin. N₂O fluxes were measured using closed static chambers, two to three times a week in the first month and less frequently in the rest of the period. The samples were collected using polypropylene syringes and sent immediately to the laboratory for analysis by gas chromatography.

PRELIMINARY RESULTS

- In both years, SCP dry matter production ranged from 4.4 to 12.8 Mg ha⁻¹, and N accumulation was from 88 to 220 kg ha⁻¹ indicating the high production capacity of biomass and biological N fixation in the case of leguminous SCP in a short period of time (78 and 88 days), enabling its cultivation in the summer during the period between crops (Table);
- N₂O emissions increased after SCP management, especially in the first 30 days, when 65% of total emissions were observed. In the two evaluated years, N₂O fluxes were positively associated with the soluble fraction and negatively related to the fibrous fraction of SCP residues;
- Cumulative N₂O emissions (Table) ranged from 0.46 to 1.38 kg N ha⁻¹, with differences between cover crops and evaluated years. Pigeon pea was the green cover plant with the lowest N₂O emissions in the first year, while the other species did not demonstrate variations between each other. In the second year, *Crotalaria spectabilis* and jack beans were the SCPs that presented the highest N₂O emissions;
- N₂O emissions were not proportional to the amount of N applied. With the exception of millet and *Crotalaria spectabilis* in the second year, the other species presented emission factors below 1%, a value recommended by the IPCC. The study demonstrated that the inclusion of SCP in cropping systems results in lower N₂O emissions.

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WEILER, D. A.; GIACOMINI, S. J.; RECOUS, S. et al. Trade-off between C and N recycling and N₂O emissions of soils with summer cover crops in subtropical agrosystems. *Plant Soil*, v. 433, p. 213-225, 2018. DOI: <https://doi.org/10.1007/s11104-018-3831-2>.

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Table 1: Amount of N added with the SCP, cumulative emission of N₂O and N₂O emission factor after PCV management in no-tillage system

Cover plant	N added		C emissions of cumulative N ₂ O		Emission factor of N ₂ O	
	2010	2011	2010	2011	2010	2011§
	kg N ha ⁻¹		kg N-N ₂ O ha ⁻¹		% do N adicionado	
Mucuna-preta	91.9	88.4	0.71 a	0.79 b	0.64	0.74
Millet	120.6	60.7	0.61 a	1.05 b*	0.39	1.5
Pigeon pea	138.4	111.6	0.46 b	1.01 b*	0.24	0.78
Crotalaria juncea	135.1	146.8	0.70 a	0.89 b	0.41	0.51
Crotalaria-spectabilis	164.6	112.1	0.82 a	1.38 a*	0.42	1.11
Jack Bean	219.9	149.9	0.70 a	1.15 a*	0.25	0.64
Fallow	-	88.5	0.14 c	1.01 b*	-	0.98

Caption: * indicates that the values differ statistically between the years evaluated according to the Scott-Knott test (- <0.05); § Estimated values assuming that N₂O emissions from the soil (basal) in 2011 was the same quantified in 2010 in the fallow treatment that was kept without plants.

Note: Averages followed by the same letter in the same column do not differ statistically according to the Scott-Knott test (- <0.05).

BIOMASS AND CARBON STOCK IN EUCALYPTUS TRESS IN LIVESTOCK INTEGRATED SYSTEMS

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Livestock has been associated with greenhouse gas (GHG) emissions, considering it is the agribusiness sector responsible for the largest emissions, especially of enteric methane. To mitigate this problem, production systems based on recovered pastures and/or on pastures with capacity to increase carbon stocks (C) in the soil and decrease the C footprint have been proposed (OLIVEIRA, 2015; FIGUEIREDO et al., 2017).

It is in this context that integrated systems are included: crop-livestock (ICL) or agropastoral, crop-forest (CFI) or silvopastoral and the crop-livestock-forest (ICLF) or agrosilvipastoral integration systems. These systems have the potential to mitigate GHG emissions through C removal from the atmosphere and C storage in biomass and soil, especially when the tree component is present (OLIVEIRA et al., 2017; DUBE et al., 2002; ALMEIDA et al., 2011; CARVALHO et al., 2014; SALTON et al., 2014).

Trees can be included in already established pastures or implanted simultaneously with pastures (silvopastoral systems) and also in systems where the pasture is renewed or rotated with crops (agrosilvipastoral systems) (BALBINO et al., 2011; GIL et al., 2015). The potential for the tree component to accumulate C in the silvopastoral system is still poorly studied in Brazilian conditions and depends, among other factors, on the species, management and population density (TSUKAMOTO FILHO, 2003; GUTMAIS, 2004; OFUGI et al., 2008, MULLER et al., 2009).

This research aimed to estimate the C biomass stock of *Eucalyptus urograndis* trees (Clone GG100) grown in different integration models at five years of age (Figure 1). The area of the experiment is located in São Carlos - SP, Brazil (21° 57'S, 47° 50'W, 860 m alt) in a sandy-clayey dystrophic Red-Yellow Latosol and Cwa climate. The trees were planted in a *Brachiaria brizantha* cv pasture area at Piatã, in April 2011. Single rows were established with 2 meter spaced between plants within the line and 15 meters between rows, totaling a density of 333 trees per hectare. A clone of the hybrid *Eucalyptus urograndis* (GG 100) was used.

The production system was conducted with two experimental areas (area repetition), of approximately 3 ha each, using rotational pasture management divided

into six paddocks with an area of approximately 5000 m² each and with an occupation period of six days and a thirty-day rest period. Thus, the experimental area contained 12 paddocks. Pasture renewal took place in one third of each area per agricultural year (2 paddocks), where the grass was reseeded simultaneously with the corn crop (*Zea Mays* L. var. DKR 390 PRO 2) for silage production. Thus, three renovation systems were established in the experimental area, where the difference between them was the time when the trees were planted. An agrosilvipastoral system with renewal of the pasture two years after planting the trees (ICLF-2), an agrosilvipastoral system with renewal of the pasture in the third year after planting the trees (ICLF-3) and a silvopastoral system where at the time of the evaluation of the trees the pasture had not yet been renewed (SSP).

PRELIMINARY RESULTS

- Equations for estimating the volume of wood and biomass of the tree component were generated in systems for crop-livestock-forest integration;
- Five years after the implementation of the systems, the variation in volume accumulation per year in the systems analyzed in this work ranged from 26.4 (SSP) to 31.2 m³ m³ ha⁻¹ ano⁻¹ (ICLF-2). Biomass production evaluated according to tree trunks varied from 11.4 (SSP) to 13.5 Mg ha⁻¹ year⁻¹ (ICLF-2);
- Regarding C stocks in stems, the data obtained in this work (*E. urograndis*) are equivalent to a carbon accumulation of 5.2 (SSP) to 6.1 Mg ha⁻¹ year⁻¹ (ICLF -2);
- This is a long duration project and new samples will be carried out after 8 and 12 years of implantation of the integrated systems.

CHALLENGES

- Provide data on the potential for production and C stock in tree biomass in integrated systems;
- Based on the production of trees and other members of the systems, promote management plans for the tree component to maintain the productive balance and environmental benefits of the integrated systems with the presence of trees;
- Support the formulation of public policies.

SOLUTIONS

- The results obtained until the evaluation enabled the creation of equations to estimate the volume and biomass of trees in integrated crop-livestock-forest systems based on simple measurements of diameter at 1.3 m in height (DBH) and height of trees;
- The system model with pasture renewal in the second year of implantation provided the highest values of wood production, biomass and C at 5 years of the systems implementation;
- The amount of C stored in tree trunks will contribute to the mitigation of GHG emissions.

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Figure: Evaluation of eucalyptus roots in ICLF system for quantification of biomass and carbon stock.

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CARBON BALANCE IN RURAL PROPERTIES WITH AGROSSILVIPASTORIL PLANTING

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Brazil has adopted several measures to mitigate greenhouse gas (GHG) emissions mainly in the agricultural area, an important source of these gases. One of these measures is the Low Carbon Emission Agriculture Plan (ABC Plan), that fosters technologies that contribute to minimizing GHG emissions throughout the country. Agroforestry systems (AFSs) which integrate agricultural crops, animals and trees are among the technologies proposed by the ABC plan. As this type of activity is recent in the country and previous estimates were established on the contribution of these systems in reducing emissions and increasing the removal of GHG, monitoring studies are needed in order to improve the values used. Thus, the objective of the studies was to evaluate the carbon balance in different silvopastoral and agroforestry (SSP) systems. Torres et al. (2017) aimed to estimate GHG and aboveground carbon emissions in four different systems in Viçosa-MG.

Three different systems were established in a small rural property: system 1: corn (*Zea mays*) + pasture (*Brachiaria decumbens*) + eucalyptus (*Eucalyptus saligna*); system 2: beans (*Phaseolus vulgaris*) + pasture (*Brachiaria decumbens*) + eucalyptus (*Eucalyptus urophylla* x *Eucalyptus grandis*); system 3: pasture (*Brachiaria decumbens*) + eucalyptus (*Eucalyptus urophylla* x *Eucalyptus grandis*).

A fourth system was established in another rural property, also in Viçosa: system 4: pasture (*Brachiaria decumbens*) + eucalyptus (*Eucalyptus urophylla* x *Eucalyptus grandis*).

Emissions from the production, storage and transportation of agrochemicals (pre-farm) and activities within the farm (on-farm) were calculated, including fertilization, enteric fermentation, waste management and machinery. Pre-farm emissions were calculated using the emission factors reported by LAL (2004). On-farm emissions, on the other hand, were calculated using the IPCC methodology (2006). In all systems, the above-ground carbon was quantified for forest planting and grasses, using the direct or destructive method (SOARES et al., 2011) (Figure).

The work by Castro Neto et al. (2017) had the objective of evaluating the contribution of two SAFs in reducing the concentration of GHG in the atmosphere. The study was

conducted on a property in the municipality of Viçosa-MG. Two agroforestry systems implemented in December 2008 were evaluated. One was an agrossilvopastoral system composed of eucalyptus + beans + brachiaria. The second was a silvopastoral system composed of eucalyptus + brachiaria. The forest component was planted at a spacing of 8 m between rows and 3 m between plants. In the units, the indirect method was used to quantify the biomass of the forest component. For pasture, the direct method made the biomass estimates. GHG emissions came from agricultural activities (nitrogen fertilization) and livestock activities (enteric fermentation and manure management). GHG emissions were estimated based on the IPCC guidelines for national greenhouse gas inventories (IPCC, 2006).

In the work by Schettini et al. (2017), the objective was to evaluate the carbon balance in a silvopastoral system, with semi-intensive dairy farming, in Visconde do Rio Branco-MG. The study was conducted on a 4.76 ha SSP, implemented in January 2010. The tree component of the silvopastoral system is a hybrid of *Eucalyptus grandis* x *Eucalyptus urophylla*, planted at a spacing of 10 m x 3 m. The pasture was composed of *Brachiaria decumbens*, which already existed on the site before the implementation of the SSP, and, for this reason, did not enter into the carbon balance calculation. The forest component was planted at a spacing of 10 m between rows and 3 m between plants. The forest inventory was the census type. The indirect method was used to quantify the biomass of the forest component. For pasture, the direct method made the biomass estimates. GHG emissions came from agricultural activities (nitrogen fertilization and liming), livestock, electricity and fossil fuels. Emissions were estimated based on the IPCC guidelines for national greenhouse gas inventories (IPCC, 2006) and the MCTI emission factors (MCTI, 2010).

In the work of Brianezi (2015), the objective was to evaluate the contribution of five SSPs in reducing the concentration of GHG in the atmosphere. The study was conducted in two rural properties in Porto Firme-MG. Four agroforestry systems implemented in December 2006 and one in January 2009 were evaluated. The five systems are composed of eucalyptus + brachiaria. The forestry component was implanted, in the 2006 SSP, in 6

m spacing between lines and 4 m between plants and in 8 m spacing between lines and 4 m between plants. The forest inventory was the census type. The indirect method was used to quantify the biomass of the forest component. Pasture was not evaluated in this work. GHG emissions came from agricultural activities (nitrogen fertilization and liming) and livestock. Emissions were estimated based on the IPCC guidelines for national greenhouse gas inventories (IPCC, 2006) and the MCTI emission factors (MCTI, 2010).

PRELIMINARY RESULTS

- Equations for estimating the volume of wood and biomass of the tree component were generated in systems for crop-livestock-forest integration;
- Five years after the implementation of the systems, the variation in volume accumulation per year in the systems analyzed in this work ranged from 26.4 (SSP) to 31.2 m³ m³ ha⁻¹ year⁻¹ (ICLF-2). Biomass production evaluated according to tree trunks varied from 11.4 (SSP) to 13.5 Mg ha⁻¹ year⁻¹ (ICLF-2);
- Regarding C stocks in stems, the data obtained in this work (*E. urograndis*) are equivalent to a carbon accumulation of 5.2 (SSP) to 6.1 Mg ha⁻¹ year⁻¹ (ICLF -2);
- This is a long duration project and new samples will be carried out after 8 and 12 years of implantation of the integrated systems.

CHALLENGES

- Emission factors for livestock and agricultural crops specific to agroforestry systems are needed in order to demonstrate that these types of systems can reduce emissions for these components
- We need to find the appropriate arrangements for the allocation of tree species in the silvopastoral system in order to obtain the best carbon balance for the climate
- We need to evaluate the economic viability of silvopastoral systems since they have higher production costs when compared to traditional cultivation systems;
- The challenge is expanding studies to verify the maximum productivity potential of agricultural products in agroforestry systems, ranging from dairy to meat, in order to reduce GHG emissions as much as possible, and increase maximum carbon removal.

SOLUTIONS

- A well-managed silvopastoral system can result in carbon storage values superior to those initially established by Nationally Determined Contributions (NDC);
- The agroforestry systems that are more intensive in inputs but that result in higher productivity of dairy or meat per cattle head result in lower GHG emissions per unit produced.

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Continued in Annex

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SOIL CO₂ AND CARBON STOCK IN AGRICULTURAL AREAS AND PLANTED FORESTS IN THE CERRADO DO MATO GROSSO DO SUL REGION

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Essentially an agricultural country, 70% of Brazil's CO₂ emissions come from agricultural activities. Likewise, converting native vegetation areas into agricultural areas promotes a significant change in the temporal pattern of soil carbon loss, through soil CO₂ emissions (FCO₂) (KAUFFMAN et al., 1995; DIAS-FILHO et al., 2001; GALFORD et al., 2013). The hypothesis of this study is that different land uses in Agricultural activities cause changes not only in soil carbon stocks, but also in the quality of that carbon, thus altering the relationships and temporal patterns of CO₂ emissions.

The objective of this work was to evaluate the influence of the following land uses: native cerrado (CE), eucalyptus forest (EU), pine forest (PI) and silvopastoral system (SI, brachiaria intercropped with red pepper), on the dynamics of CO₂ emissions, as well as its relationship with the degree of humification of organic matter and the carbon stock of a latosol in the Cerrado region of Mato Grosso.

All experimental areas used in this study belong to the Teaching, Research and Extension Farm, Faculty of Engineering of Universidade Estadual Paulista, Ilha Solteira Campus, located in the municipality of Selvíria-MS. The soil CO₂ emissions (FCO₂) were measured using the LI-COR system (LI-8100). The soil temperature was monitored simultaneously with a temperature sensor that is an integral part of the LI-8100 system. Soil moisture was determined using Time Domain Reflectometry - Hydrosense TM.

The determination of the uptake of O₂ (FO₂) by the soil was carried out using the 25% UV flux system, which is adapted to a microcomputer with software (Gaslab).

The following routine analyzes were performed: hydrogenic potential (pH), determination of soil organic matter (MO) content (RAIJ et al., 1987), available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sum of bases (SB) and potential acidity (H+Al).

The exchangeable calcium, magnesium, potassium and available phosphorus contents were extracted using the ion exchange resin method (RAIJ, 2001); the cation exchange capacity (CTC) and the base saturation (V%) were also calculated, according to Embrapa (1997). Carbon stocks (CS) were adjusted for changes in soil density (Ds) that occur after the change in

land use (LUC) in the areas. For this, the methodology described by Ellert and Bettany (1995) was used to correct the soil carbon stocks at a depth of equivalent mass. The soil density was determined in undisturbed samples collected with a sampler adapted on cylinders, with average dimensions of 5.0 cm in internal diameter and 4.0 cm in height (EMBRAPA, 2011). The total pore volume was calculated based on the density value. To determine the degree of humification of soil organic matter (HLIFS), laser-induced fluorescence analyzes (LIFS) were used, as proposed by Milori et al. (2006).

PRELIMINARY RESULTS:

- The average carbon emission (FCO₂) values obtained during the total period differed significantly for each studied production system. PI and SI were the managements that presented the smallest averages (2.98 μmol m⁻² s⁻¹ and 3.22 μmol m⁻² s⁻¹, respectively), demonstrating a contrast with the area of native cerrado (CE), which presented the highest emission (4.55 μmol m⁻² s⁻¹) during the same evaluation interval;
- The averages of O₂ absorption (FO₂) of the soil varied, and they differed significantly for the PI, which presented the lowest average of O₂ absorption throughout the studied period (0.15 mg m⁻² s⁻¹);
- The carbon stock (CS) in the 0.0 a 0.1m layer, the largest came from CE (21.57 t ha⁻¹), followed by SI (21.34 t ha⁻¹), and EU (20.67 t ha⁻¹), and PI (13.91 t ha⁻¹), respectively. In the other depths, SI had the highest CS levels, always followed by EC, EU and PI;
- The constant k values indicate that, in the soil of CE, EU and PI, carbon was decomposed faster when compared to SI; that is, the residence time of labile carbon in these systems was shorter;
- In all depths, the highest HLIFS index was found in PI. In the EU, an intermediate value was found between the management with the highest HLIFS (PI) and treatments with lower HLIFS values (CE and SI). This result shows that as SI integrates two cultures in the same area, promotes a greater accumulation of labile organic material, resulting in less humidification. Regarding the depths, the HLIFS was higher as it

distanced itself from the soil surface;

- Despite the low ratios observed, there was a trend towards a decrease in C-CO₂ emission as the HLIFS increased. That was even more intense in the first layers, which is where most soil microbial activity occurs;
- In the Pearson linear correlation analyses, the attributes of F02 - Temperature (Ts) and Moisture (Ms) – and its relationship with the FCO₂ variable were studied. The results showed that, for EU, the FCO₂ variable presented positive correlations with Ts (r = 0.70, p < 0.05) and Ms (r=0.30, p<0.05), the latter correlation considered average – on a scale that considers from 0.10 to 0.29 as weak, from 30 to 50 as average and if higher, it's interpreted as large correlations. These correlation values found between Ms and FCO₂ corroborates what authors such as Pinto Junior et al. (2009) observed in transition forests between Amazon and Cerrado and in pasture areas. In CE, the relationships between Ts (r = 0.80, p <0.05) are considered high for the classification method, whereas, for Ms, the correlation was non-significant. In PI, FCO₂ correlated positively with Ts (r = 0.57, p <0.05) and Ms (r = 0.62, p <0.05). In SI, a high positive correlation was observed between Ts (r = 0.78, p <0.05) and a low positive correlation for Ms (r = 0.24, p <0.05).

CHALLENGES

- Agricultural activity in the country has a fundamental role in GHG mitigation. Since agriculture is one of the activities that emits the most CO₂, if it adopted the right soil management it has the potential of becoming a great ally by creating carbon sinks and consequently, producing more sustainably;
- In order to adapt, the productive system needs to be aware of the physical, chemical and biological characteristics of the soil, so that it can become an atmospheric carbon sink. Some of the characteristics are: lower CO₂ emissions in the soil have a higher content of carbon stock in the soil, which in this state, is also more easily decomposable. According to the studies conducted by this project, the crop-livestock-forest system (ICLF) has enormous potential for use, as it promotes integration of animals, forage plants and trees in the same environment (GARCIA; COUTO, 1997). The challenges, therefore, will be numerous and should involve governments, society and farmers.

SOLUTIONS

- Conservation management systems, such as silvipastoral systems, have soil attributes that are favorable to maintaining carbon in the soil, due to its low FCO₂, thus constituting a suitable system for the capture and storage of carbon and consequently, for additional greenhouse effects mitigation.

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Continued in Annex

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N₂O EMISSIONS, NITROGEN INCREASE AND SOIL CARBON REDUCTION THROUGH ORGANIC MANAGEMENT IN CITRUS ORCHARD

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Due to the need to assess greenhouse gas (GHG) emissions from the soil under different management systems and to establish GHG mitigation methods in citrus orchards, the present study was developed to verify the capacity of an organic management system to contribute to carbon sequestration, and to quantify emissions of CO₂, CH₄ and N₂O in soils under an orange plantation in the state of São Paulo, Brazil, with organic and conventional fertilization. Emissions were measured during two consecutive applications to the soil with organic and inorganic fertilizers.

The use of organic matter is important for the sustainability of organic agriculture, mainly due to nutrient cycling and greenhouse gas emissions into the atmosphere. Organic management was suggested at the beginning to assess the feasibility of replacing the conventional management system across the entire production area.

The hypothesis was that the carbon (C) and nitrogen (N) stocks in an organic management system are greater than in conventionally managed soils. For this purpose, a native forest was used as a reference, in order to evaluate the stock and the stable isotopic composition of carbon and nitrogen in the soil profile (depth from 0 to 100 cm). The hypothesis of an increase in GHG emissions for orange plantations was also evaluated in case organic fertilizer was applied, in comparison to inorganic fertilizer.

The study was carried out on a commercial farm cultivated with oranges (*Citrus sinensis*), located in the municipality of Sorocaba-SP (23° 34'-35.76"-S, 47° 30'-58.95"-W). An adjacent seasonal fragment of a semi-deciduous forest was used as a reference for C and N stocks and stable isotopic ratios. The forest fragment has a floristic composition represented mainly by species belonging to the families: Lecythidaceae, Fabaceae, Asteraceae, Malvaceae, Lauraceae, Arecaceae and Rutaceae. The conversion of the forest to the citrus orchard was carried out 42 years before the installation of the experiment and, since the conversion, the orchards were replanted approximately every ten years.

Orchards had the same history of soil management until the conversion from conventional to organic management. This conversion occurred concurrently in the two replanted orchards, six years before the measurements. Irrigation was not carried out during the planting of seedlings or during the decades of citrus cultivation. The spacing between the plants was 7 m x 3.5 m. The plants growing between them belonged predominantly to the genus *Brachiaria*. The midline plants were cut once a year in both orchards, during the winter, to facilitate circulation and harvesting by the machines and to control the incidence of non-grass species.

The average orange production was respectively, 9.9 t ha⁻¹ and 23.3 t ha⁻¹ in the organic and conventional management systems. In this work, organic farming is synonymous with biologic farming, which includes not only sources of nutrients, but also pest control methods. Organic management was initially suggested to assess the feasibility of replacing the conventional management system across the entire production area. However, the organic production area was only used partially as an isolated organic orchard on the farm, to minimize the border effect. The areas with similar declivity (<10%) within the sites were selected for soil and gas samples, in order to reduce the impact of the field's heterogeneity.

PRELIMINARY RESULTS:

- Organic agriculture did not promote C sequestration after six years of management, although conventional and organic management improved soil C stocks when compared to native forest. However, the results from the soil suggest a small positive C balance during the sixth year (1%), which can represent significant C sequestration after a long period of management. The organic system changed the rotation of the soil's organic matter, along the 0 to 100 cm profile, and increased the soil's N stock;
- The hypothesis that the stocks of C and N in an organic management system, would be greater in relation to

the soils in the conventional management system was partially confirmed, based on the increase of the N stock, but not on the C content, with changes in the composition of isotopes C and N in the soil profile from 0 to 100 cm, after six years of organic management. Notably, after six years of organic management, there were significant changes in C and N levels in isotopic compositions. Citrus are C3 plants, while grasses (*Brachiaria*) grew predominantly on C4. The effect of these grasses on the composition of the isotope C was observed at a depth of 0 to 30 cm. This change took place during the 42 years that the forest was replaced by citrus groves. On the other hand, the organic system influenced the isotope composition throughout the profile (0 to 100 cm), during six years of organic management;

- Based on the results, it is estimated that the C portion of the C3 and C4 plants, presented during six years of organic management, resulted in an increase of at least 20% of C in the entire profile of the analyzed soil. We can assume that in this study the estimate was underestimated, because the base of the poultry feed was composed only of C4 plants. However, no increase in C stocks was observed, which reinforced the occurrence of a primary effect, mineralizing soil organic carbon and its replacement with C derived from the fertilizer;
- The hypothesis that the application of organic fertilizer would increase GHG emissions, compared to the application of inorganic fertilizer on soils cultivated with orange, was confirmed based on the increase of GHG emissions from the soil under organic agriculture, mainly the emissions of N₂O;
- The conclusion reached is that organic management did not promote C sequestration after six years of management. In addition, organic management increased N₂O emissions, and the GHG balance showed better responses to conventional agriculture in determining the relationship between harvest and emissions.

CHALLENGES

- The results of this study should be considered together with other potential benefits of organic agriculture, such as social well-being and the maintenance of agroecosystem biodiversity, thus contributing to decision-making in the chosen management adopted in food production.

SOLUTIONS

- The results of this study should help not only to validate the available estimates of gas emissions from Brazilian citrus production, but also to assess the management practices to be adopted;
- The results of this study contribute to more accurate estimates of primary greenhouse gas emissions from citrus orchards and provide a better understanding of C and N cycling in the soil, thereby contributing to the development of more sustainable agricultural practices in tropical regions.

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ORGANIC CARBON STOCK AND GREENHOUSE GASES FROM THE SOIL IN A NATURAL GRASSLAND FROM THE PAMPA BIOME

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Over 50% of the bovine herd in Rio Grande do Sul and almost its entire herd of sheep is still raised in natural grassland, characteristic of the Pampa biome. This biome represents about 63% of the territory of Rio Grande do Sul state, and is responsible for the maintenance and production of bovine and sheep herds. However, the natural grassland vegetation also occurs in significant areas of the Pantanal, Atlantic Forest and Cerrado biomes. This natural ecosystem, even when managed with livestock, is environmentally multifunctional and provides numerous ecological functions. This characteristic is responsible for its potential to contribute to the conservation of natural resources (soil, water and biodiversity), differentiation of products, provision of ecosystem services and adaptation to climate change. Another important point is the fact that State Decree nº 52.431 of 2015, which regulates the use of Legal Reserves in the Rural Environmental Registry for the Pampa biome, allows rural areas and properties belonging to the Legal Reserve to be used for livestock production. Thus, the Embrapa Pecuária Sul research group has been making an effort to define management systems that protect this vegetation in accordance to environmental legislation, while delivering society a number of ecosystem services (such as carbon and nitrogen sequestration in soil and the decrease of greenhouse gas emissions) and ensuring livestock production and income for farmers. To this end, this research group conducted activities not only to characterize the carbon and organic nitrogen stock and the emission of greenhouse gases (GHG) from the soil, but also to understand how they relate to vegetation and animal management. Assessments of soil gas emissions were carried out between 2014 and 2015, in a native field area with Hereford steers at three intensification levels: natural grassland (NG), fertilized natural grassland (FNG) and fertilized natural grassland with ryegrass (*Lolium multiflorum*) and red clover (*Trifolium pratense*; PNM) overseeded. Assessments of carbon and organic nitrogen stock in the soil were carried out in 2015, in the same area mentioned above, up to a depth of 50 cm, following the standardized methodology proposed to members of the PECUS project. In order to understand the soil-plant-animal relationship established in this natural system when used for raising livestock, soil and root mass of the plants were also physiochemically assessed.

Some valuable results have already been reached and made available to the scientific community and farmers, but much remains to be done and researched.

PRELIMINARY RESULTS

- Organic carbon stock in the soil (without considering the vegetation and its roots) varied between 90 and 120 t/ha, considering the depth of 0 to 50 cm;
- A positive and significant relationship was found between the carbon and nitrogen stock in the soil and root mass, indicating that correct animal grazing management leads to an increase in the production of roots and an increase in the Corg and Norg stock;
- The greater diversity of the botanical composition is positively related to the greater Corg stock in the soil;
- CO₂ was the main GHG issued, however with very low values (oscillating between 0 and 250g C/ha/day), during autumn/winter with an average rate of 25 g C/ha/day and in spring summer with an average rate of 100 g C/ha/day);
- The emission of greenhouse gases fluctuated throughout the year, showing a strong dependence on climatic factors (rain and temperature, mainly);
- N₂O emissions were very low (about 63 g N₂O/ha during a 30 day period), only observed in the areas that received nitrogen fertilization (about 180 g N₂O/ha within 30 days after fertilization).

CHALLENGES

- Imaging areas and vegetation using drones is a potential method to estimate the carbon stock in the soil;

- In addition to being essential for precision livestock, sensors in the soil and a large amount of data can help us to better understand the soil-plant-animal relationship that regulates the way these natural systems function with livestock;
- The relationship between the structure of vegetation and its impact on the carbon and nitrogen stock needs to be further studied;
- The C balance in this type of system is more complex than in agricultural systems and depends on other emission factors that have not yet been evaluated.

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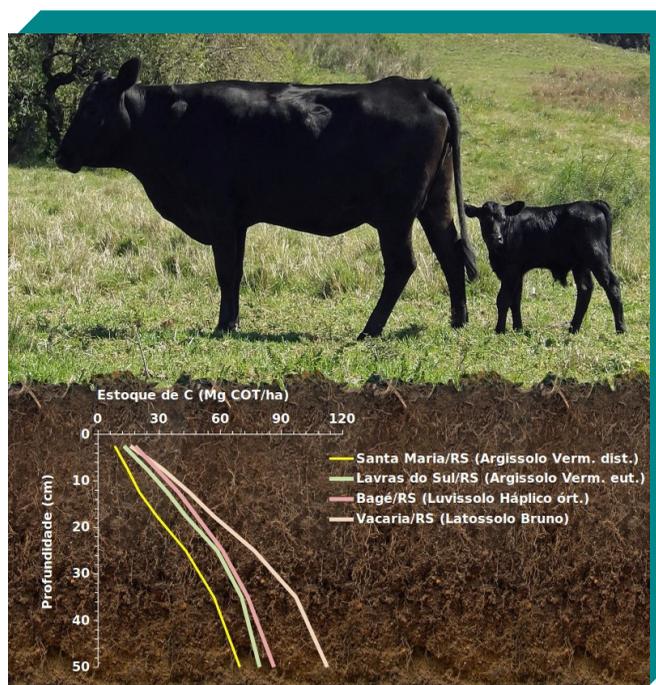
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SOLUTIONS

- Management practice recommendations for farmers aiming at maintaining Corg and Norg stocks and maintaining field resilience have been widely disseminated in technology transfer tools.

Figure: Stocks of total organic carbon in four soils under grazed natural grassland.



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SOIL QUALITY INDICATORS IN AN INTEGRATED LIVESTOCK SYSTEM WITH LOW CARBON EMISSIONS IN THE AMAZON BIOME

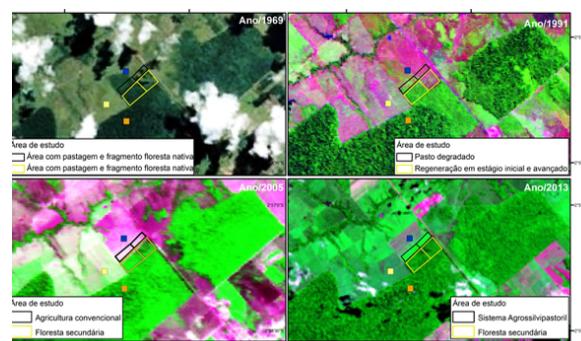
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Under the Component 7 Project, research actions were developed to assess the dynamics of organic matter in the soil (SOM) in agricultural production systems in the Amazon Biome. The objective of this study was to evaluate the carbon stock in the soil in improved pastures, in the municipality of Paragominas, in the Southeast of the State of Pará. The research was carried out in the area of Fazenda Vitória (Vitória Farm), destined to be the technological reference unit (URT) of Embrapa Amazônia Oriental. The local soil is classified as a Yellow Latosol and has a clayey texture. For the research, the following chronosequence was evaluated: native vegetation (NV), used as a reference, classified as dense ombrophilous forest (located close to pasture); degraded pasture (DP), intended for extensive livestock, formed by *Brachiaria humidicola*, with high weed infestation and managed with fire for renovation; improved pasture in integration with paricá - *Schizolobium amazonicum* - (PP) and improved pasture in integration with African mahogany - *Khaya grandifoliola* (PM). Soil collections were carried out over different years, throughout the study (Figure 1), in which Camargo et al. (1999) evaluated the NV and DP areas in 1993, and the PP and PM areas were evaluated in 2013. The process of improving the pasture (transition from DP to PP and PM), started in 2009, with the correction of soil fertility, for later implementation of the crop-livestock-forest integration system. The crop component was developed by June 2012, following the pasture succession model (*B. brizantha* cv. Piatã) and corn (*Zea mays*), grown in strips (20 m wide) and separated by forest components. From the second semester of 2012, the livestock and forest components were kept in the area, during the phase in which the animals were included for direct grazing. In the improved pastures (PP and PM), the samples were collected according to the recommendations from the PECUS Network protocol, in 0-10, 10-20 and 20-30 cm layers. The collections in the NV and DP areas were performed according to Camargo et al. (1999), also in the same layers. The carbon concentration (C) and the isotopic composition of the soil ($\delta^{13}C$) were evaluated in an elementary analyzer (Carlo Erba), coupled in a continuous flow isotopic ratio mass spectrometer (Delta Plus). Soil density (Ds) was calculated according to Embrapa (1997). The calculation of the C stock, which corresponds to the product of the C content ($g\ kg^{-1}$) by Ds ($g\ cm^{-3}$) and the layer depth, was adjusted according to the reference area (NV), according to Ellert and Bettany (1995). The origin of SOM in pastures differed from the native vegetation area

in the 0-10 cm layer. The pasture areas showed similarity in relation to $\delta^{13}C$, with about 22% of the soil C identified in these areas originating from plants in the C_4 photosynthetic cycle. This fact is related to the clayey texture of the soil that favors the physical protection of SOM in aggregates, a factor that reduce the previous vegetation cover's (C_3) SOM decomposition process. It is also inferred that the contribution of C_3 plants in the soil from the PP and PM areas is related to the incorporation of weed biomass (of the C_3 cycle) that remained in the area before the pasture improvement process. There was no significant difference in the C stock between improved pastures (average of $55\ Mg\ ha^{-1}$) and in NV ($55\ Mg\ ha^{-1}$) in the 0-30 cm layer. The lowest C stock was identified in the DP area ($42.4\ Mg\ ha^{-1}$), which varied from the others up to 20 cm in depth. The increase in the C stock in the improved pasture indicates improvements in soil quality. The increase in SOM in these areas increases the resilience capacity in integrated agricultural systems, with the C stock is an indicator of environmental sustainability when comparing these systems to degraded pastures that use fire as an annual renewal strategy.

Figure: Chronosequence in the Fazenda Vitória area (Paragominas, PA) in the years 1969, 1991, 2005 and 2013. In all the images, the orange dots indicate a fragment of native forest, the yellow dots indicate a homogeneous pasture and the blue dots (in the years 1969, 1991 and 2005) indicate managements similar to the black rectangle. In 2013, the area limited by the black rectangle (identified as the agrosilvopastoral system) corresponds to the improved pastures evaluated in the present study.



PRELIMINARY RESULTS

- The carbon stock in the soil (0-30 cm) of the vegetation area was similar to the areas of recovered pastures (close to 55 Mg ha⁻¹) and differed from the degraded pasture area (42.4 Mg ha⁻¹);
- Most of the carbon stored in the soil of the recovered pastures comes from plants with a C3 type photosynthetic route. The greatest contribution of pastures (C4 plants) occurred in the 0-10 cm layer, with 21% in the PM and 23% in the PP, remaining below 15% in the subsurface layers. Identifying the origin of soil organic matter is a tool that has the potential to be used as an indicator of C increase in pasture soil, over time, taking the edaphoclimatic characteristics of the environment and the management of the system into account;
- The improvement of pastures with the implementation of the crop-livestock-forest integration system (CLFI) shows that Embrapa's technology transfer strategy in the Paragominas region was successful. The research carried out at Fazenda Vitória showed an increase in carbon fixation in the soil of the area managed according to the CLFI system, showing favorable contributions to environmental sustainability, after the pasture recovery process.

CHALLENGES

- To recover pastures on their way to degradation, in the Amazon Biome, by adopting specialized agricultural techniques, aiming at the rational use of natural resources and increase of carbon stocks in the soil;
- To recompose the loss of organic matter and soil compaction due to inadequate management of agricultural cultivation and livestock production areas, encouraging the development of specialized conservationist systems to increase the resilience of the productive areas and prevent the degradation of the productive area;
- Disclosure of economically viable agricultural practices, capable of mitigating GHG emissions and optimizing productivity. We must encourage the recovery of pastures to mitigate GHG emissions in pastures that are undergoing degradation in the Amazon;
- To generate scientific information regarding soil quality indicators in integrated agricultural systems, in order to provide information to support public policies for the sustainable agricultural development of the Amazon Biome.

SOLUTIONS

- The results suggest the importance of developing research on agricultural systems that defend the rational use of natural resources;
- The evaluation of the dynamics of soil organic matter along the chronosequence, pointed out that investments in recovery and improvement of pastures is viable and environmentally correct, since it increased the carbon stock in the PP and PM areas;
- The increase in the carbon stock in the soil after the recovery of pastures is an indicator of the environmental sustainability of the production system.

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Continued in Annex

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STATISTICAL MODELING OF SOIL CARBON IN SPECIALIZED INTEGRATED-CROP-LIVESTOCK-FOREST PRODUCTION SYSTEM IN PARAGOMINAS-PA

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The Brazilian Amazon is considered the largest remaining tropical forest in the world and provides important ecosystem services, such as the maintenance of several species of flora, fauna, and water cycling, in addition to storing a large amount of carbon in its soil-plant system. Therefore, existing knowledge is that converting native forests to pastures, as well as the use of fire to renew pastures, may threaten the balance of ecosystem functions. Agricultural production systems developed in the Amazon biome must be managed using techniques that advocate the rational use of natural resources. For this reason, there is an increasing interest in evaluating and modeling the concentration of Carbon (C) and Nitrogen (N) in the soil, in different land use systems, because the dynamics of these elements are directly related to the sustainability of the productive arrangement and the mitigation of possible environmental impacts. The approach of non-linear models is becoming more and more common, citing as an example studies such as de Oliveira et al. (2000) which compares models to describe the growth of Guzerat breed females. Paz et al. (2004) also used models to explain the association between genetic polymorphisms and growth in cattle. In this context, Zeviani et al. (2012) used non-linear models to describe the release of nutrients in the soil, demonstrating different possibilities for applying statistical analysis with mixed non-linear models to assess and explain natural phenomena. Thus, this chapter presents modeling results that explain the dynamics of C and N concentrations at different depths of the soil in the CLFI system. The survey was carried out at Fazenda Vitória, located in the municipality of Paragominas, southeastern Pará, enclosed by geographic coordinates 02°59'58.37 "S and 47°21'21.29" W. Three different patterns of land and forage use were studied: I. Agrosilvopastoral system formed by *B. brizantha* cv. *piatã* between cultivation strips of *Schizolobium amazonicum* (*paricá*); II. Agrosilvopastoral system formed by *B. brizantha* cv. *piatã* between cultivation strips of *Khaya* spp. (*African mahogany*); III. Secondary forest. Soil collection was carried out in 2013, with three replications in each area, in the following layers: 0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-130 and 130-150 cm. For the evaluation of the C and N content ($g\ kg^{-1}$), soil samples (TFSA) were analyzed

by a Carlo Erba CHN 1110 elemental analyzer. Data was used to test the mixed nonlinear models and to describe the average behavior of the responses of C and N levels in pastures and in the secondary forest. The repeated measure in space (depth) was considered as well as the heterogeneity of variances in this space. In general, the levels of C and N in the *i*-th sample (individual), in the *j*-th depth of the *u*-th system can be represented by $Y_{iju} = \beta_{0u} X_{ij}^{\beta_{1u}} + \epsilon_{iju}$ where x_{ij} is the depth at the *i*-th sample ($i = 1, \dots, N$), at the *j*-th depth ($j = 1, \dots, n_i$). In terms of mixed models, we have $Y_{iju} = \beta_{0u} X^{-\beta_{1u} + b_{ij}} + \epsilon_{iju}$ is the mean value of the grade under study in the system, β_{1u} is the rate of accumulation of this grade, b_{ij} is the random effect associated with β_{1u} , independently and identically distributed as $N(0, \sigma^2 b)$ and ϵ_{iju} is the random error associated with Y_{iju} , independently and identically distributed as $N(0, \sigma^2 \epsilon)$, and independent from b_{ij} . Robust methods that allow modification of matrix structures should be used to capture such heterogeneity, based on the mixed nonlinear model. Among all those tested, the f2C model with a structure assuming equal covariance for random effects and a varPower structure for residues, was the one that best adjusted to the observed data on carbon in the soil, validated through residue assesment.

RESULTS

- High variability in the most superficial layers of C and N contents in the soil;
- Several models tested, based on the likelihood ratio test, modifying structures of intra-individual covariance matrixes;
- The model with the variance function was the one that best suited the data observed in the livestock production system in Paragominas.

CHALLENGES

- High cost for collecting the soil and carrying out chemical assessments in the laboratory;

- The number of repetitions increases the statistical significance, but the high costs for carrying out assessments are factors that must be considered when assessing results carried out in the field and statistical modeling;
- A larger number of soil samples is needed, along the profiles, to ensure greater accuracy in the model for estimating C incorporation in soils with pasture management in the Amazon biome, as was the case in the study in Paragominas.

SOLUTIONS

- The adoption of a production system that prioritizes the recovery of pastures has the capacity to increase carbon in the soil;
- The mixed model used proved to be efficient for describing C and N over long soil profiles, being a valuable tool for monitoring and estimating the dynamics of C in the soil.

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Figure: Sistema agrossilvipastoril formado por *B. brizantha* cv. *piatã* entre faixas de cultivo de *Khaya* spp. (mogno africano). Fazenda Vitória – Paragominas, PA



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Figure: Soil profile evaluated in a agrossilvipastoral system made up of *B. brizantha* cv. *piatã* between strips of *Schizolobium amazonicum* (paricá). Yellow clayey Latossol. Fazenda Vitória – Paragominas.



GREENHOUSE GAS EMISSIONS AND ENVIRONMENTAL INDICATORS IN A EUCALYPTUS PLANTED FOREST IN THE CORE CERRADO REGION

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Study 1. This study evaluated the dynamics of CH₄ and N₂O fluxes in soils under eucalyptus plantations and native Cerrado vegetation, as well as possible interactions between environmental factors and fluxes. The accumulated fluxes were not influenced by the age of the eucalyptus stands, history of use, and years studied. The cumulative N₂O fluxes in all three areas was ≤ 0.85 kg ha⁻¹ year⁻¹. As for CH₄, the values were negative, and ranged from -1.86 to -0.63 kg ha⁻¹ year⁻¹, in eucalyptus plantations, as well as in native Cerrado vegetation.

The study period suggests the uptake of CH₄ from the atmosphere and the contribution of CH₄ and N₂O to the global warming potential (GWP) which ranged from 82 to 228 kg CO₂eq ha⁻¹ year⁻¹ for eucalyptus plantations and from 57 to 82 Kg CO₂eq ha⁻¹ year⁻¹ for native Cerrado vegetation.

Study 2. The study evaluated the litter dynamics in stands of *Eucalyptus urophylla* × *E. grandis* with different ages and Cerradão. In the evaluation, higher biomass and C contents were observed in the litter for older eucalyptus. On the other hand, the highest decomposition rate was for the Cerradão (remaining mass of 23% in 720 days), attributed to the greater apparent release of N, soil moisture and biodiversity in the native area. Lignin levels increased, cellulose decreased and hemicellulose remained stable, over 720 days. An increase in the concentration of N and P in the remaining mass and positive correlations between the remaining mass and the C: N and C: P ratios were also observed. The litter C: N ratio was $\geq 76: 1$ at zero time and $\geq 30: 1$, at 720 days for the areas assessed.

PRELIMINARY RESULTS

- The objective of the study was not to obtain emission factors; however, this research generated the following results presented below: In already established eucalyptus forest stands, the daily fluxes of (N₂O and CH₄) greenhouse gases were low and did not differ of Cerradão. In relation to mineral N, the predominant form was ammonia.

- The decomposition of litter was positively correlated with the reduction of cellulose content. The concentrations of N and P increased, indicating that the greater the loss, the greater the concentration of the elements in the remaining mass.
- Planting eucalyptus after agricultural use reveals a higher concentration of P. The soil in this area showed about three times more P when compared to Cerradão and eucalyptus planted in an area, with no history of agricultural use.
- The C:N and C:P ratios had positive correlations with the loss of litter mass, due to the fact that C presented an average release of 21% for the evaluated areas.
- It is also worth mentioning that if the study period had been only one year (360 days), no difference would be detectable in the remaining litter mass between the eucalyptus stands and the native vegetation.

CHALLENGES

- Evaluate greenhouse gas emissions and infer about environmental indicators in forests planted with eucalyptus and natural forests of the Cerrado biome.

SOLUTIONS

- Forests already planted with eucalyptus of different ages have the potential to mitigate greenhouse gas emissions.

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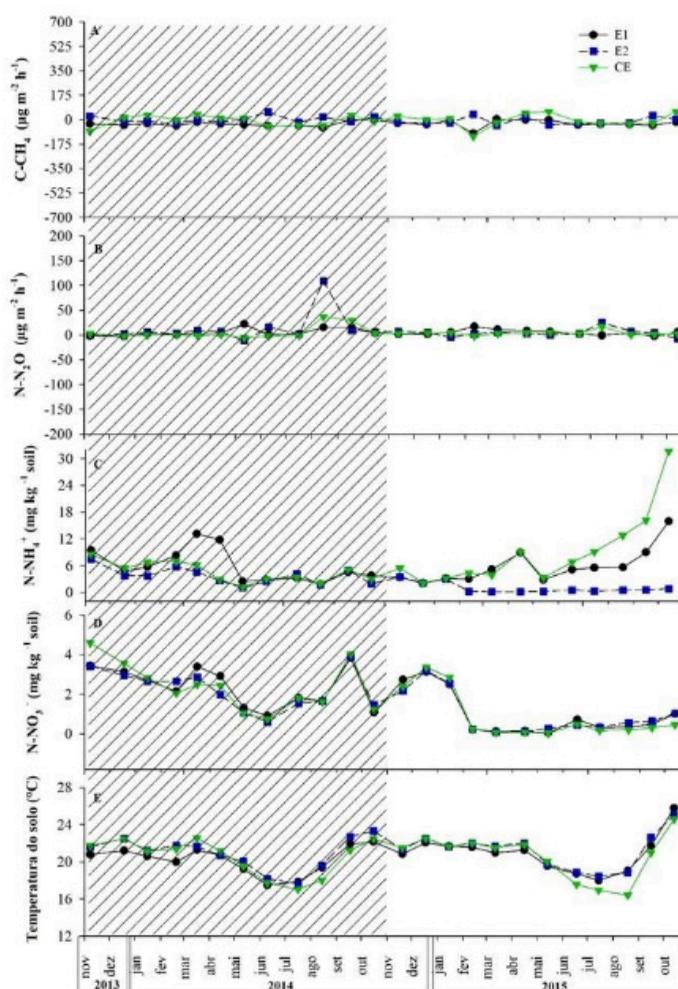
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Figure: Daily fluxes of methane - CH₄ (A), daily fluxes of nitrous oxide - N₂O (B), ammonium NH₄⁺ (C), nitrate NO₃⁻ (D) and soil temperature (E) from November 2013 to October 2015 in plantations of *Eucalyptus urophylla* x *Eucalyptus grandis* 48 months - E1, 72 months - E2 and in Cerradão Vegetation CE. Source: Oliveira et al. (2021)



Annex -Continuation of References

Complement of bibliographic references and publication of contribution data:

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