


# Soil Management and Nitrous Oxide ($N_2O$) Emissions

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# Research Team

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- Embrapa Cerrados (Arminda Carvalho and asssintant team)
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- Universities (UFRRJ, UFG, UFSM, UnB, professors and students)

# Soil Management


Soil management practices:

* Conventional tillage (CT, disk plow and light disc harrowing)
* Zero – tillage with crop sucsession and crop rotation
* Minimum tillage

Nitrogene management: Nitrogene sources (mineral N and BNF)

# $N_2O$ Emissions

Direct emissions: * Fertilizers
* Plant residues
* BNF ?
* SOM mineralization

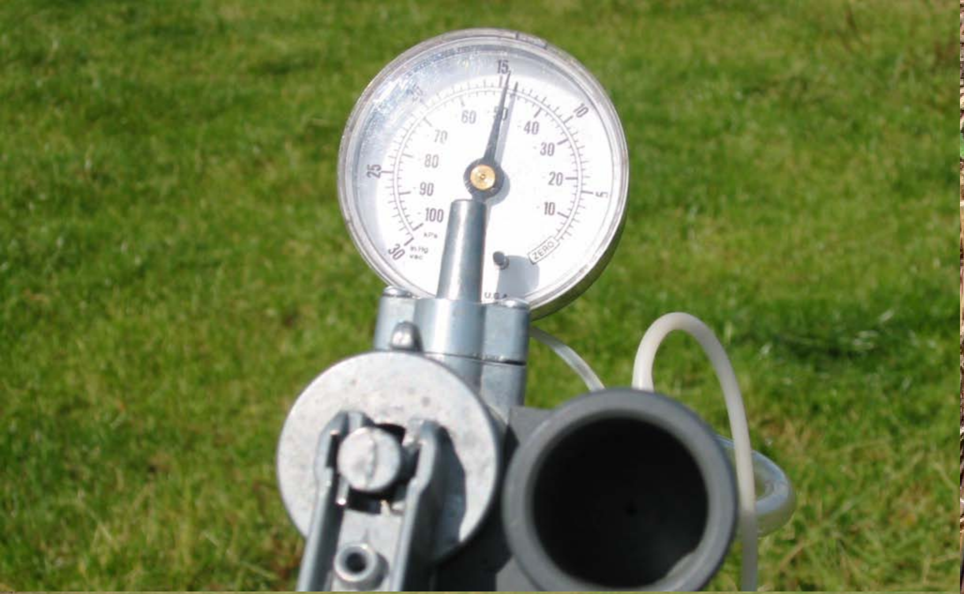
Indirect emissions: * $NH_3$ volatilisation
* $NO_3$ leaching
* BNF ?

# Presentation Outline (topics)

- Applied methodology (field and laboratory);
- Zero – Tillage versus Conventional Tillage;
- Crop Sucsession versus Crop Rotation;
- $N_2O$ emission predictors;
- Mineral N sources;
- $N_2O$ emission from bovine excreta;
- Indirect emissions;
- Emission factors;
- Conclusions

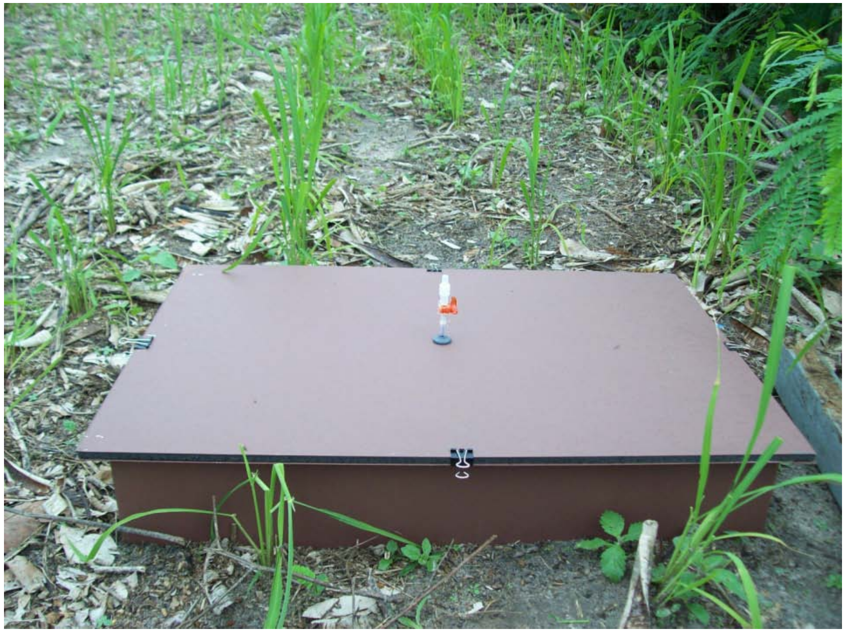
Data sources: Literature and own data

# Applied Methodology



Static chambers and manual vacuum pump (-80 kPa) were used to collect $N_2O$

A variations of the static chamber



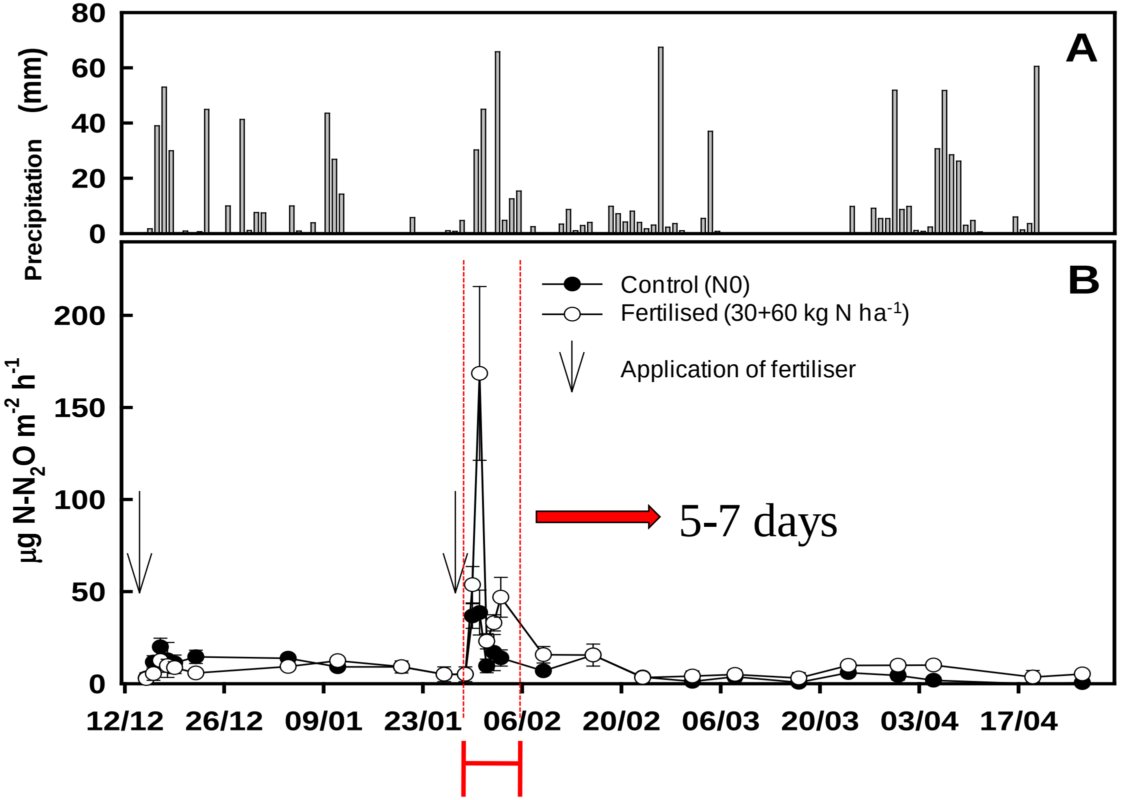
# Gas chromatograph

Porapak Q column (2 m) and electron capture detector


# Timing measurements

• Literature: frequency and timing of measurement varies;
• Own data: daily after sowing+N application for 5-7 days, then weekly or twice a week;
• Generally at the same period of the day

**$N_2O$ fluxes from Rhodic Ferralsol with upland rice under ZT em Santo Antônio de Goiás-GO**

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**Zero – Tillage versus Conventional Tillage (existance or lack of soil disturbance)**

**Crop Sucsession versus Crop Rotation (existance or lack of cover crop or green manure and its quality)**

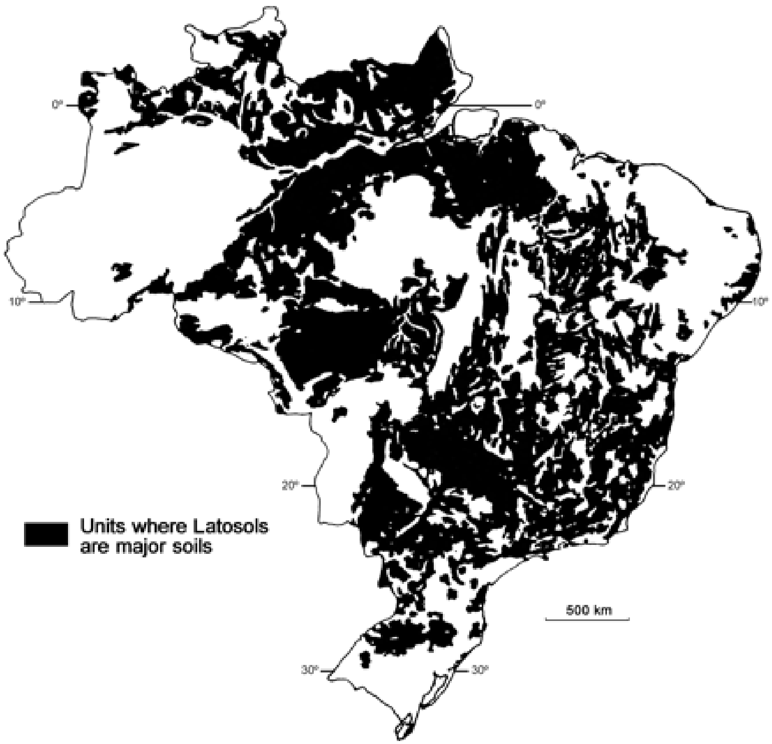
**Zero-Tillage System = Direct Drill + Crop Rotation**

# The Soil

Rhodic Ferralsol heavy clay (63% clay, 1% silt and 24% sand), Biome: Atlantic forest

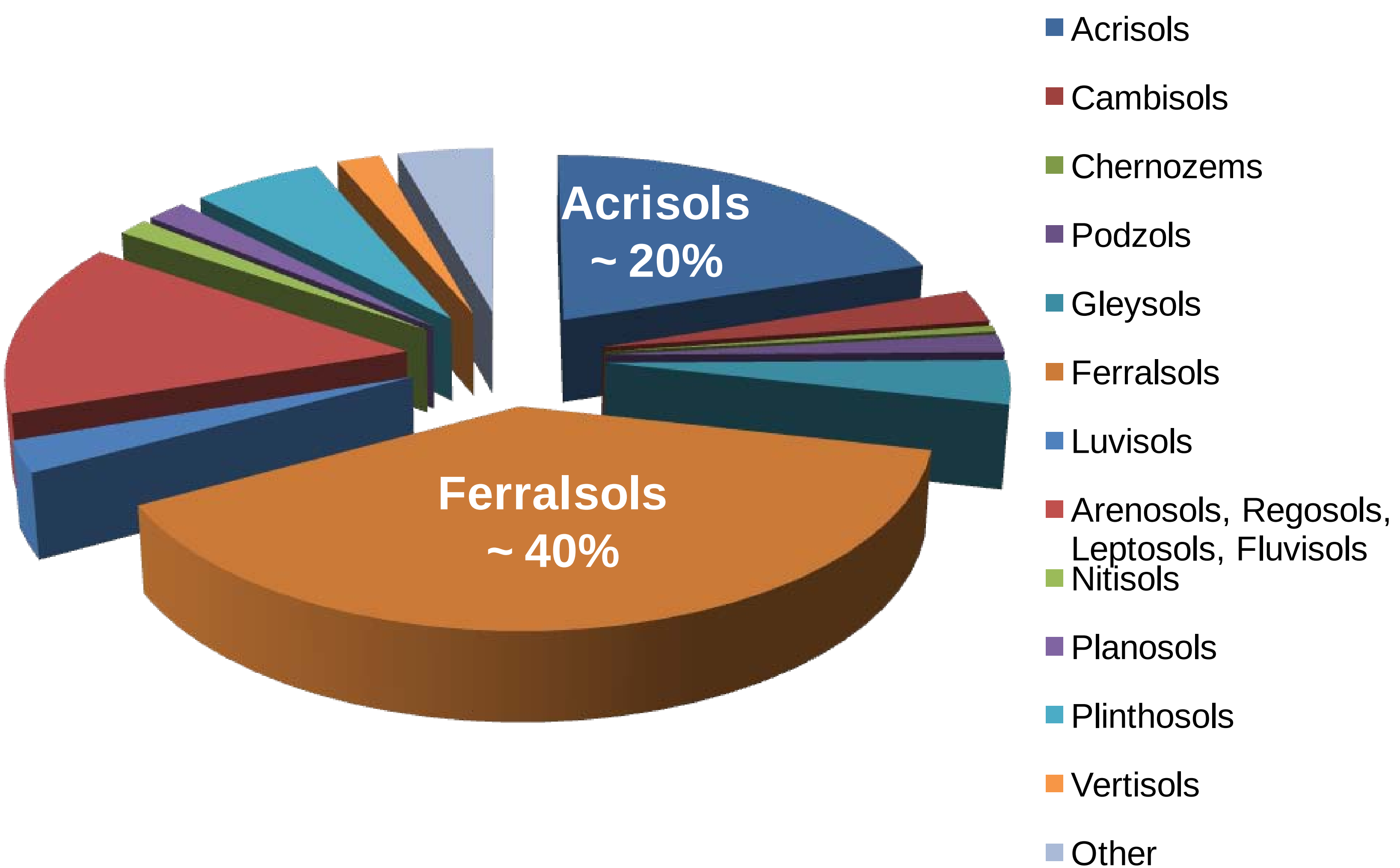
Rhodic Ferralsol clay (51% clay, 9% silt, 40% sand), Biome: Cerrado

Units where Ferralsols are major soils.


*Source:* Camargo et al., 1988 in SCHAEFER, C. E. G. R., FABRIS, J.D., KER, J.C. Minerals in the clay fraction of Brazilian Latosols (Oxisols): a review. Clay Minerals 43(1):137-154; doi: 10.1180/claymin.2008.043.1.11

# Distribution of Soil Types in Brazil by WRB



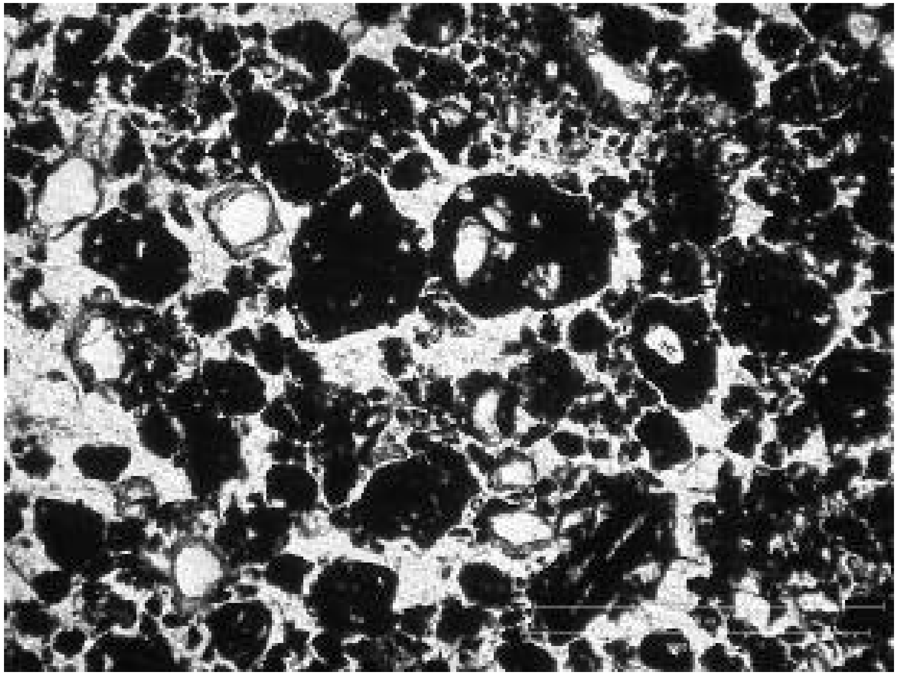
# Distribution of Latosol (Ferralsols) mapping-units in Brazil

*Photo:* Madari, BE

Latosols comprise soils at advanced weathering stages, with consequent concentration of 1:1 clay minerals and oxides (including oxyhydroxides and hydroxides). Goethite (-FeOOH) and hematite (-$Fe_2O_3$) are amongst the most abundant pedogenic Fe oxides, and are identified by a yellowish colour (2.5Y–10YR) in the absence of hematite and reddish colour (even when hematite is present in very minor amounts; 2.5YR–5R), respectively.

The binding of clay particles to form very small aggregates in ferralsols is particularly pronounced. It can be referred to as microaggregation, which in the earlier literature was known as the formation of pseudo-sand and pseudo-silt. By this process soils with high clay contents feel loamy in the field, and actually behave mechanically as medium or even light textured soils: high water infiltration rate and evapotranspiration.

Water infiltration in a clayey (>50% clay) Rhodic Ferralsol, Santo Antônio de Goiás, Cerrado, Brazil (*Photo:* Alves, BJR)



Photomicrograph of the ferralic horizon of a clayey ferralsol. Extensive pore space (white) is visible.

*Source:* Cooper, M, Vidal-Torrado, P., Chaplot, V. 2005. Origin of microaggregates in soils with ferralic horizons. Scientia Agricola 62(3):256-263, doi: 10.1590/S0103-90162005000300009

Estimates of N loss in the form of $N_2O$ (g N–$N_2O$ $ha^{-1}$) from the two different crop rotations under zero (ZT) and conventional tillage (CT), and from the adjacent native vegetation for the period. Rhodic Ferralsol, heavy clay (63% clay, 1% silt and 24% sand), Southern-Brazil, Biome: Atlantic forest

| 2002/2003 Crop rotation | Tillage treatment (g N–$N_2O$ $ha^{-1}$) | | Mean |
|---|---|---|---|
| | ZT | CT | |
| **1 suc.** | 670 a[d] | 942 a | 806 A[d] |
| **2 (A) rot. w/ legume** | 758 a | 688 a | 723 A |
| **2 (B) rot. no-legume** | 670 a | 984 a | 827 A |
| **Mean** | 699 a | 871 a | |
| Coef. variation (%) | 33 | | |
| Native vegetation | 671 | | |
| Analysis of variance | | | |
| Factor: Tillage (T) | ns[e] | | |
| Rotation (R) | ns | | |
| Interaction T × R | ns | | |

| 2003/2004 Rotation | Tillage treatment (g N–$N_2O$ $ha^{-1}$) | | Mean |
|---|---|---|---|
| | ZT | CT | |
| **1 suc.** | 596 a[d] | 689 a | 643 A[d] |
| **2 (A) rot. w/ legume** | 609 a | 717 a | 663 A |
| **2 (B)** | 738 a | 621 a | 680 A |
| **Mean** | 648 a | 676 a | |
| Coef. variation (%) | 23 | | |
| Native vegetation | 630 | | |
| Analysis of variance | | | |
| Factor: Tillage (T) | ns[e] | | |
| Rotation (R) | ns | | |
| Interaction T × R | ns | | |

ZT1 Continuous wheat/soybean; ZT2(A) First year of two-year rotation—soybean/vetch; ZT2 (B) Second year of two-year rotation—maize/wheat; d Means in the same row followed by the same lower case letter, or in the same column followed by the same upper case letter, are not significantly different at $P \leq 0.05$ (Student 't' test) e ns—no significant difference between means at $P \leq 0.05$ (F test).

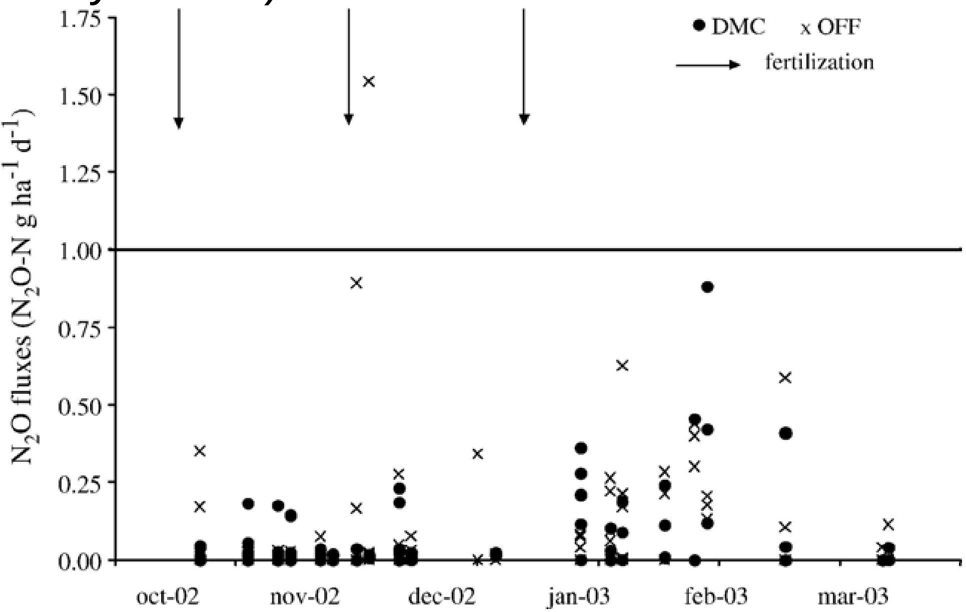
*Source*: Jantalia, C.P., Santos, H.P., Urquiaga, S., Boddey, R.M., Alves, B.J.R. 2008. Fluxes of nitrous oxide from soil under different crop rotations and tillage systems in the South of Brazil. Nutr. Cycl. Agroecosyst. 82:161–173, DOI 10.1007/s10705-008-9178-y

Nitrous oxide emission from measured field data and estimated from IPCC emission factor 1 (EF1 = direct emission from soil) of 0.01 for the three different crop rotations (ZT1, ZT2A and ZT2B) under no-tillage (ZT) and conventional soil preparation (CT), for two consecutive years *Source*: DOI 10.1007/s10705-008-9178-y

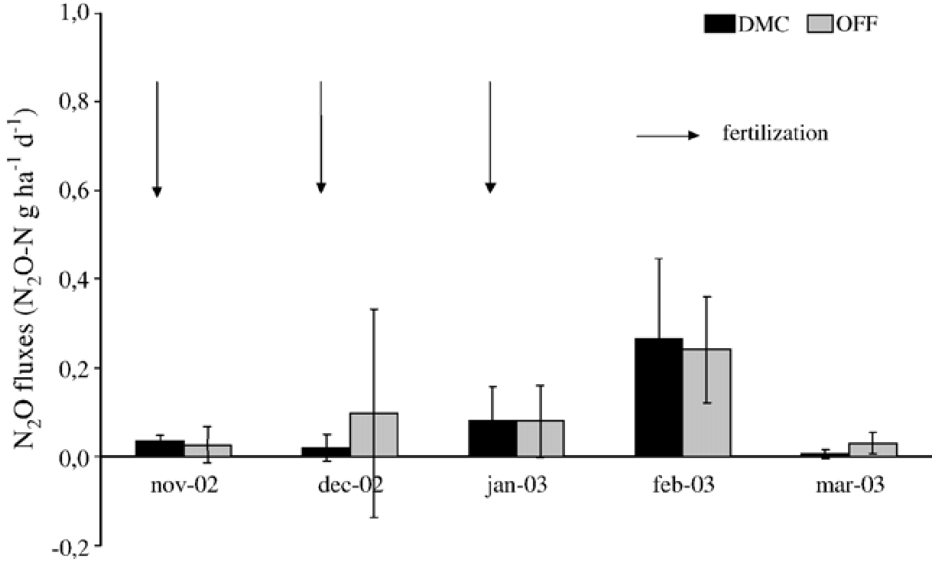
| Evaluation period | Field data (% IPCC total) | IPCC (EF1 = 0.01; uncertainty from 30% to 300% of the calculated value) | | |
|---|---|---|---|---|
| | | Fertiliser | N in residues ($kg\ N–N_2O\ ha^{-1}\ year^{-1}$) | Total |
| *Winter and summer* | | | | |
| 2003 | | | | |
| R1 ZT (Soybean/wheat) | 0.67 (56) | 0.45 | 0.74 | 1.19 |
| R1 CT | 0.94 (81) | 0.45 | 0.71 | 1.16 |
| R2A ZT (Soybean/vetch) | 0.76 (39) | 0 | 1.95 | 1.95 |
| R2A CT | 0.69 (40) | 0 | 1.71 | 1.71 |
| R2B ZT (Maize/wheat) | 0.67 (41) | 0.45 | 1.17 | 1.62 |
| R2B CT | 0.98 (70) | 0.45 | 0.96 | 1.41 |
| 2004 | | | | |
| R1 ZT (Soybean/wheat) | 0.60 (47) | 0.45 | 0.82 | 1.27 |
| R1 CT | 0.69 (52) | 0.45 | 0.87 | 1.32 |
| R2A ZT (Sorghum/wheat) | 0.61 (24) | 1.05 | 1.48 | 2.53 |
| R2A CT | 0.72 (29) | 1.05 | 1.48 | 2.53 |
| R2B ZT (Soybean/vetch) | 0.74 (78) | 0 | 0.94 | 0.94 |
| R2B CT | 0.62 (79) | 0 | 0.78 | 0.78 |

# Rhodic Ferralsol, clay (51% clay, 9% silt, 40% sand), Central-Brazil, Biome: Cerrado

$N_2O$ fluxes (g $N_2O$–N $ha^{-1}$ $day^{-1}$) measured in situ from Zero-Tillage (DMC) (cover crop *Brachiaria ruziziensis*) and Conventional Tillage (OFF) (disc harrow) treatments from October 2002 to March 2003 (mean daily values)




$N_2O$ fluxes (g $N_2O$–N $ha^{-1}$ $day^{-1}$) measured in situ from Zero-Tillage (DMC) (cover crop *Brachiaria ruziziensis*) and Conventional Tillage (OFF) (disc harrow) treatments from November 2002 to February 2003 (monthly mean ($n$= 20)).




*Source:* Metay, A., Oliver, R., Scopel, E., Douzet, J-M., Moreira, J.A.A., Maraux, F., Feigl, B.J., Feller, Ch. $N_2O$ and $CH_4$ emissions from soils under conventional and no-till management practices in Goiânia (Cerrados, Brazil). Geoderma 141(1-2):78-88, doi: 10.1016/j.geoderma.2007.05.010

# $N_2O$ fluxes observed in studies conducted in Brazil

| Reference | Biome | Soil Type | Growing Season | N Source | Plant | Flux N-$N_2O$ ($\mu g\ m^{-2}\ d^{-1}$) ZT | CT |
|---|---|---|---|---|---|---|---|
| Carvalho et. al, 2008 | Cerrado | Ferralsol | Winter, Dry | Urea | *Phaseolus vulg.* | 1.700 | - |
| Giacomini et. al, 2006 | Atlantic Forest | Acrisol | Summer | Swine slurry | *Avena sativa* mulch | 7.100 | 7.100 |
| Jantalia et. al, 2008 | Atlantic Forest | Ferralsol | Summer/Winter | Mineral N | *Glycine max/Triticum* | 2.400 | 3.720 |
| | | | | | *Glycine max* | 1.680 | 3.072 |
| | | | | | *Glycine max* | 2.352 | 2.640 |
| Jantalia et. al, 2006 | Atlantic Forest | Ferralsol | Summer/Winter | BNF + Mineral N | *Glycine max/Lupinus* | 840 | 720 |
| | | | | | *Zea mays/Avena st.* | 504 | 528 |
| Zanatta, 2009 | Atlantic Forest | Acrisol | Summer | No mineral N | *Zea mays/Avena st.* | 1.200 | 2.880 |
| | | | | | *Vicia sp/Zea mays* | 4.560 | 3.840 |
| Gonçalves, 2002 | Cerrado | Ferralsol | Winter, Dry | Ammonium Sulph. | *Phaseolus vulg.* | 1.872 | - |
| | | | | Slurry | *Phaseolus vulg.* | 480 | - |

ZT = Zero-Tillage; CT = Conventional Tillage

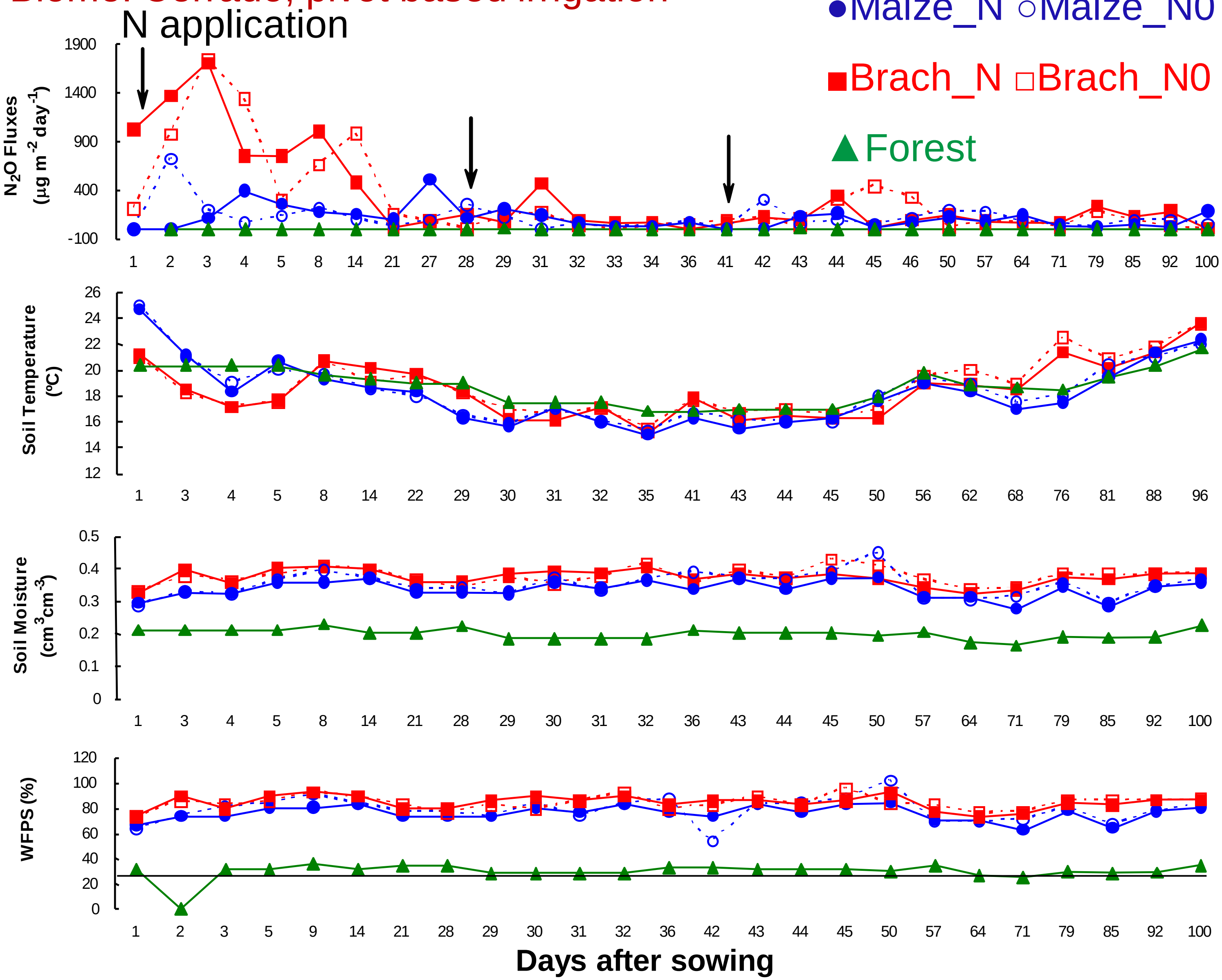
# Emission Factors for $N_2O$ obtained in Brazil in Field Experiments using mineral N fertilizer

| Soil use | Evaluation cycle (dias) | N-Fertiliser (source - kg N $ha^{-1}$) | Soil Type | EF based on reference area (%) |
|---|---|---|---|---|
| Londrina, PR / Cerrado | | | Rhodic Ferralsol | |
| Maize MT rotation (year 1 e 2) | 136/141 | Urea – 80 | | **0.05/0.04** |
| Maize ZT rotation (year 1 e 2) | 136/141 | Urea – 80 | | **0.09/0.03** |
| Passo Fundo, RS / Atlantic forest | | | | |
| Wheat ZT rotation | 137 | Urea – 40 | | **0.13** |
| Soybean/Wheat ZT (year 1 e 2) | 1 ano | Fert+Res – 120/116 | | **0.56/0.81** |
| Soybean/Wheat CT(year 1 e 2) | 1 ano | Fert+Res – 126/133 | Rhodic Ferralsol | **0.47/0.52** |
| Maize/Wheat ZT | 1 ano | Fert+Res – 162 | | **0.41** |
| Maize/Wheat CT | 1 ano | Fert+Res – 141 | | **0.70** |
| Sorghum /Wheat ZT | 1 ano | Fert+Res – 193 | | **0.24** |
| Sorghum /Wheat CT | 1 ano | Fert+Res – 193 | | **0.29** |
| Santo Antônio de Goiás, GO / Cerrado | | | | |
| Maize ZT sucession | 140 | Urea – 80 | Rhodic Ferralsol | **0.22** |
| Upland rice ZT(year1 e 2) | 133/132 | Urea – 90 | | **0.13/0.14** |
| Common beans (irr) ZT | 149 | Urea – 80 | | **0.12** |
| Seropédica, RJ – Atlantic forest | | | | |
| Maize MT | 120 | Urea – 50 | | **0.16** |
| Maize MT | 120 | Urea – 100 | Acrisol | **0.35** |
| Maize MT | 120 | Urea – 150 | | **0.33** |
| Panicum sp. | 180 | Urea – 40 | | **0.18** |
| Panicum sp. | 180 | Urea – 80 | | **0.22** |
| Panicum sp. | 180 | Urea – 120 | | **0.22** |
| Panicum sp. | 180 | Urea – 160 | | **0.37** |

**Direct Emission Factors Measured in Brazil General Mean 0.28 % (0.03 – 0.81%)**

Data by Embrapa Agrobiology, Soybean, Wheat, Rice and Beans

# Rhodic Ferralsol, clay (51% clay, 9% silt, 40% sand), Central-Brazil, Biome: Cerrado, pivot based irrigation




$N_2O$ fluxes, temperature, moisture and water filled porous space in the soil, at 0-10 cm layer, during the life cycle of irrigated common beans under zero – tillage with two types of crop residue: maize and brachiaria, unfertilized and fertilized with mineral N (ureia). Comparision: natural forest. Arrows indicate first, second and third date of N application.

*Source*: Carvalho MTM, Madari BE, Meinke H, Machado PLOA, Alves, BJR, Heinemann, AB, Leal WGO, Costa AR, Souza DM (in preparation)

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**Rhodic Ferralsol, clay (51% clay, 9% silt, 40% sand), Central-Brazil, Biome: Cerrado, pivot based irrigation**

**Zero-Tillage with and without cover crop, here Brachiaria grass**


Rhodic Ferralsol, clay (51% clay, 9% silt, 40% sand), Central-Brazil,
Biome: Cerrado, pivot based irrigation
Zero-Tillage with Brachiaria grass
Zero-Tillage without Brachiaria grass

Carbon and Nitrogen in microbial biomass averages of nitrous oxide and ammonia fluxes total nitrous oxide emissions and ammonia volatilization and total Nitrogen losses by volatilization and emission in no-till irrigated common beans production system under brachiaria and maize as crop residues unfertilized and fertilized with mineral N and forest.

Rhodic Ferralsol, clay (51% clay, 9% silt, 40% sand)

| | CMB* | NMB* | $N_2O$ Fluxes | $NH_3$ Fluxes | Total direct emissions ($N_2O$) * | Total indirect emissions ($NH_3$)* | Total N emissions* |
|---|---|---|---|---|---|---|---|
| | mg kg $^{-1}$ | | mg $m^{-2}$ $day^{-2}$ | mg $m^{-2}$ $day^{-2}$ | kg N $ha^{-1}$ $year^{-1}$ | | |
| **Brach_N** | 413 ab | 45 b | 307 (± 410) | 21 (± 12) | 0.229 a | 4.28 a | 4.52 a |
| **Brach_N0** | 377 abc | 41 b | 206 (± 278) | 19 (± 7) | 0.213 a | 3.73 ab | 3.94 ab |
| **Maize_N** | 288 bc | 39 b | 122 (± 120) | 18 (± 8) | 0.107 b | 3.52 ab | 3.62 ab |
| **Maize_N0** | 239 c | 38 b | 122 (± 143) | 16 (± 6) | 0.094 b | 3.10 b | 3.19 b |
| **Forest** | 482 a | 76 a | 2 (± 3) | 8 (± 4) | 0.001 c | 0.78 c | 0.78 c |

*Means in the same column followed by the same lower case letter are not significantly different at P≤0.05 (Tukey ‘t’ test).

*Source*: Carvalho MTM, Madari BE, Meinke H, Machado PLOA, Alves, BJR, Heinemann, AB, Leal WGO, Costa AR, Souza DM (in preparation)

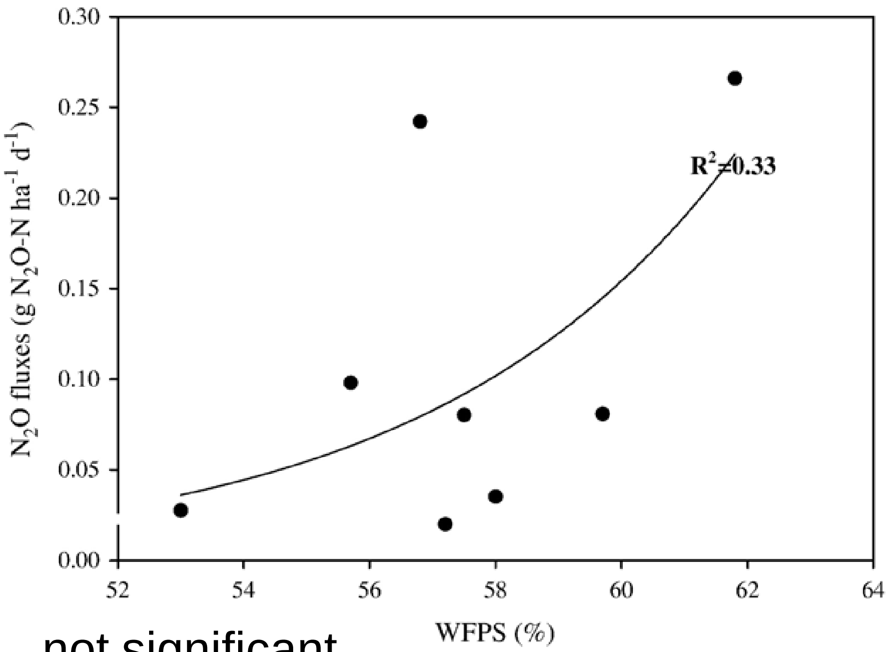
# $N_2O$ emission predictors

- Soil inorganic N pools;
- N mineralization rates;
- Water filled pore space;
- Soil biological activity.

# Water filled pore space (%WFPS)

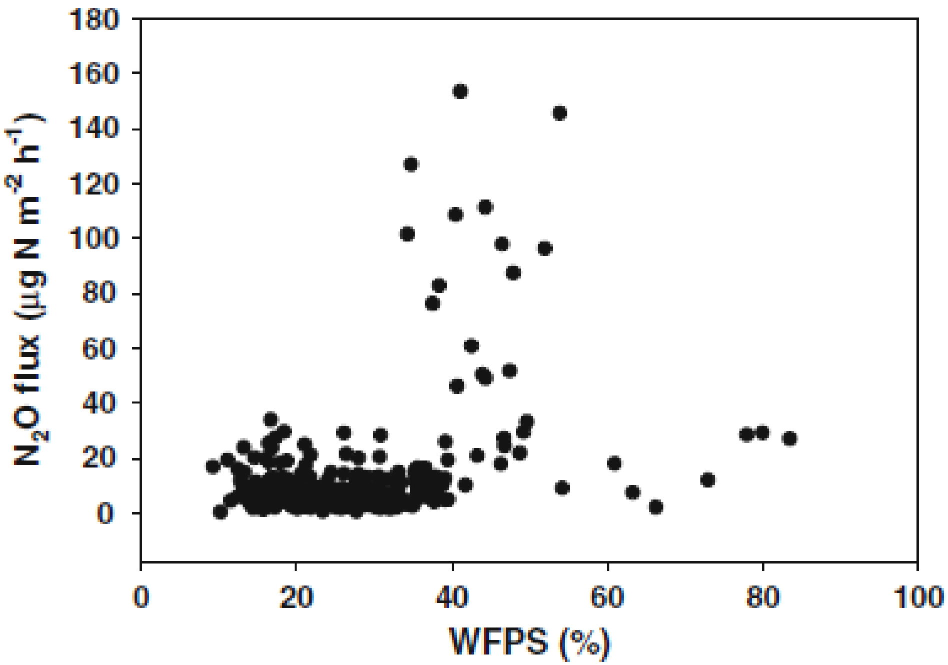
$N_2O$ fluxes (g $N_2O$–N $ha^{-1}$ $day^{-1}$) versus WFPS (%) for the topsoil layer 0–10 cm

Cerrado




not significant

Atlantic Forest

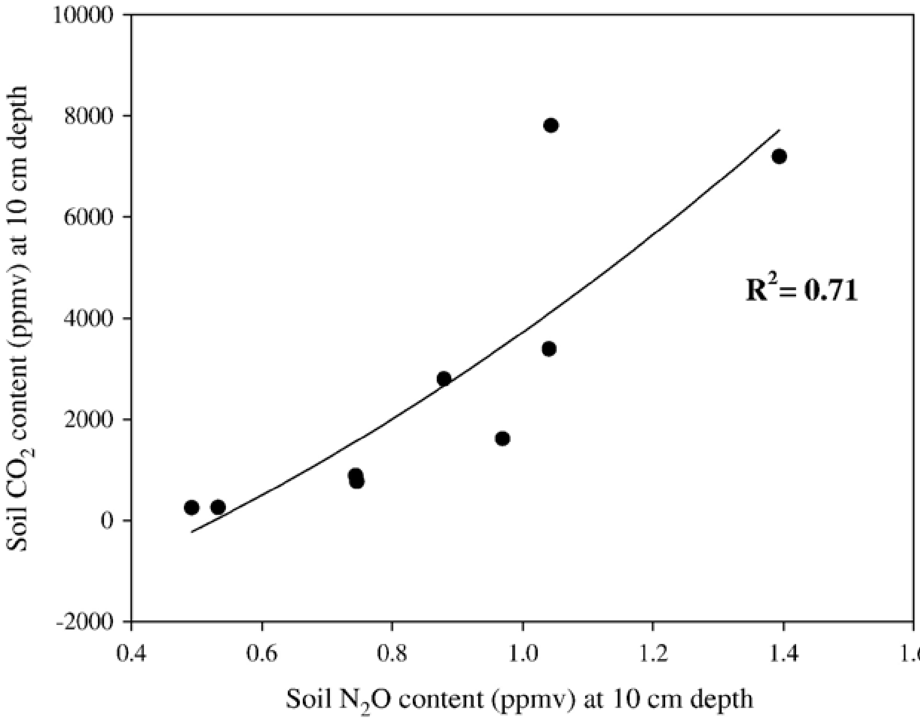



*Source:* doi: 10.1016/j.geoderma.2007.05.010

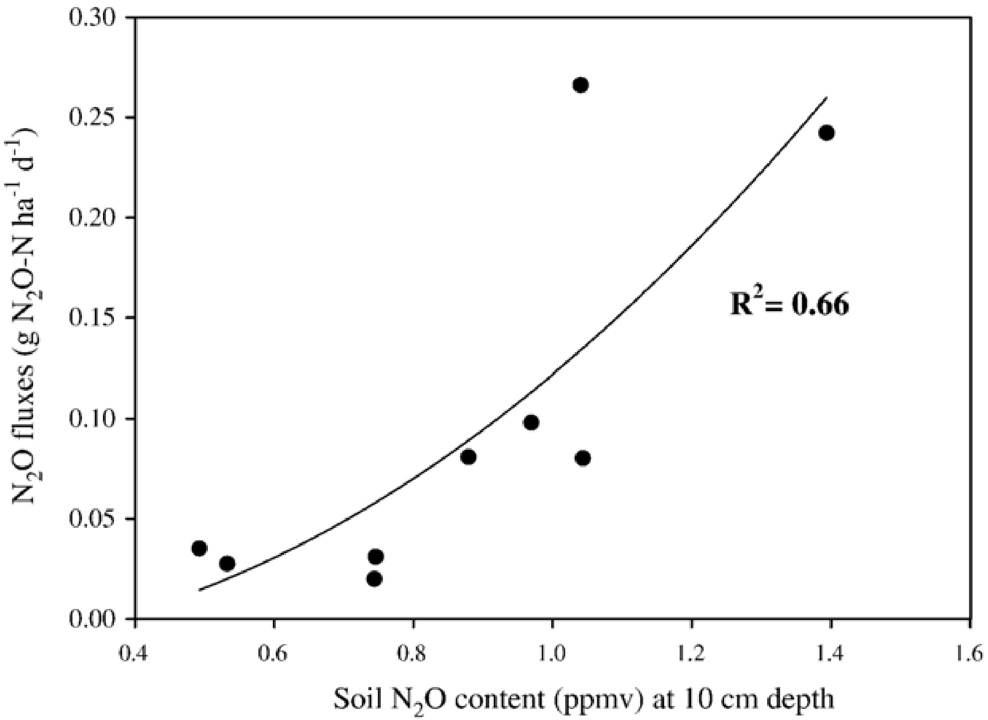
*Source*: doi: 10.1007/s10705-008-9178-y

# Soil biological activity

Soil $CO_2$ content (ppmv) versus soil $N_2O$ content (ppmv) at 10 cm depth (dots represent monthly averages) $p<0.05$.




$N_2O$ fluxes (g $N_2O$–N $ha^{-1}$ $day^{-1}$) versus soil $N_2O$ content (ppmv) at 10 cm depth (dots represent monthly averages).




*Source:* doi: 10.1016/j.geoderma.2007.05.010

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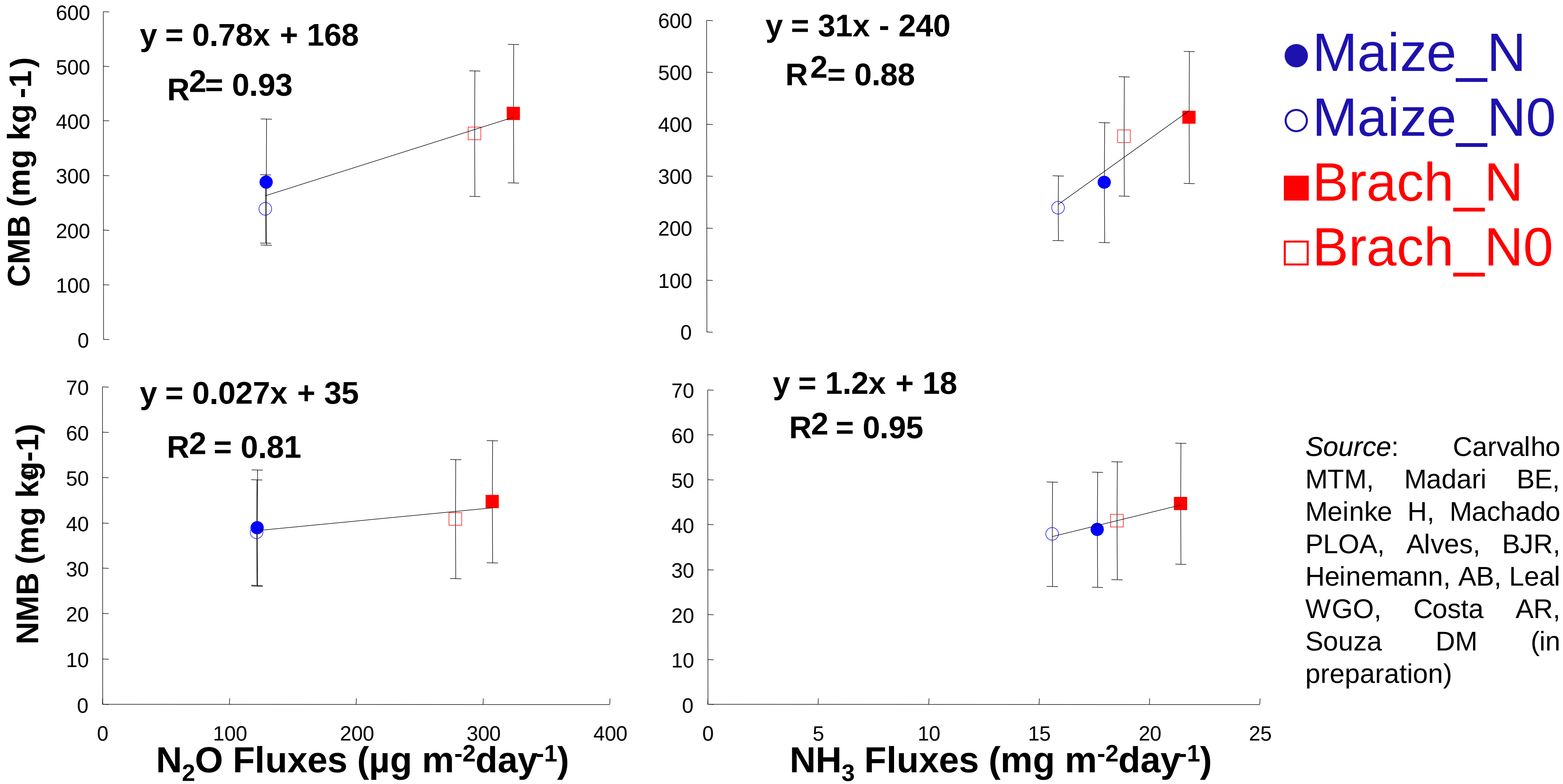



*Source*: Carvalho MTM, Madari BE, Meinke H, Machado PLOA, Alves, BJR, Heinemann, AB, Leal WGO, Costa AR, Souza DM (in preparation)

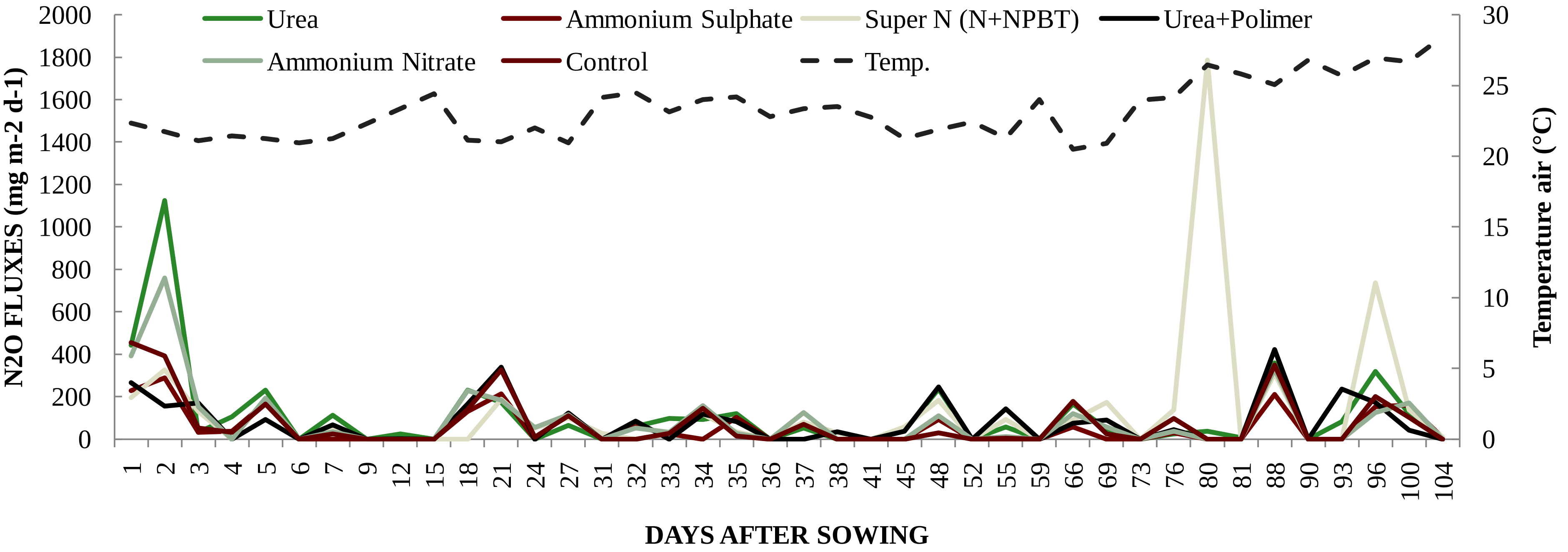
Linear correlation between averages of nitrous oxide and ammonia fluxes and content of Carbon and Nitrogen in microbial biomass, at 0-10cm, under no-till irrigated common beans production system with two types of crop residues, maize and brachiaria, unfertilized and fertilized with mineral N (error bars are sd, n=6 for each dot).

# Nitrogene Sources

# Rhodic Ferralsol, clay (55% clay, 11% silt, 33% sand), Central-Brazil, Biome: Cerrado

## Inorganic Nitrogene Sources

$N_2O$ fluxes at 0-10 cm soil layer during the life cycle of irrigated common beans.

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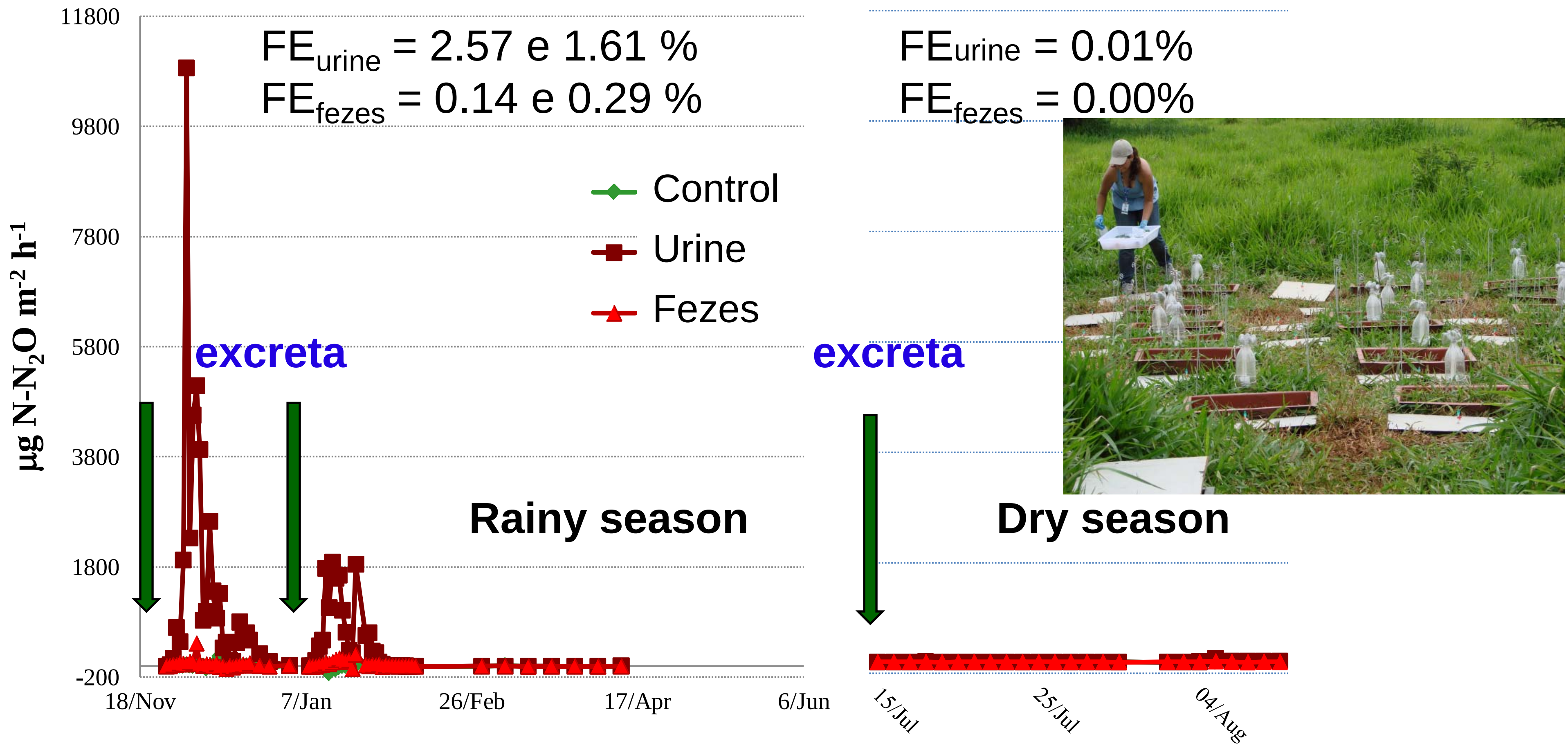
**Total direct $N_2O$ emission, emission factors, yields and emission efficiency of different mineral N sources.**

| Mineral N Source | Emission 9 days | Total Emission (TE) | Emission Factor | Yield | Emission Efficiency |
|---|---|---|---|---|---|
| | g N-$N_2O$ $ha^{-1}$ | | % | kg $ha^{-1}$ | TE $Mg^{-1}$ grain |
| **Urea** | 20.48 a | 83.68 b | 0.02 | 2421 | 34.56 |
| **Super N (Urea+NPBT)** | 8.95 b | 128.41 a | 0.07 | 1887 | 68.05 |
| **Urea+Polimer** | 7.53 b | 72.62 b | 0.01 | 2528 | 28.73 |
| **Ammonium Nitrate** | 15.35 ab | 63.77 b | 0.00 | 2388 | 26.70 |
| **Ammonium Sulphate** | 7.59 b | 43.43 b | 0.00 | 2340 | 18.56 |
| **N0** | 11.21 b | 62.74 b | - | 1836 | 34.17 |

Note: Variability (spatial) of fluxes is high, existence of hot spots of emissions, difficult to avoid even with high sampling density or frequency.

# $N_2O$ emission from bovine excreta

## $N_2O$ fluxes from bovine excreta in brachiaria pasture from a Rhodic Ferralsol (clayey) in Santo Antonio de Goiás-GO, Cerrado, Brazil




(*Source:* Lessa, ACR, Santos, EB, Paredes, DS, Otoni, RF, Sampaio, GC, Madari, BE, Alves, BJR. Emission of $N_2O$ and volatilization of $NH_3$ from bovine excreta in a Rhodic Ferralsol under pasture in the Brazilian Cerrado. FERTBIO, Guarapari – ES, Brazil, Sept. 13-17, 2010.

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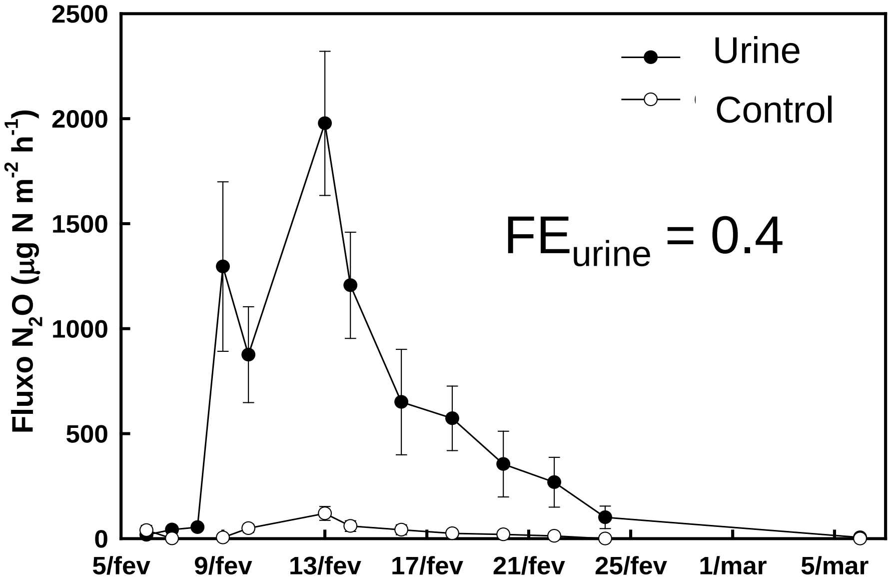
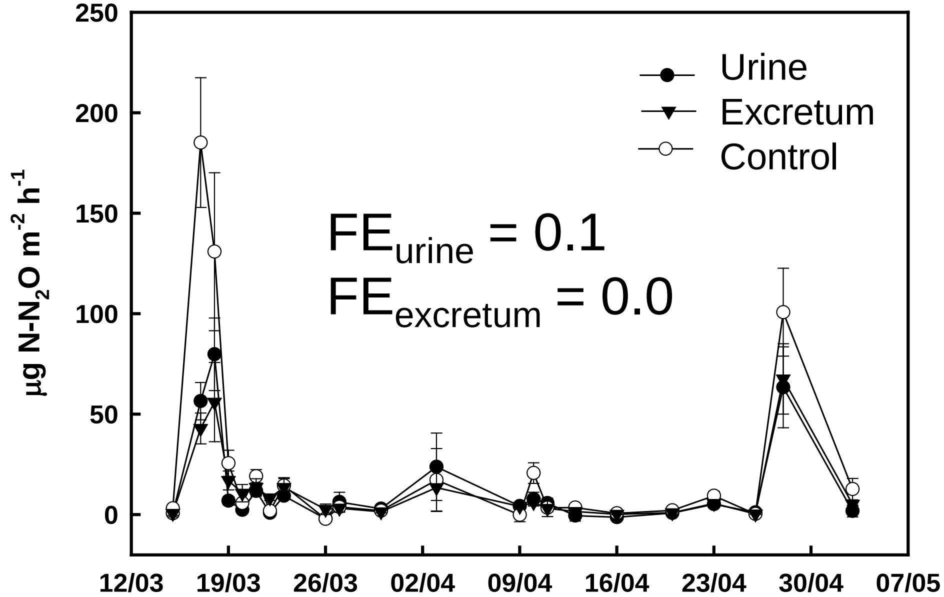
# $N_2O$ emissions from pasture bovine urine and excretum




Soil with impedement for drainage (Planosol, South-East Brazil)

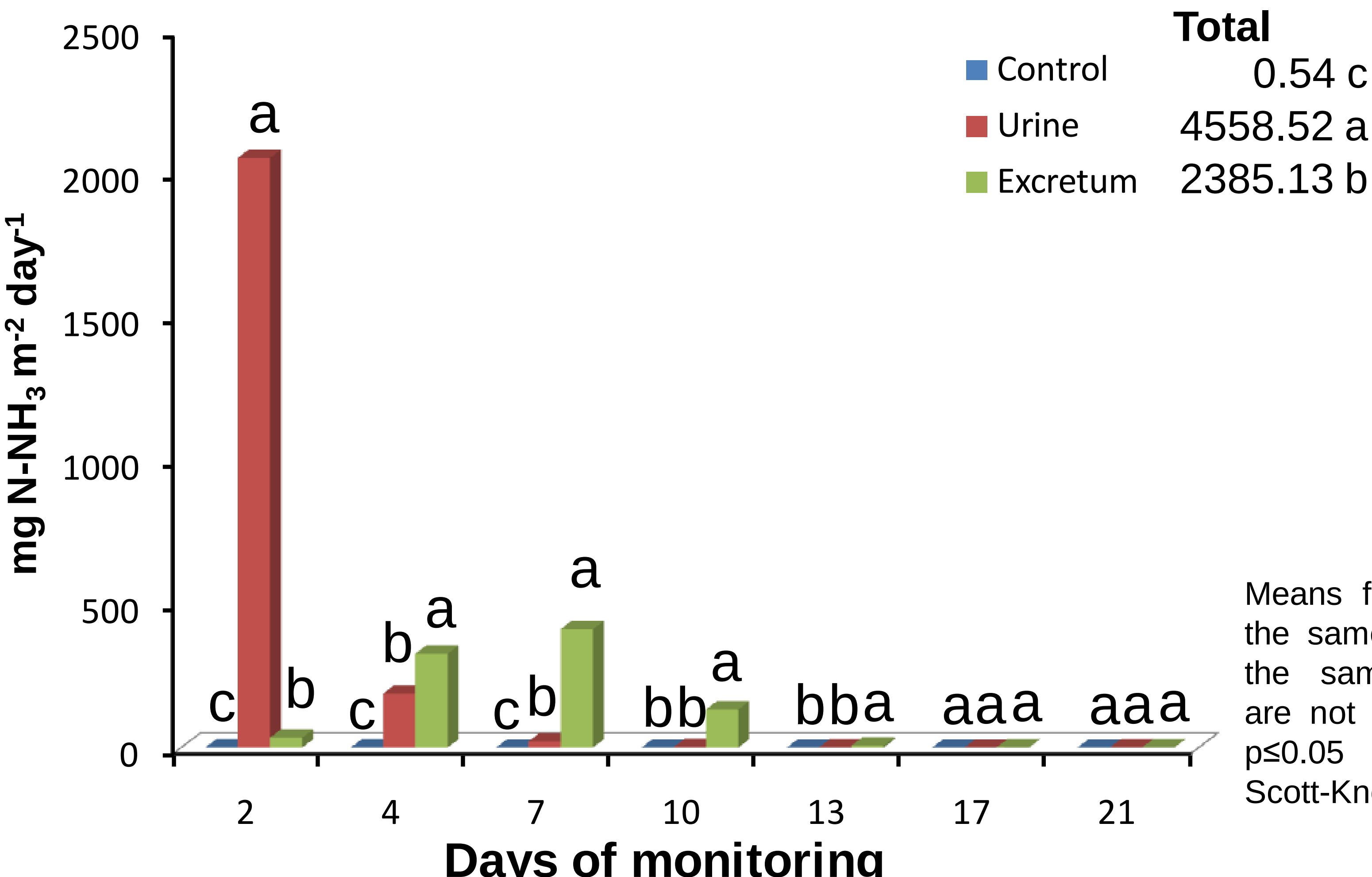



Soil without impedement for drainage (Acrisol)

*Source:* Alves, BJR. Emissões de $N_2O$ em sistemas agrícolas. Presentation (Brasília-DF, April 08, 2008).

• These preliminary data indicate that the emission factor for N in urine is between ~1.2 -1.4% and for N in fezes between ~ 0.1 a 0.2 %;
• The “Tier 1” value of IPCC is 2%;
• In conditions of extensive pasture grazing rarely more than 60% of the N is excreted in the urine, that would lead to an emission factor of around 0.5-0.7%.

N lost in the form of $NH_3$ from urine and excretum compared with control during 21 days of monitoring.




Means followed by the same letters in the same column are not different at $p \leq 0.05$ by the Scott-Knott test.

*Source:* Lessa, ACR, Santos, EB, Paredes, DS, Otoni, RF, Sampaio, GC, Madari, BE, Alves, BJR. Emission of $N_2O$ and volatilization of $NH_3$ from bovine excreta in a Rhodic Ferralsol under pasture in the Brazilian Cerrado. FERTBIO, Guarapari – ES, Brazil, Sept. 13-17, 2010.

# Biological Fixation of Nitrogene

# Biological $N_2$ Fixation

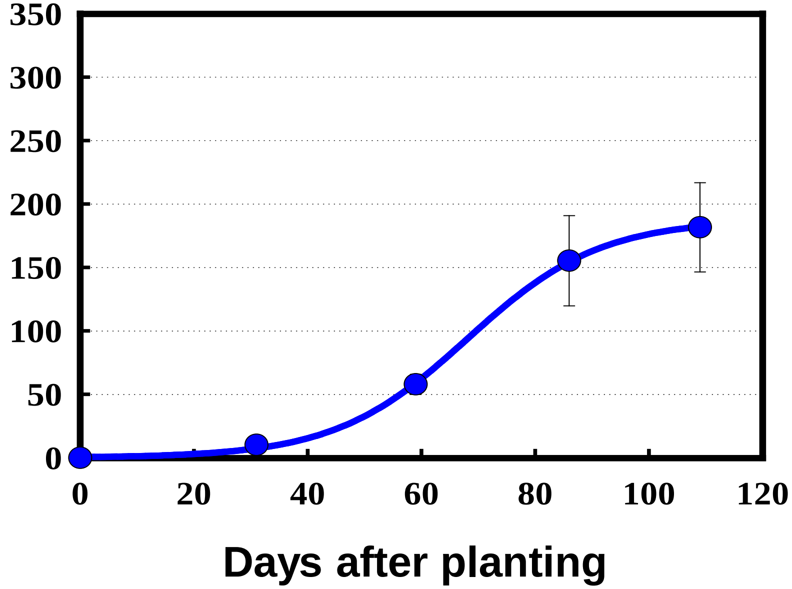
**IPCC 1996**

**Nodulating bacteria are capable of denitrification.**

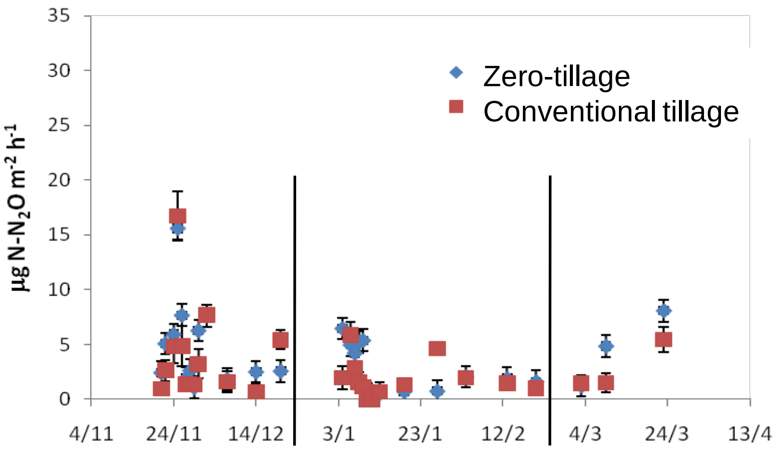
**$N_2O$ emission from BNF equals to 1.25% of N fixed by leguminous plants.**

$$N - N_2O_{\,direct} = \left[\left(F_{SN} + F_{AM} + F_{BN} + F_{CR}\right) \times EF_1\right] + \left(F_{OS} \times EF_2\right)$$

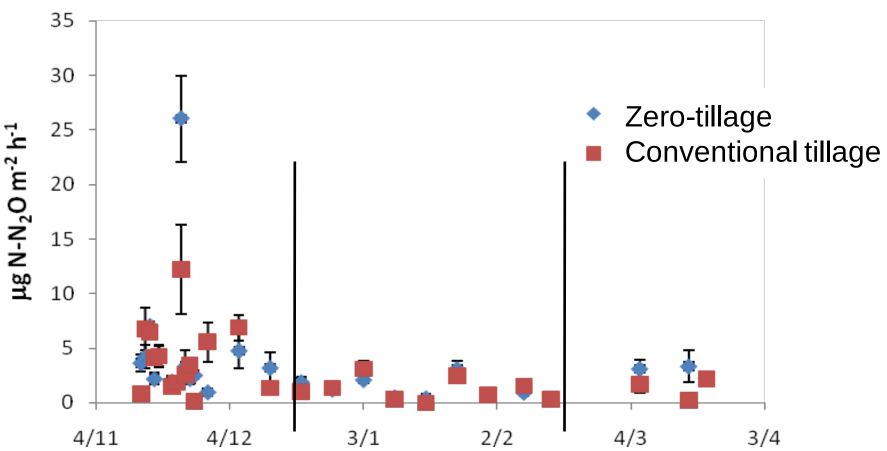
If BNF produces $N_2O$ the highest fluxes are expected between 40 to 90 days after planting



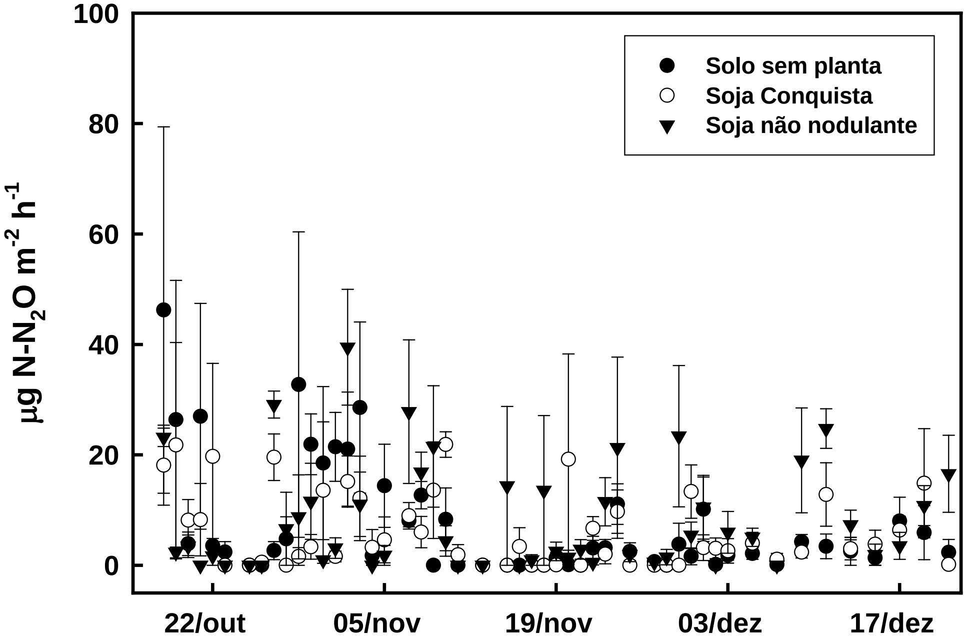

## Londrina, PR, Biome: Atlantic forest




## Passo Fundo, RS, Biome: Atlantic forest



# BNF is not direct source of $N_2O$




$N_2O$ fluxes measured in pots planted with nodulating and non-nodulating cultivars of soybean and without plants (64 days of evaluation) (Cardoso et al, 2008).

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## A fixação biológica de nitrogênio não é uma fonte direta de N2O de solos agrícolas

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O óxido nitroso (N2O) é um dos gases que reconhecidamente contribui para o efeito estufa na atmosfera, juntamente com gás carbônico (CO2) e metano (CH4). No Brasil, a agricultura é considerada como sendo a atividade que mais contribui no volume total de N2O emitido anualmente para a atmosfera. (MCT, 2004).

As emissões de N2O de solos agrícolas, que fazem parte do inventário nacional de GEEs, são computadas com base na metodologia desenvolvida pelo Painel Intergovernamental de Mudanças Climáticas, elaborada em 1996 (IPCC, 1996), e no Guia de Boas Práticas e Gestão de Incertezas para Inventários de GEEs do ano 2000 (IPCC, 2000). Em 2006, foi divulgada a mais recente revisão das metodologias do IPCC (IPCC, 2006), no entanto ainda não foi aprovada pela Convenção Quadro das Nações Unidas para as Mudanças do Clima (UNFCCC).

De acordo com a metodologia do IPCC de 1996, as emissões de N2O de solos agrícolas ocorrem após a aplicação ao solo de fertilizantes nitrogenados e adubos de origem animal, de resíduos de colheita que mineralizam e liberam N mineral para o solo, da deposição de excrementos de animais, do manejo de solos orgânicos e da fixação biológica de nitrogênio (FBN). De todas essas fontes, a mais questionada é a FBN, pois não existem evidências científicas que sustentem que 1,25% do N2 fixado do ar por leguminosas sejam emitidos como N2O durante o crescimento da planta (ROCHETTE e JANZEN, 2005), tal como consta na metodologia do IPCC (1996).

Os trabalhos de BREMNER et al. (1980) e de DUXBURY et al. (1982) foram os primeiros a sugerir que o processo de FBN teria relação direta com as emissões de N2O, o que foi reforçado com a demonstração da capacidade desnitrificadora do rizóbio (O'HARA & DANIEL, 1985). Estudos *in vitro*

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$$N - N_2O_{direta} = \left[\left(F_{SN} + F_{AM} + \cancel{F_{BN}} + F_{CR}\right) \times EF_1\right] + \left(F_{OS} \times EF_2\right)$$

## Conclusions

• $N_2O$ fluxes at a standard rate of N application are generally low, especially compared to temperate climate zones (Chouldhary et al. 2002; Liu et al. 2006);

• ZT did not promote higher $N_2O$ emissions compared to CT and no influence of $N_2O$ fluxes could be detected in the areas with N richer residues coming from winter legume for green manuring;

• ZT with legumes for green manuring will not affect significantly soil $N_2O$ emissions to the point of offsetting the already shown benefits of C sequestration when compared to the traditional soybean-wheat system under CT;

•Brachiaria grass as cover crop is an important component of zero-tillage systems as well as in ILPF in tropical agroecosystems, especially in the Cerrado (savannah) biome for its high capacity to provide SOM input into soil and avoid much of soil erosion, however it seems to enhance direct, but principally indirect $N_2O$ emissions in irrigated systems (dry season);

• In the examined soils $N_2O$ emission predictors (inorganic N pools, %WFPS) do not seem to be useful; however cover crop management on soil biological activity is important as it influences $N_2O$ emissions;

## Conclusions

• $N_2O$ emissions from different mineral N sources can be different; the whole plant cycle has to be considered for the evaluation;

• Among bovine excreta urine is the most important source of direct and indirect $N_2O$ emission;

• $NH_3$ can be an important source of indirect emissions, more study is needed;

• Results suggest that BNF is not a direct source of $N_2O$ emission;

• Emission factors:

- Considering the large uncertainty range of EF1 (IPCC 2006) field measured $N_2O$ emissions matched the IPCC based estimates but always with lower values;

- Considering field data obtained in Brazil the EF would be ~0.28, close to the inferior limit of the range proposed by IPCC (0.03-3%), still >3 times smaller than the mean value (1%) used in inventories.

- In conditions of extensive pasture grazing rarely more than 60% of the N is excreted in the urine, that would lead to an emission factor of around 0.5-0.7%.

# Conclusions

- Problems:
  - High spatial variability of fluxes, hot spots;
  - Experimental design, practical constraints