Uncovering a Hidden Methane Source: Grass Management and Soil Liming as Mitigation Strategies in Amazon Pasture Soils

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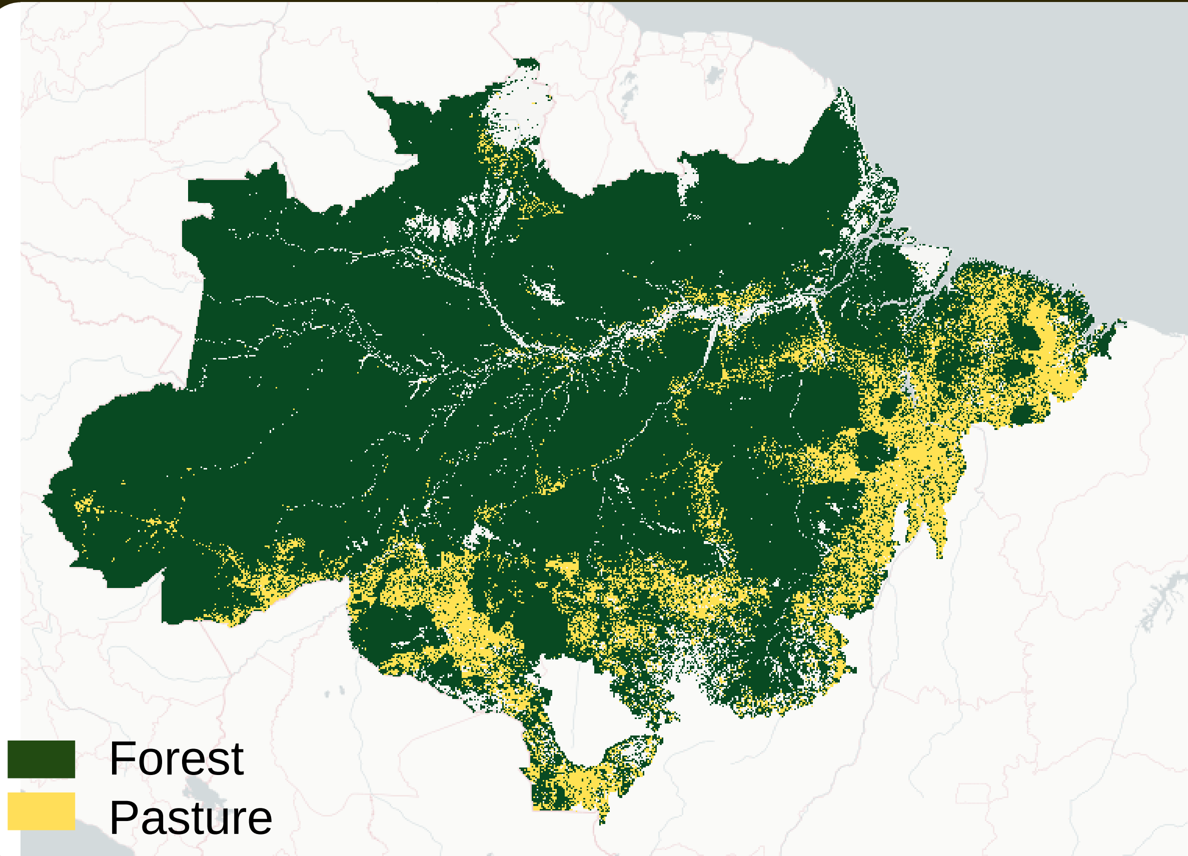
14th January 2026

Brazilian Amazon



Area:

421 mi ha[a]

Pastures:

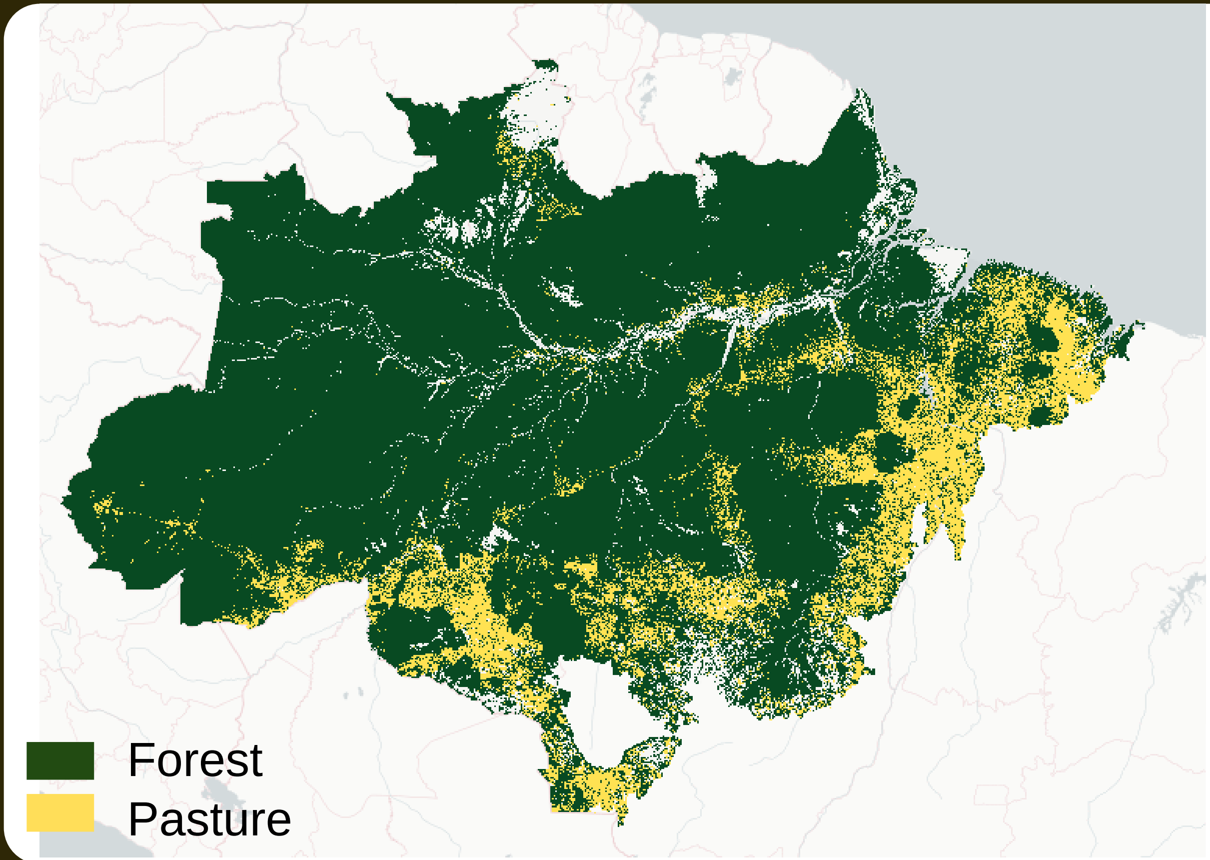
56,1 mi ha[a]

Degraded or under degradation pasture:

> 30 mi ha[a]

[a] MapBiomas – 2024
https://brasil.mapbiomas.org/

Brazilian Amazon



Area:

421 mi ha[a]

Pastures:

56,1 mi ha[a]

Degraded or under degradation pasture:

> 30 mi ha[a]

~24 mi ha

[a] MapBiomas – 2024
https://brasil.mapbiomas.org/

Slash and burn and soil pH

Fonte: https://amazoniareal.com.br/

Ashes incorporation to the soil ↑ pH ↓ Al^{3+}

With time... ↓ pH ↓ Ca^{2+}

Without management... ↑ Degradation

Need of liming to:

- Calcium and Magnesium supply
- Restoration of degraded areas

Methane and forest-to-pasture conversion in the Amazon

1976 – CH_4 is a greenhouse gas

12 November 1976, Volume 194, Number 4266 SCIENCE

Greenhouse Effects due to Man-Made Perturbations of Trace Gases

Anthropogenic gases may alter our climate by plugging an atmospheric window for escaping thermal radiation.

W. C. Wang, Y. L. Yung, A. A. Lacis, T. Mo, J. E. Hansen

tion with the hydroxyl radical OH (K2), with small additional contributions due to photolysis (J2) and reaction with $O(^1D)$ (K3). The all-important hydroxyl radical involved in reaction K2 is mainly derived from

$$O(^1D) + H_2O \rightarrow 2OH \quad (K10)$$

where $O(^1D)$ is formed by photolysis of ozone

$$O_3 + h\nu \rightarrow O_2 + O(^1D) \quad (J8)$$

The concentration of OH is limited by reaction K2 and by reaction with carbon monoxide

$$OH + CO \rightarrow CO_2 + H \quad (K11)$$

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 91, NO. D11, PAGES 11,791–11,802, OCTOBER 20, 1986

Emissions Of N_2O, CH_4 and CO_2 From Tropical Forest Soils

MICHAEL KELLER

Department of Geology, Princeton University, Princeton, New Jersey

WARREN A. KAPLAN AND STEVEN C. WOFSY

Center for Earth and Planetary Physics, Harvard University, Cambridge, Massachusetts

1986 –Tropical forest soils sink atmospheric methane

1988 – Forest-to-pasture conversion can result in soil emissions

Tropical Deforestation: Some Effects on Atmospheric Chemistry

Report

By Thomas J. Goreau and William Z. de Mello

Ambio. 1988. 17(4): 275-281

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 101, NO. D13, PAGES 18,547–18,554, AUGUST 20, 1996

Consequence of forest-to-pasture conversion on CH_4 fluxes in the Brazilian Amazon Basin

Paul A. Steudler,[1] Jerry M. Melillo,[1] Brigitte J. Feigl,[2] Christopher Neill,[1] Marisa C. Piccolo,[2] and Carlos C. Cerri[2]

*

1996 – Consistent measurements of pasture emissions

Methane and forest-to-pasture conversion in the Amazon

2000 – Importance of seasonality in soil CH_4 fluxes (east)

Ecosystems (2000) 3: 41–56
DOI: 10.1007/s100210000009
ECOSYSTEMS
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ORIGINAL ARTICLES

Land-Use Change and Biogeochemical Controls of Methane Fluxes in Soils of Eastern Amazonia

Louis V. Verchot,[1,2]* Eric A. Davidson,[1,2] J. Henrique Cattânio,[2] and Ilse L. Ackerman[1]

ELSEVIER
Geoderma 107 (2002) 227–241
GEODERMA
www.elsevier.com/locate/geoderma

Seasonal variation of soil chemical properties and CO_2 and CH_4 fluxes in unfertilized and P-fertilized pastures in an Ultisol of the Brazilian Amazon

Silvana Aparecida Pavan Fernandes[a,*], Martial Bernoux[b], Carlos C. Cerri[a], Brigitte J. Feigl[a], Marisa C. Piccolo[a]

2002 – Importance of seasonality in soil CH_4 fluxes (west)

frontiers in Microbiology
ORIGINAL RESEARCH
published: 06 October 2015
doi: 10.3389/fmicb.2015.01057
CrossMark

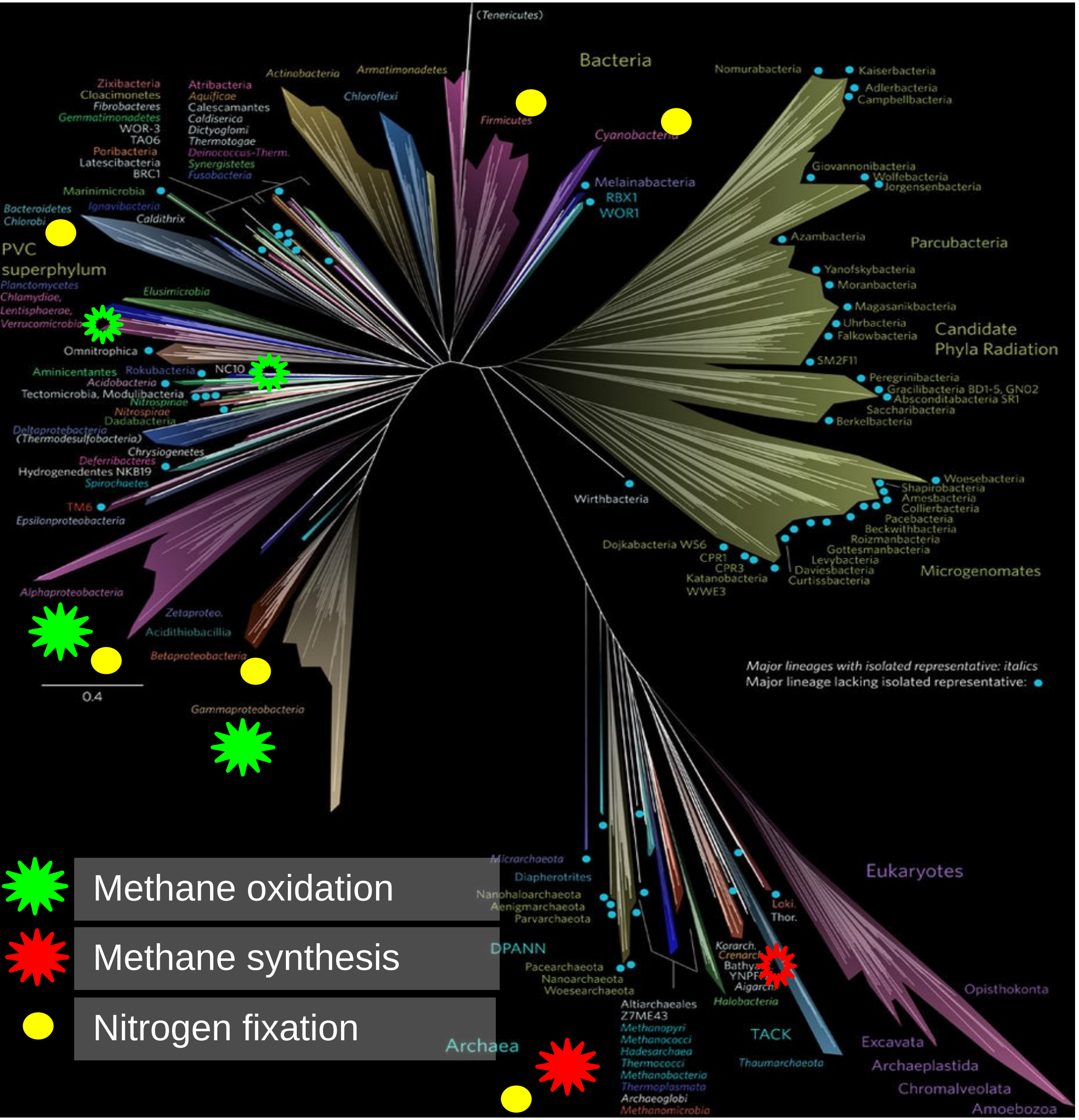
OPEN ACCESS

Edited by:
Silvia Pajares Moreno,

Specific microbial gene abundances and soil parameters contribute to C, N, and greenhouse gas process rates after land use change in Southern Amazonian Soils

Daniel R. Lammel[1,2]*, Brigitte J. Feigl[1], Carlos C. Cerri[1] and Klaus Nüsslein[2]*

2015 – First *insights* on Amazon soil methane microbiota



Methane producers and consumers (best characterized)

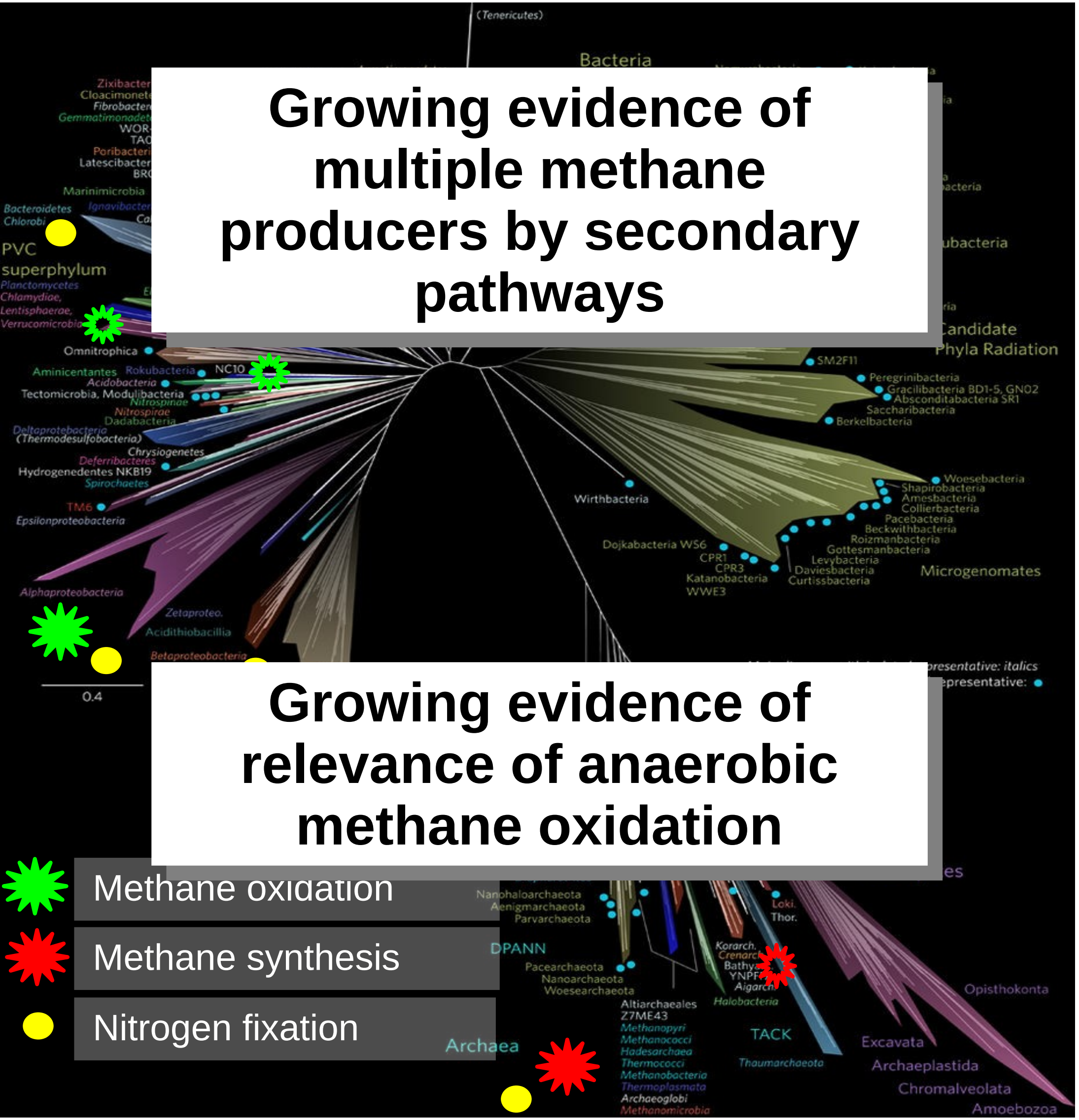
Methanogens

- Euryarchaeota
  - Methanomicrobiales
  - Methanocellales
  - Methanosarcinales
  - Methanobacteriales
  - Methanococcales
  - Methanopyrales
- Bathyarchaeota **(2015)**

Methanotrophs

- Alfaproteobactérias
  - Methylocystaceae
  - Beijerinckiaceae
- Gamaproteobactérias
  - Methylococcaceae
  - Methylothermaceae
  - Crenotrichaceae
- Verrucomicrobia
  - Methylacidiphilaceae

Knief. 2015. Fron. Micr. 6: 1346
Evans e col. 2015. Science 350(6259): 434-438



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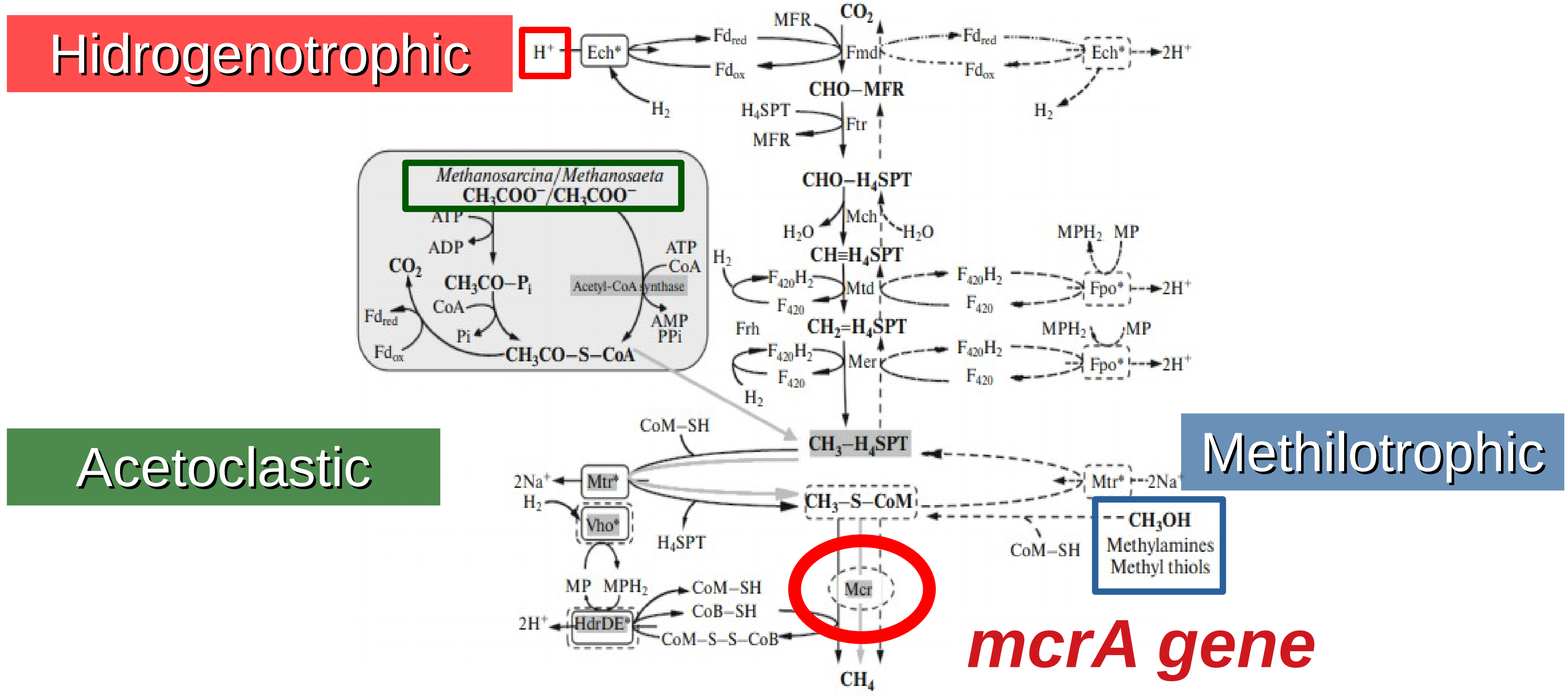
Knief. 2015. Fron. Micr. 6: 1346
Evans et al. 2015. Science 350(6259): 434-438
Evans et al. 2019. Nat Rev Mic. 17: 219-232

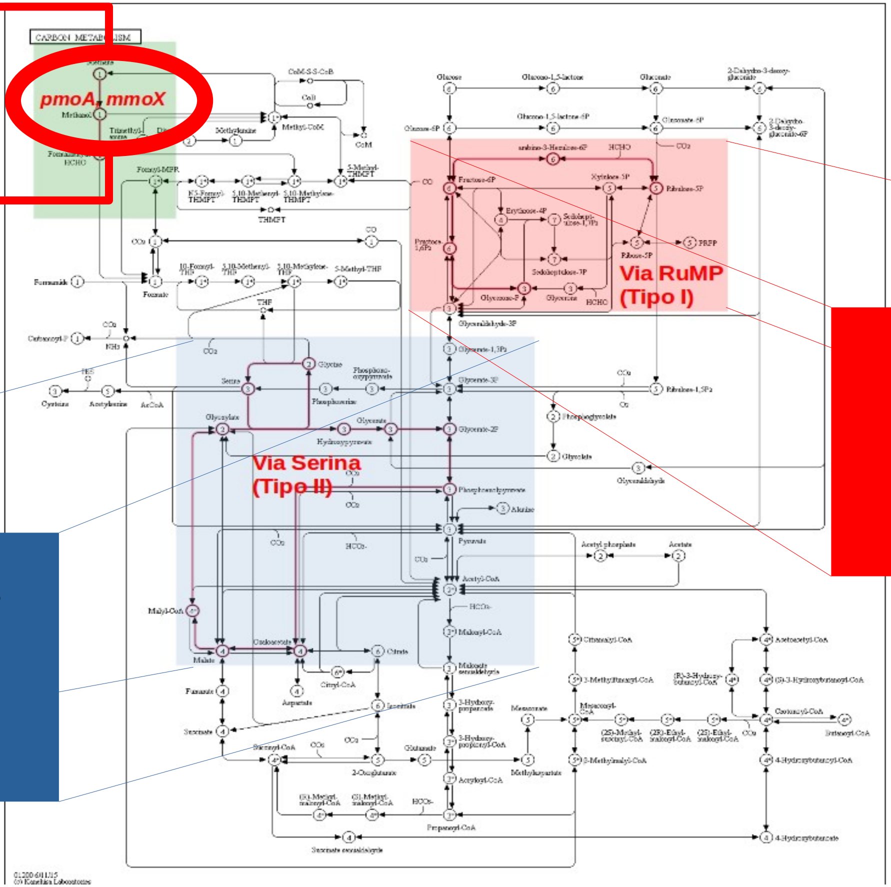


Kallistova e col. 2017. Microbiology 86(6): 671-691

Methanotrophy

Methane

Methanol



Type I Methanotrophs
Gamaproteobacteria

RUMP pathway

Type II Methanotrophs
Alfaproteobacteria

Serines pathway

Kanehisa e Goto. 2000. Nuc. Ac. Res. 28: 27-30

How does grass coverage and soil liming influence methane fluxes in pastures?

Science of the Total Environment 838 (2022) 156225

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Maintaining grass coverage increases methane uptake in Amazonian pastures, with a reduction of methanogenic archaea in the rhizosphere

Check for updates

Leandro Fonseca de Souza[a,b,*], Dasiel Obregon Alvarez[a,c], Luiz A. Domeignoz-Horta[b,d], Fabio Vitorino Gomes[a], Cassio de Souza Almeida[a], Luis Fernando Merloti[a], Lucas William Mendes[a], Fernando Dini Andreote[e], Brendan J.M. Bohannan[f], Jorge L. Mazza Rodrigues[g], Klaus Nüsslein[b], Siu Mui Tsai[a]

[a] Center for Nuclear Energy in Agriculture, University of Sao Paulo, Piracicaba, SP, Brazil
[b] Department of Microbiology, University of Massachusetts, Amherst, MA, USA
[c] Applied Soil Ecology Lab, School of Environmental Sciences, University of Guelph, Guelph, ON, Canada
[d] Department of Evolutionary Biology and Environmental Studies, University of Zurich, Zurich, Switzerland
[e] Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, SP, Brazil
[f] Institute of Ecology and Evolution, University of Oregon, Eugene, OR, USA
[g] Department of Land, Air and Water Resources, University of California Davis, CA, USA

Methodology – Study 1

Experiment 1

Amazon West
~250 dias

Experiment 2

Amazon East
~80 dias

Sequencing 16S *rRNA*

qPCR – *pmoA and mcrA*

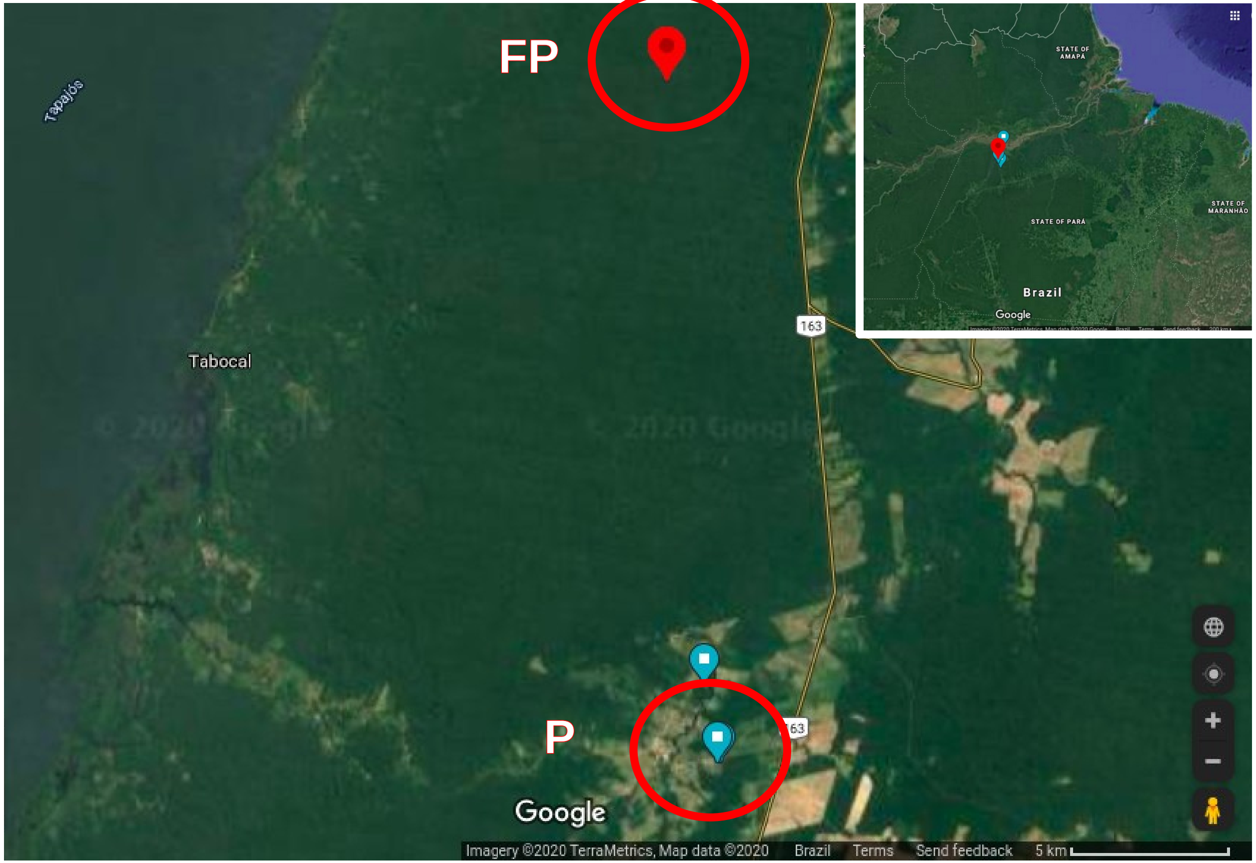
CH_4 fluxes

Field Study

Belterra/PA

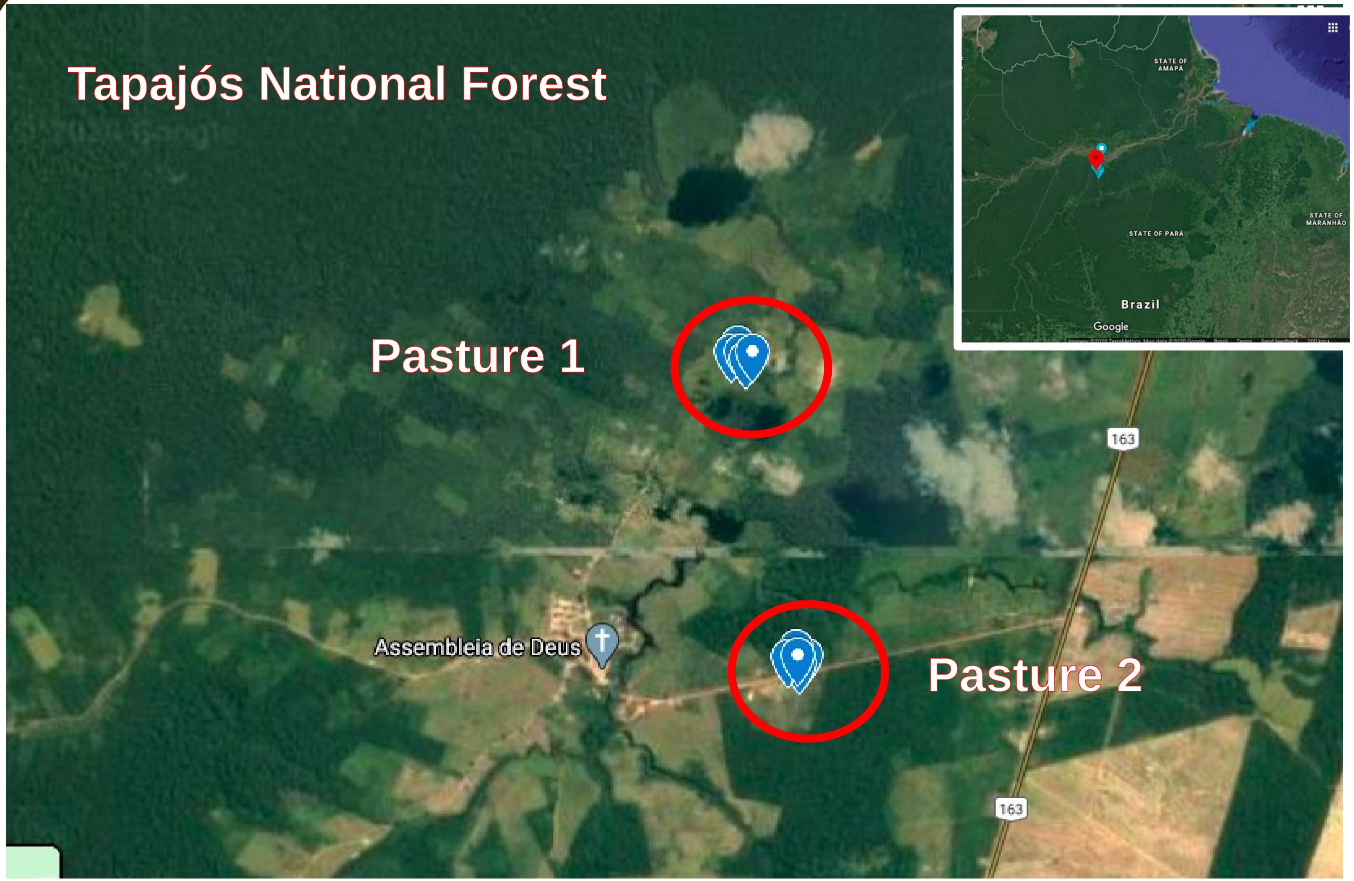
Ariquemes/RO
Amazon West

- Pastureland – 1972
- Fazenda Nova Vida
- Forest fragment
- Smallholding
- Soil type: Yellow–red Oxisols
- Texture: medium clay to sandy
- Sampling (0–10 cm): Apr/2017 (rainy season)
- Transect sampling: 5 points, 50 m apart



Belterra-Santarém/PA
Amazon East

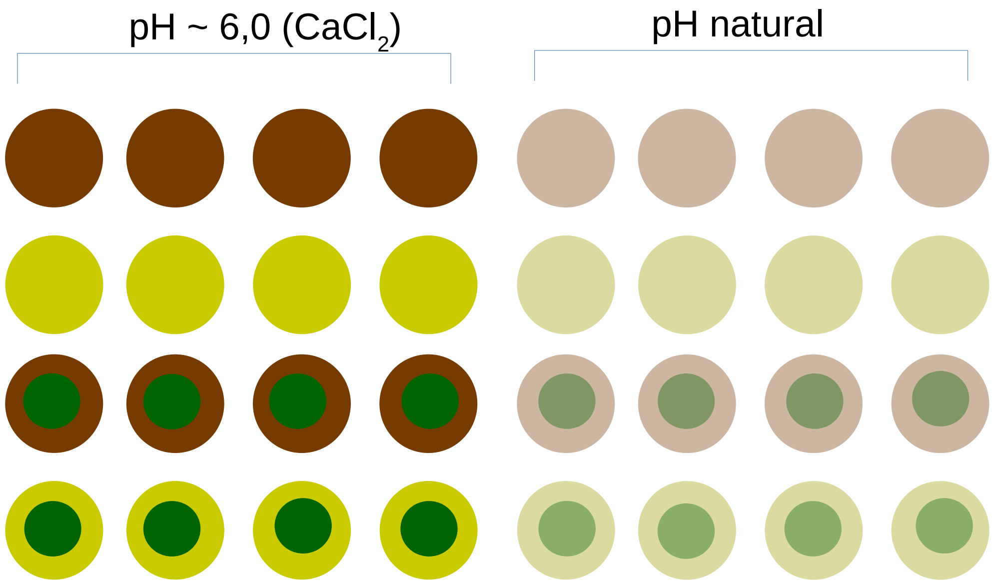
- Pastureland – 1989–1994
- Smallholding
- National forest
- Conservation area
- Texture: medium clay to sandy
- Sampling (0–10 cm): Aug/2019 (end of the rainy season)
- Transect sampling: 5 points, 50 m apart



Belterra-Santarém/PA
Amazon East

- Pastureland – 1989–1994
- Smallholdings
- Texture: sandy
- Sampling period: Aug/2019 (rainy season)
- Sampling design: 5 points forming a quadrilateral plus a central point; 100 m side length
- Pasture condition: few signs of degradation
- Samples: bulk soil, rhizosphere, and adjacent soil

Methodology - Experiments 1 and 2



Brachiaria
Pasture soil
Forest Soil

- 10 L clay pots
- 5 kg of soil sieved to 5 mm
- 10 cm soil layer
- Moisture: 70% of water-holding capacity
- Adjustment: every 2–4 days

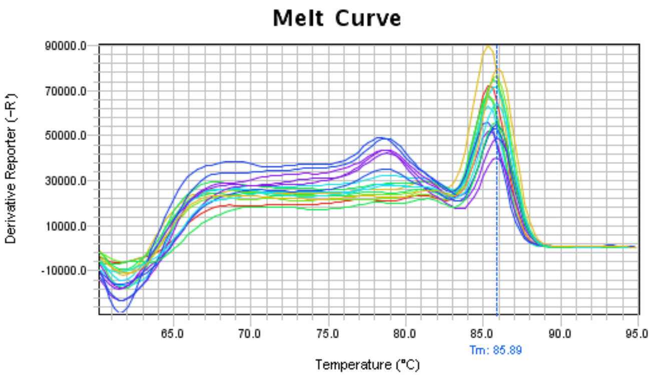
Methodology – soil gas fluxes

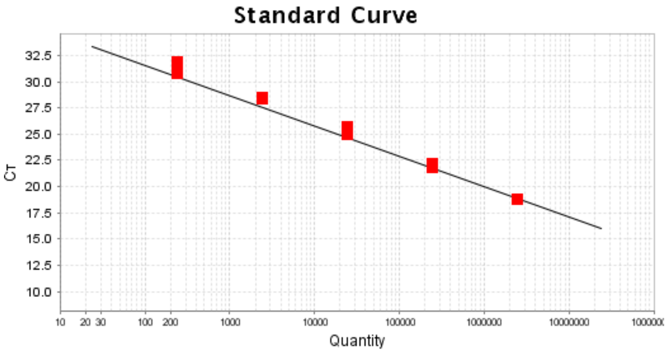
- ✔ CH_4, CO_2, and water vapour
- ✔ No daily calibration required
- ✔ Cylindrical chambers: 12 cm radius × 30 cm height; volume ~6 L
- ✔ Measurement time: 10 min; one data point every 10 s
- ✔ Linear fitting model to estimate the rate of change
- ✔ Measurement times (days):
- ✔ Exp 1: 7, 18, 28, 84, 96, and 108
- ✔ Exp 2: 7, 13, 21, 28, and 35

Laser spectroscopic analyser (ABB, Switzerland)

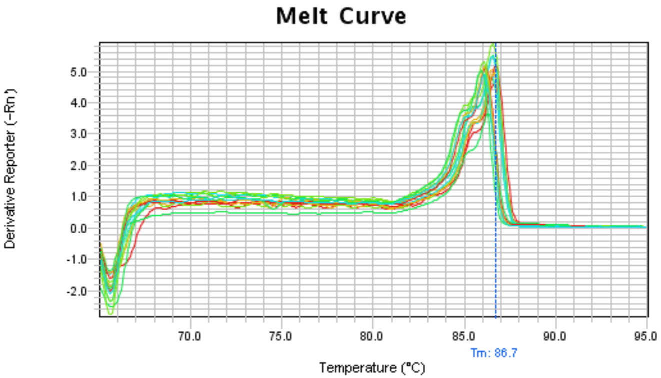
Methodology – qPCR

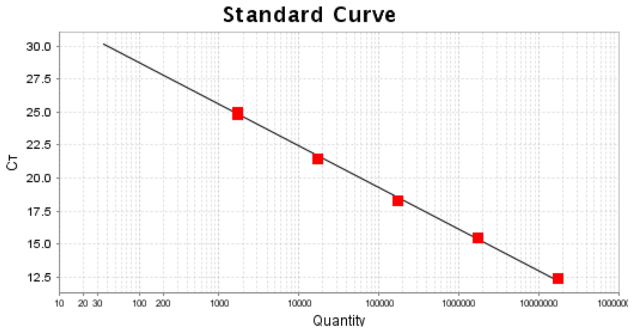
mcrA



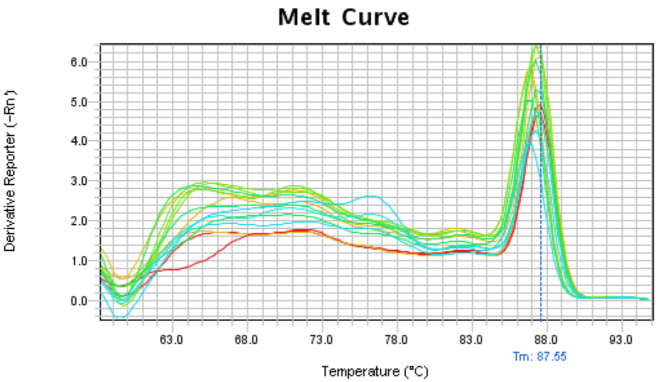


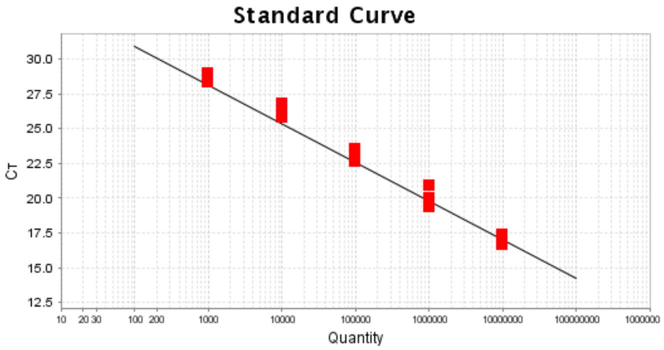
mmoX





pmoA





* linreg

Methodology – Sequencing

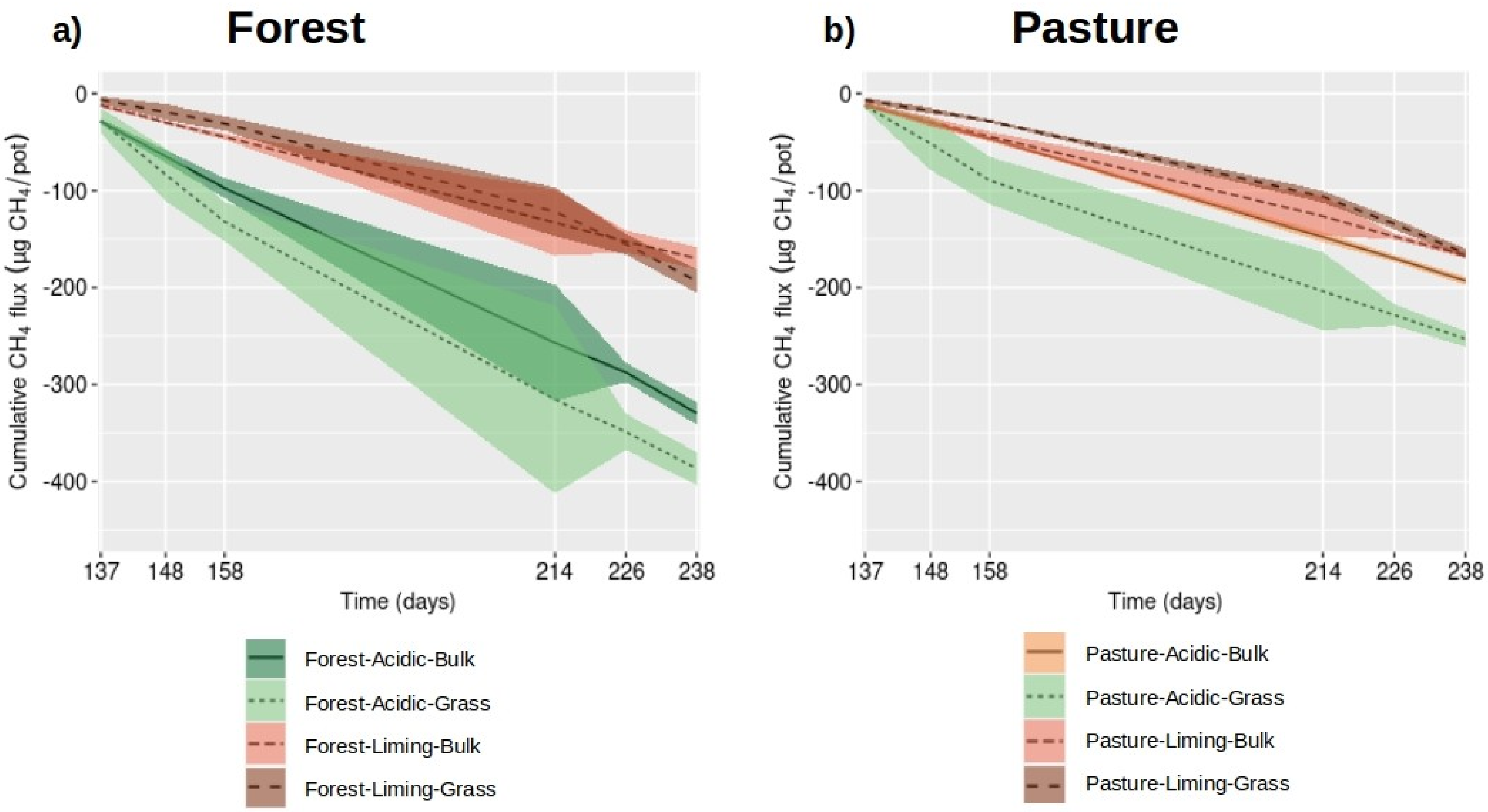
Sequencing

- University of Sao Paulo
- Illumina MiSeq v3 (2x250pb)
- *Paired-end*
- 16S *rRNA* (v4)
- 515F (Parada)/ 806R (Apprill)

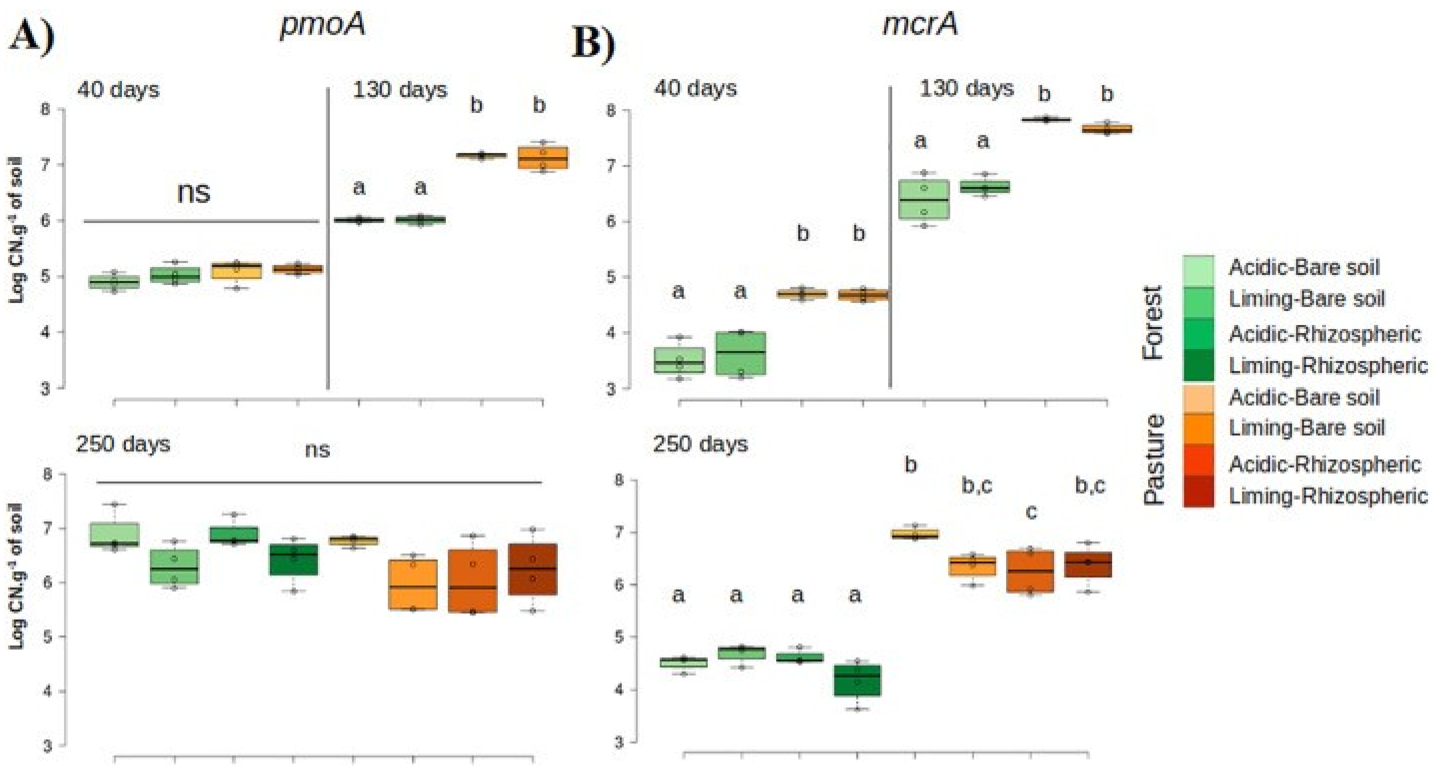
Data processing

- Qiime2
- Dada2 (ASVs)
- SILVA 132
- RDA/ PCA
- PERMANOVA
- DEICODE/ QURRO – differential abundance of taxa
- ANOVA anda Tukey HSD

Forest soils sink more CH_4. Liming does not help, but grass does.

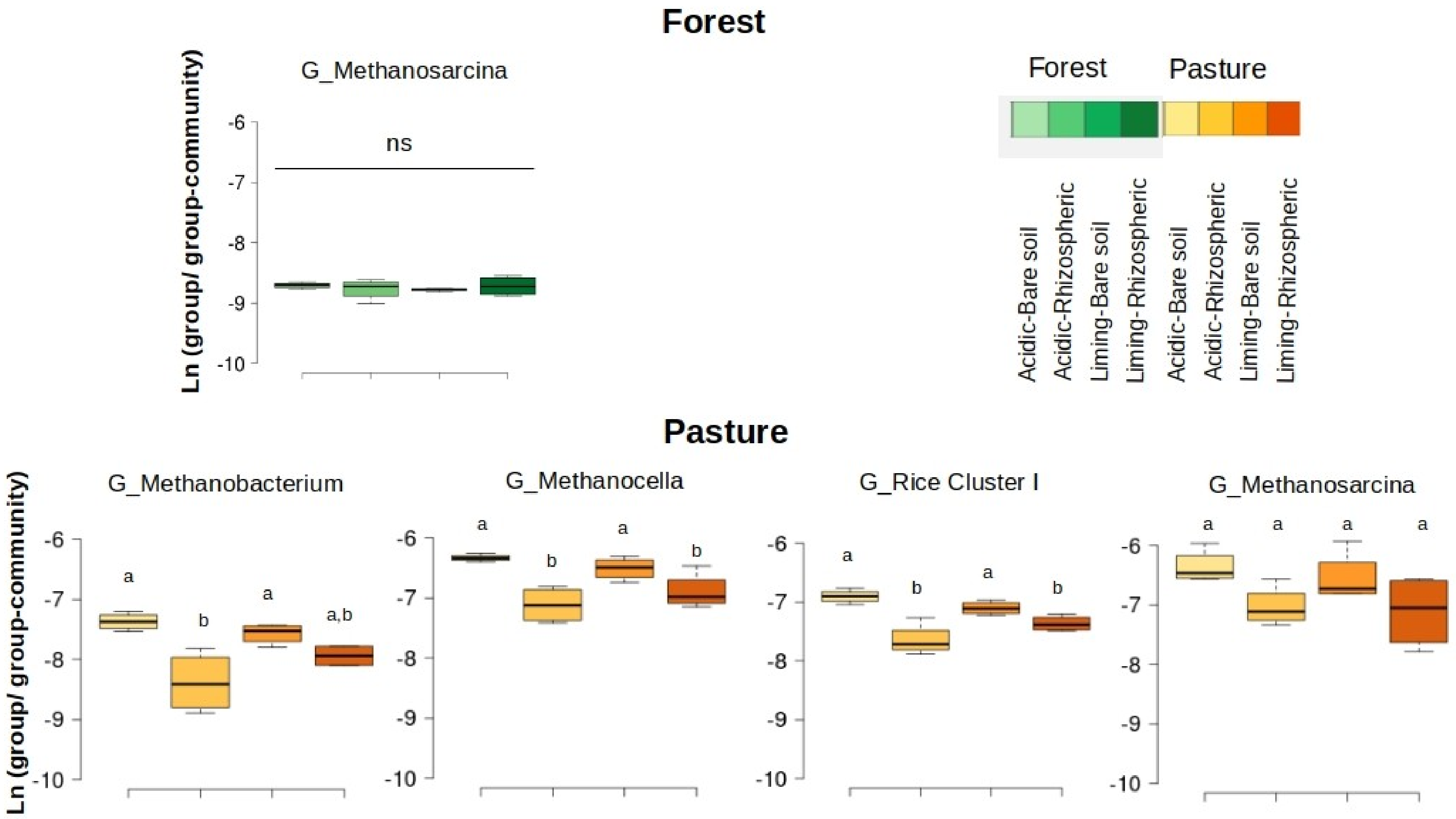


Less methanogens in the grass rhizosphere

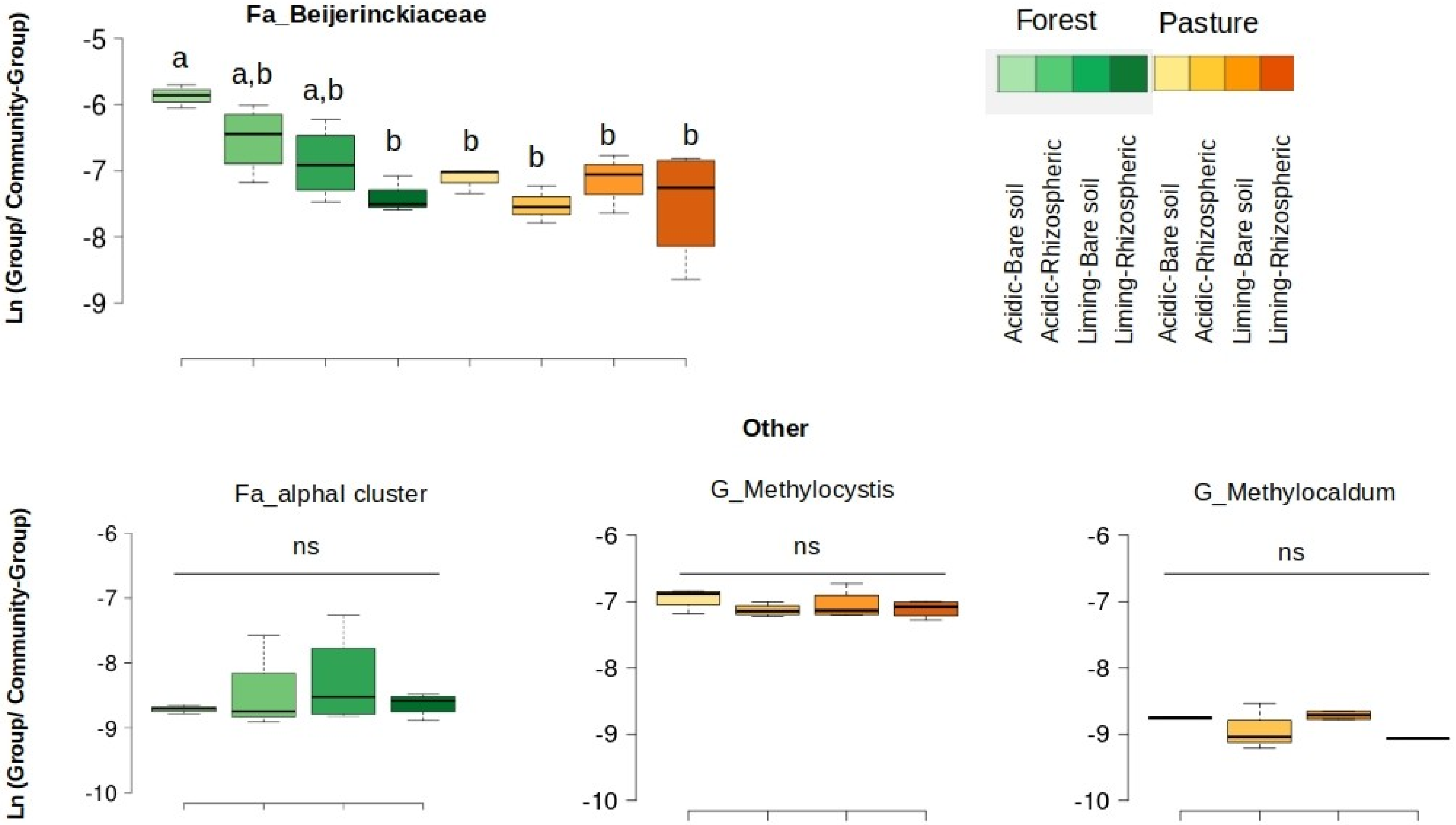


- *mcr*A is more abundant in pasture soils
- *pmo*A tends to decrease in forest soils under liming (ns)
- *mcr*A is significantly reduced in the rhizosphere of pasture soils
- *mmo*X shows no significant changes

Less methanogens in the grass rhizosphere



Methanotrophs are resilient to most soil changes



Conclusions – Study 1

- Grass coverage increases methane uptake in pasture soils compared to bare soils.

- Methanogens were reduced by 10 fold in the grass rhizosphere compared to bulk soil.

- Soil liming can compromise the capacity of forest and pasture soils to sink methane.

- Pasture management strategies have potential to mitigate soil methane emissions.

First study opened new questions

Methanogens are reduced in pasture grass rhizosphere, and explain at least part of the changes in CH_4 fluxes.

What about the forest soils? They change in flux with liming, but not much the abundance of microbes.

Maybe the activity?

How do methanotrophs activity respond to soil pH shifts?

Journal of Applied Microbiology, 2025, 136(1), lxae303
https://doi.org/10.1093/jambio/lxae303
Advance access publication date: 19 December 2024
Research Article

JOURNAL OF APPLIED MICROBIOLOGY
OXFORD UNIVERSITY PRESS

Soil pH modulates the activity of low-affinity methane oxidation in soils from the Amazon region

Leandro Fonseca de Souza[1,2,3,*], Fernanda Mancini Nakamura[1,4], Marie Kroeger[5], Dasiel Obregon[1,6], Moacir Tuzzin de Moraes[1,7], Mariana Gomes Vicente[1], Marcelo Zacharias Moreira[1], Vivian Helena Pellizari[4], Siu Mui Tsai[1], Klaus Nüsslein[3]

[1]Center for Nuclear Energy in Agriculture, University of Sao Paulo, Piracicaba, SP 13400-970, Brazil
[2]Center for Agricultural Sciences and Engineering, Federal University of Espirito Santo, Alegre, ES 29500-000, Brazil
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[4]Oceanographic Institute, University of Sao Paulo, Sao Paulo, SP 05508-120, Brazil
[5]Bioscience Division, Los Alamos National Laboratory, Los Alamos, NM 87545-1663, USA
[6]School of Environmental Sciences, University of Guelph, Guelph, ON N1G 2W1, Canada
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*Corresponding author. Center for Nuclear Energy in Agriculture, University of Sao Paulo, Piracicaba, SP 13400-970, Brazil.
E-mail: leandro_fonseca@alumni.usp.br

Preliminary experiment

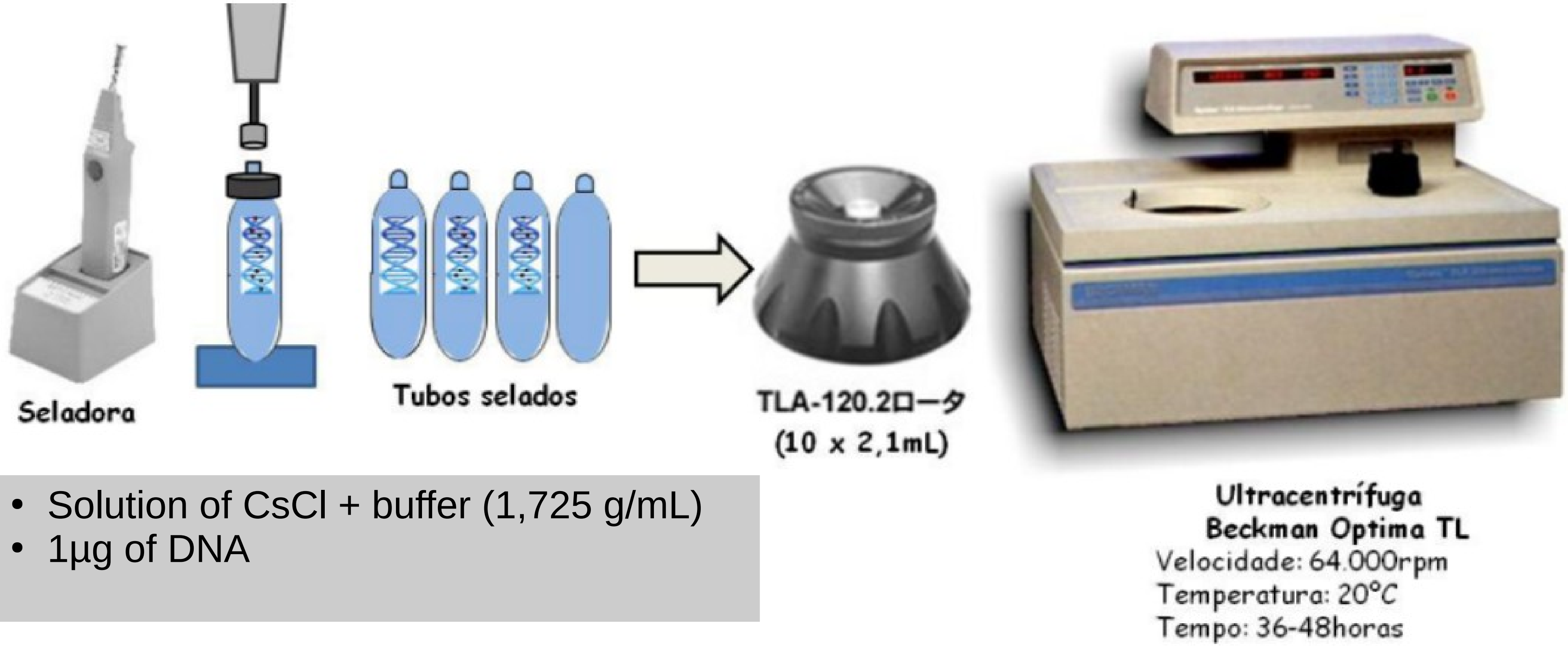
Experiment design

- Microcosms
  - Hermetically sealed 1.65 L jars (5 replicates)
  - 400 g of soil
- Temperature: 25 °C (BOD)
- Moisture: 70–80% of water-holding capacity
- $^{12}CH_4$ concentrations:
  - ~2 ppm
  - ~200 ppm
  - ~2,000 ppm
  - ~20,000 ppm (forest soils only)
- Duration: 24 days
- CH_4 flux measurements: weekly

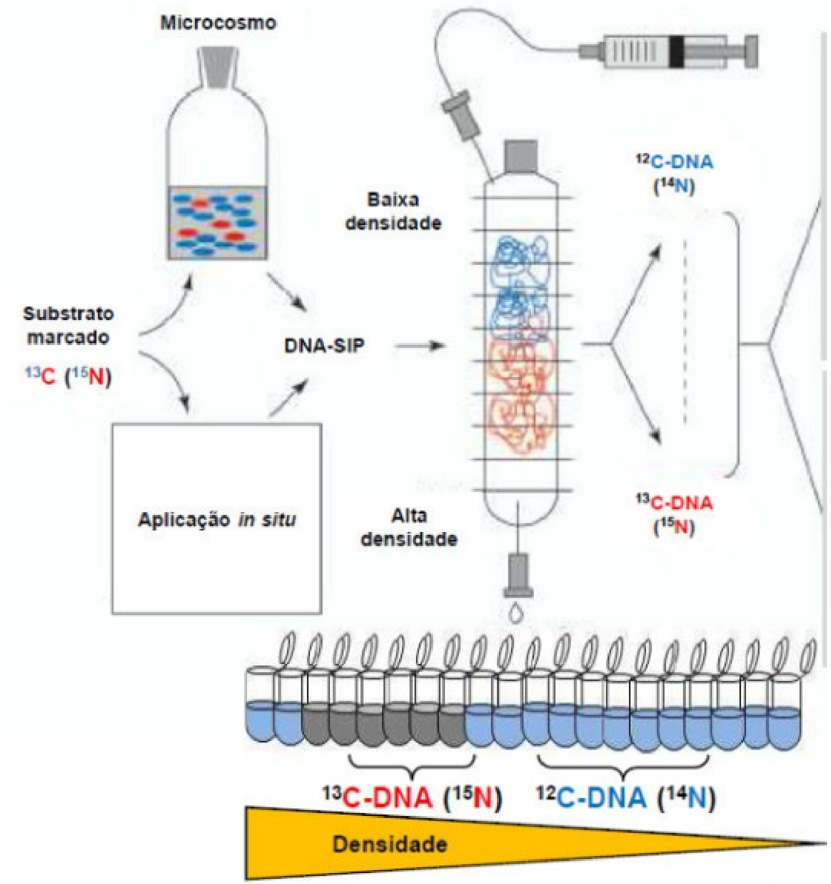
Experiment

- Microcosms sealed with rubber lids
  - 120 mL
  - 10 g of soils
  - Temperature: 25 ºC BOD
- Moisture: 70-80%
- Concentration of $^{13}CH_4$
  - ~10,000 ppm
- 24 days
- Readings and replacement of $^{13}CH_4$ every 2-4 days

Methodology – SIP



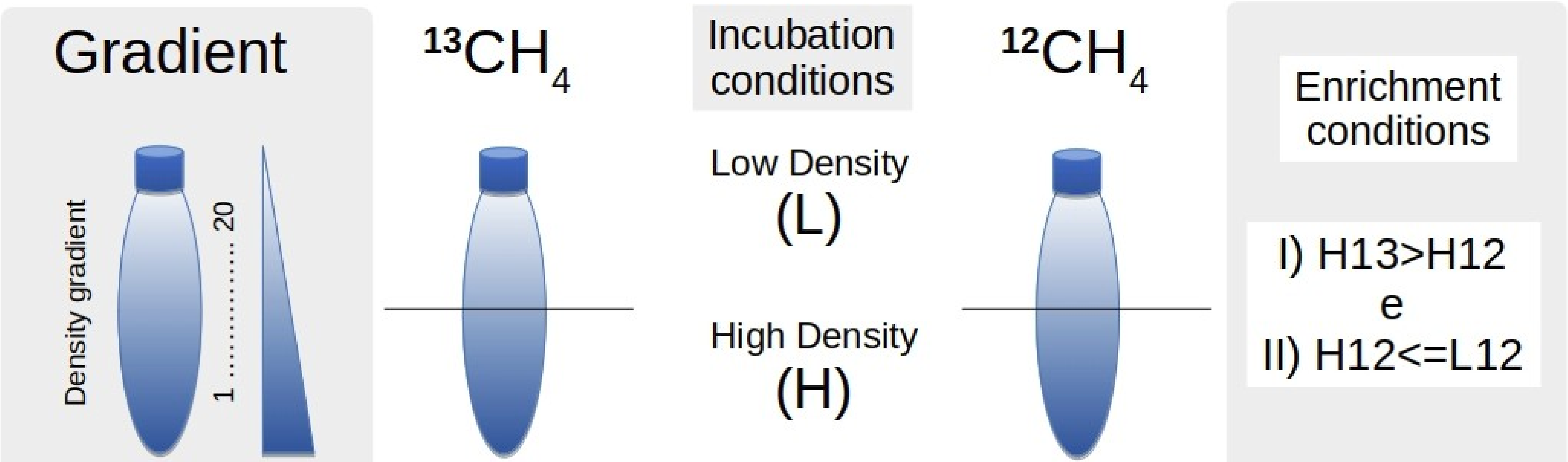
- Solution of CsCl + buffer (1,725 g/mL)
- 1µg of DNA



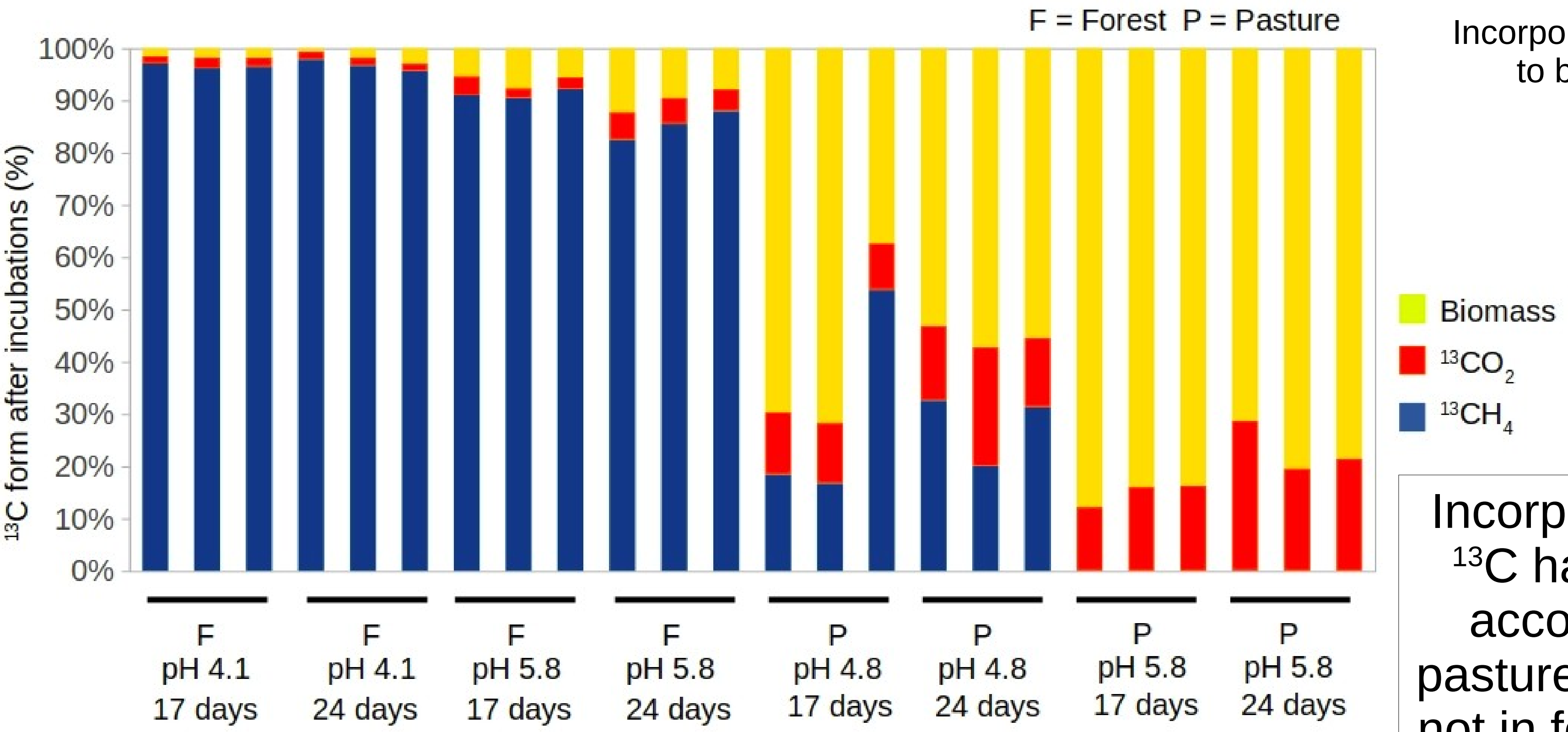
Fractionation

- Pump
- Blue solution (resazurine 0.1 %)
- Drops sampled at the bases, 100 µL fractions
- Density measurement
- DNA quantification

Methodology - SIP



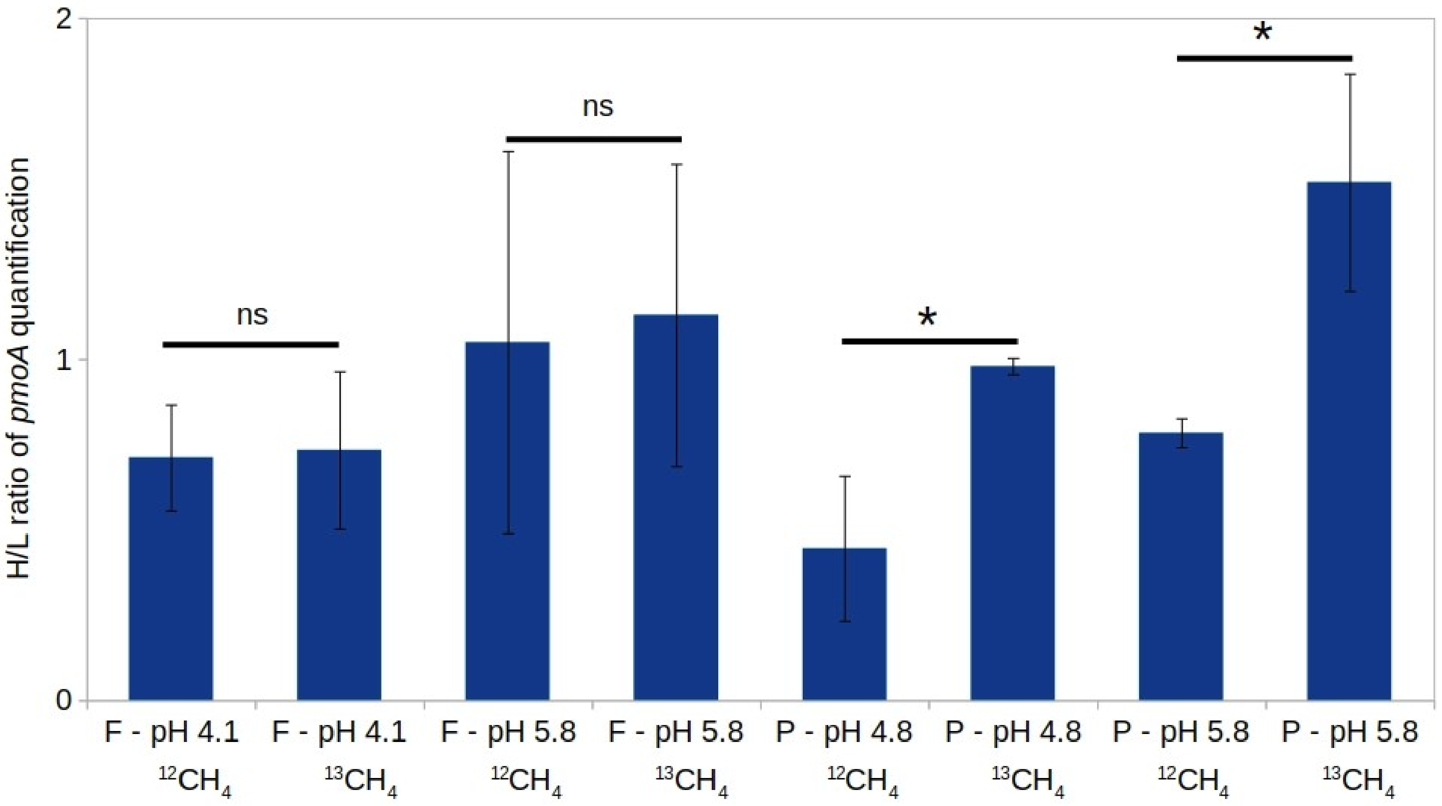
Pasture and pasture limed soils incorporated ^{13}C



Incorporation of ^{13}C to biomass

Incorporation of ^{13}C happened according in pasture soils, but not in forest soils

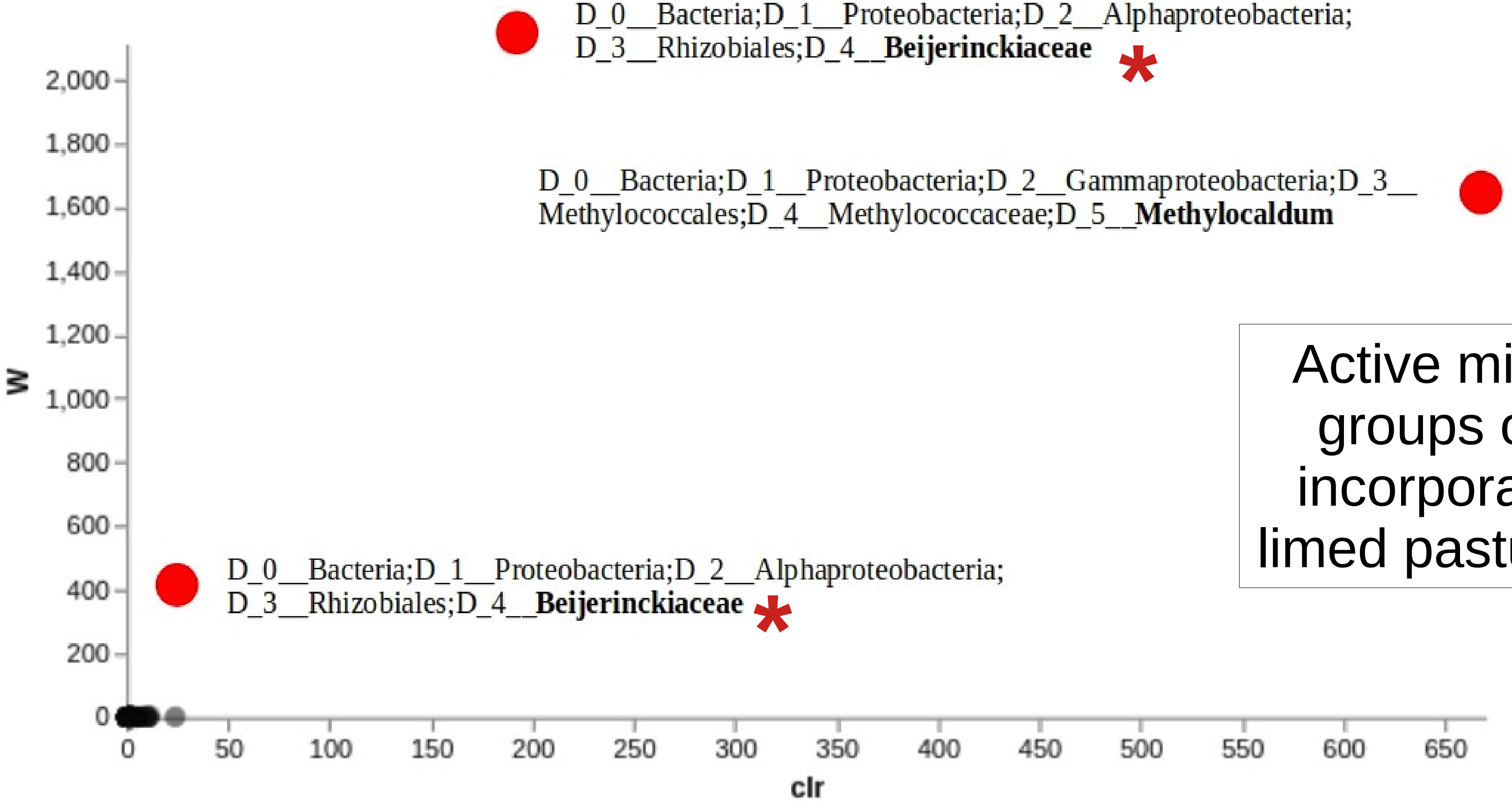
Methanotrophs were active in pasture and limed pasture soils



qPCR of *pmoA* between H/L

The abundance of ACTIVE methanotrophs (pMMO) increased only in pasture soils.

The active methanotrophs were from Types I and II

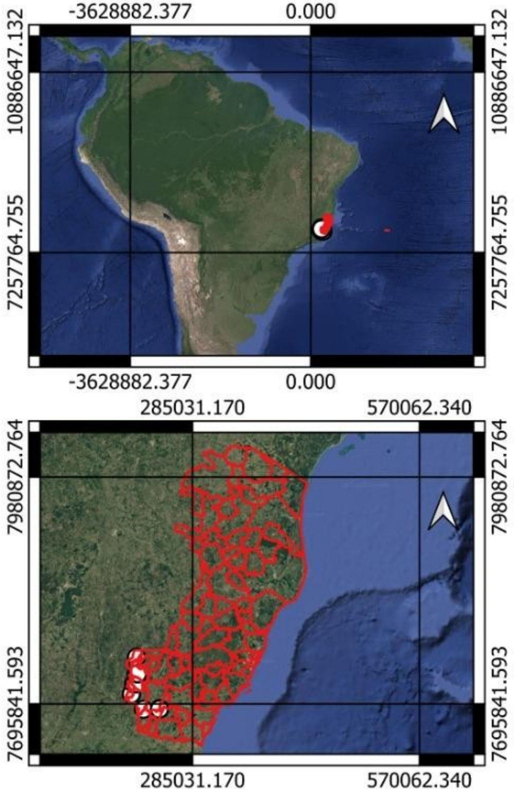


Active microbial groups on ^{13}C incorporation in limed pasture soils

Conclusions

- ✓Under High CH_4, *Methylocaldum sp*. (type I) e Beijerinckiaceae (type II) are active. Under atmospheric concentrations, soil sinks less methane.
- ✓Methane sinking in forest soils depend on its acidic pH.
- ✓Liming pastures and conserve grass coverage can mitigate soil methane emissions, depending of methane concentrations.

Last research



Soil quality and biolodiversity in Coffee cultivation comparing conventional and agroforestry systems to forest soil

- Biodiversity
- Soil fertility
- Soil biological quality

FUNDAÇÃO DE AMPARO À PESQUISA E INOVAÇÃO DO ESPÍRITO SANTO

Last research

- **Target**
  - Couple long-reads and short-reads to biodiversity evaluation of multiple taxonomic groups.
- **Challenges**
  - Optimize methodology to use nanopore long-reads to target soil meso and macroorganisms (cluster 18S-ITS-28S)
  - Create database and adjust to use with current bioinformatics amplicon tools

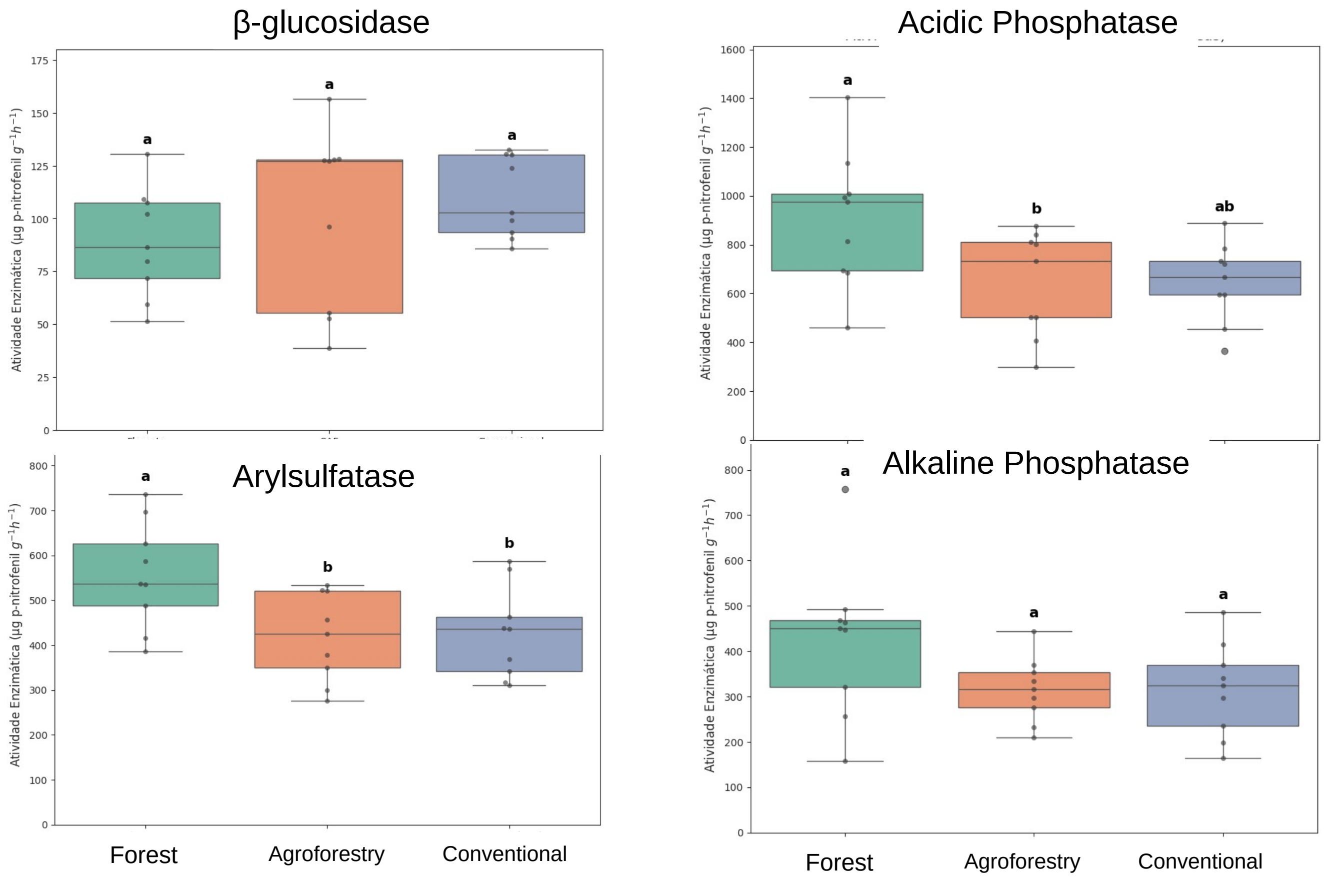
Last research

Conventional
Coffea arabica

Agroforestry
Coffea arabica

Atlantic Forest fragment

Last research



Acknowledgments

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E INOVAÇÃO DO ESPÍRITO SANTO

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