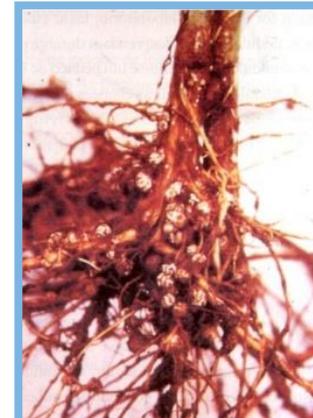
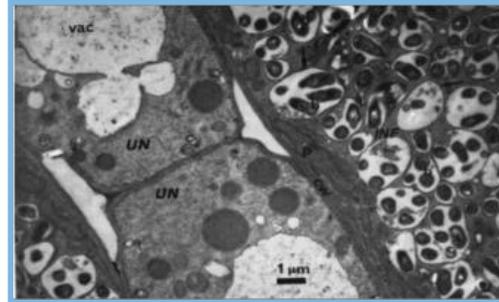


Plant-growth-promoting bacteria: Opportunity to improve agriculture sustainability

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Marco Antonio Nogueira
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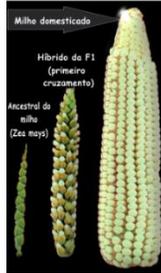
Plants need nutrients

Forest in equilibrium



Nutrient cycling

Demands of ancestral x modern genotypes



Large-scale agriculture requires chemical fertilizers



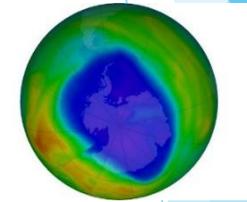
Chemical Fertilizers

1) Low efficiency of use by plants

N, 30-50%;
P, 15%;
K, 50-60%

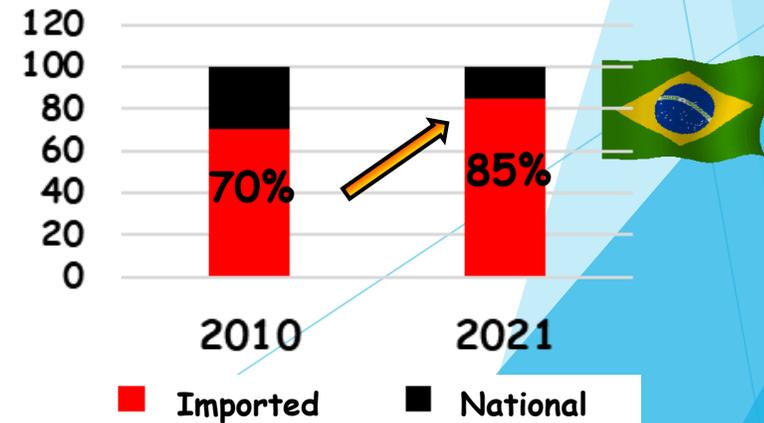


2) Water contamination, emission of GHG



1 kg N = 10.7 kg CO₂-e

3) Price, importation in most countries

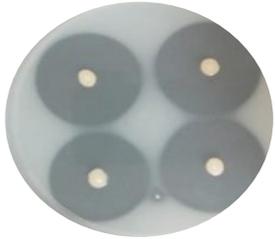


Alternatives?

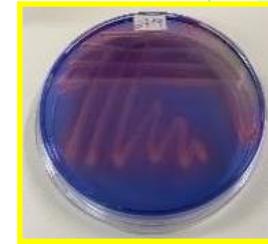
Plant-Growth-Promoting Microorganisms (PGPM)



Capable of fully or partially replace chemical fertilizers



With economic, environmental and social benefits



Plenty of opportunities!!!

(K, P, N)



In the market in Brazil

Inoculants (=biofertilizers)

Nitrogen

Biological nitrogen fixation



symbiosis



+ bacteria - bacteria

<i>Acacia</i> spp.	acacia	5-50
<i>Arachis hypogaea</i>	groundnut	32-206
<i>Cajanus cajan</i>	pigeonpea	68-88
<i>Calopogonium muconoides</i>	calopogonium	64-182
<i>Centrosema</i> spp.	centrosema	41-280
<i>Cicer arietinum</i>	chickpea	0-141
<i>Desmodium</i> spp.	desmodium	25-380
<i>Gliricida sepium</i>	gliricida	26-75
<i>Glycine max</i>	soybean	0-450
<i>Lathyrus sativus</i>	lathyrus	172-227
<i>Lens culinaris</i>	lentil	5-191
<i>Leucaena leucocephala</i>	leucaena	98-274
<i>Lupinus albus</i>	sweet lupin	40-160
<i>Lupinus angustifolius</i>	lupin	19-327
<i>Lupinus mutabilis</i>	bitter lupin	95-527
<i>Macroptilium atropurpureum</i>	siratro	46-167
<i>Medicago sativa</i>	alfalfa	45-470
<i>Melilotus officinalis</i>	yellow sweet clover	84
<i>Neonotonia wightii</i>	perennial soybean	126
<i>Phaseolus vulgaris</i>	common bean	0-165
<i>Pisum sativum</i>	field pea	4-244
<i>Pueraria phaseoloides</i>	tropical kudzu	115
<i>Sesbania</i> spp.	sesbania	7-109
<i>Stylosanthes</i> spp.	stylosanthes	4-263
<i>Trifolium</i> spp.	clover	67-260
<i>Vigna mungo</i>	black gram	119-140
<i>Vigna radiata</i>	green gram	58-107
<i>Vigna unguiculata</i>	cowpea	9-201
<i>Zornia glabra</i>	zornia	61

kg N/ha

Inoculants + 60 years, + 90 million doses

Research... takes a whole life to be successful!!!

"New" areas

Inoculated



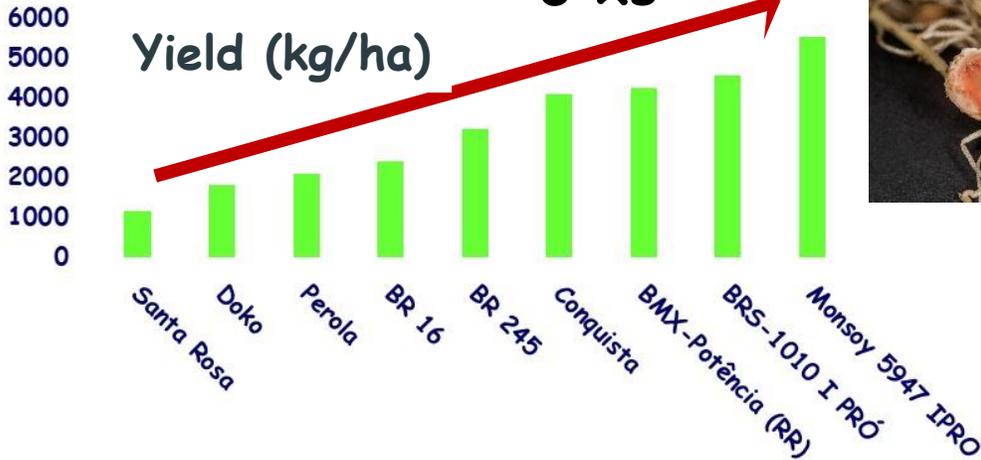
Non-inoculated

Strain selection



6 xs

Yield (kg/ha)



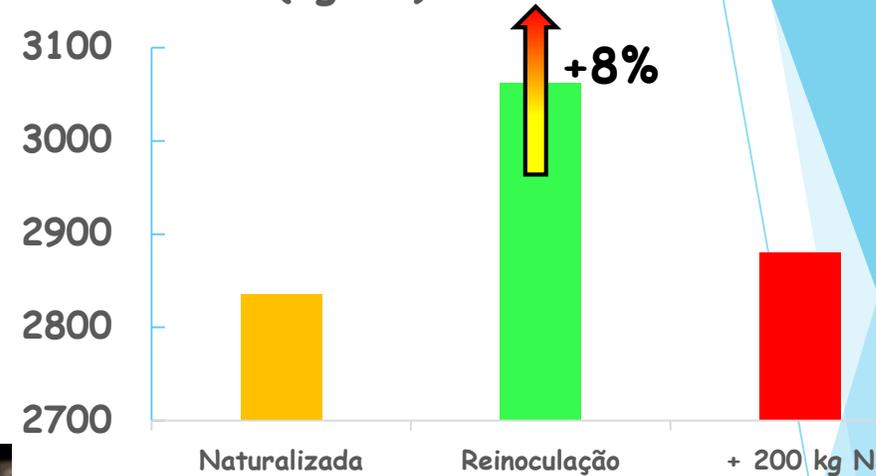
1960 1970 1980 1990 2000 2010 2013 2016 2017

Hungria & Mendes, Chapter (2015)

Reinoculation

+ 300 field trials
 10^3 a 10^6 cells/g soil
 + 8% ($p < 0.05$)

Rendimento (kg/ha)



(Hungria et al.,
 Chapter,
 Communicates,
 2006, 2007;
 Hungria & Mendes
 Chapter, 2015)



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Plant Cell Environ. 2020;1-15.

ORIGINAL ARTICLE

Plant Cell & Environment | WILEY

Insufficient nitrogen supply from symbiotic fixation reduces seasonal crop growth and nitrogen mobilization to seed in highly productive soybean crops

Nicolas Cafaro La Menza¹ | Juan Pablo Monzon^{1,2} | John L. Lindquist¹ |
 Timothy J. Arkebauer¹ | Johannes M. H. Knops^{3,4} | Murray Unkovich⁵ |
 James E. Specht¹ | Patricio Grassini¹

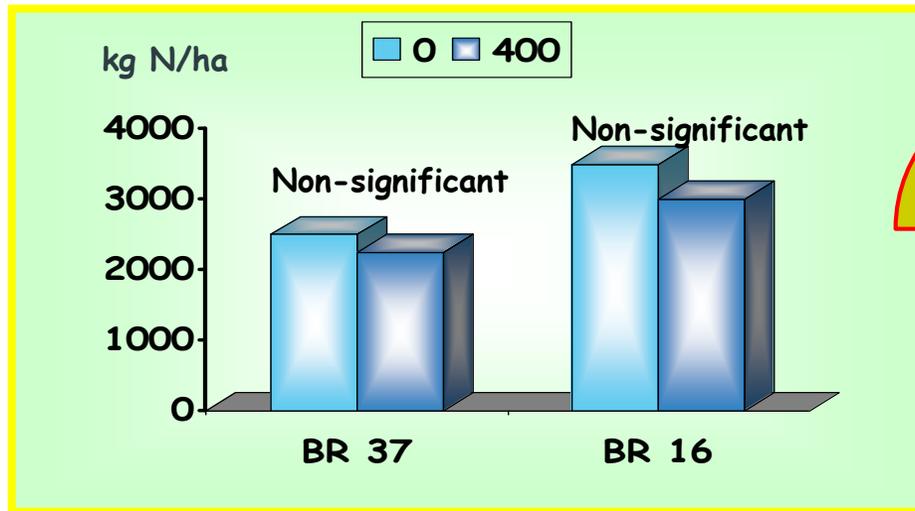


Did not include reinoculation
 +10.5% by adding 870 kg N !!!

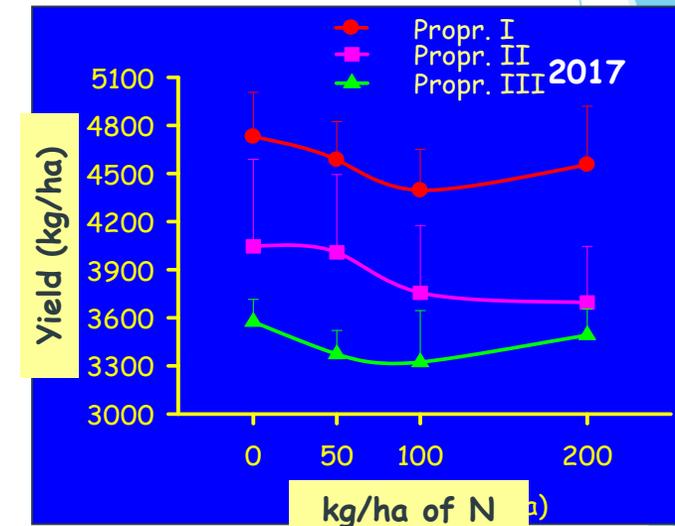
Long-term research

N-fertilizers?

Experiments every year (pressure to sell fertilizers)



Hungria et al., Technical Communicate (1997)



Saturno et al., J. Plant Nutr. (2017)

20 years

+ 300 field trials, 30 years



- No till, conventional till;
- Different plant growth types;
- Transgenic, conventional;
- Different maturity groups;

- Application in different plant growth stages;
- N sources;
- Methods of application.

We have to do it so that the farmer will save money and the planet will be more sustainable

Main world soybean producers

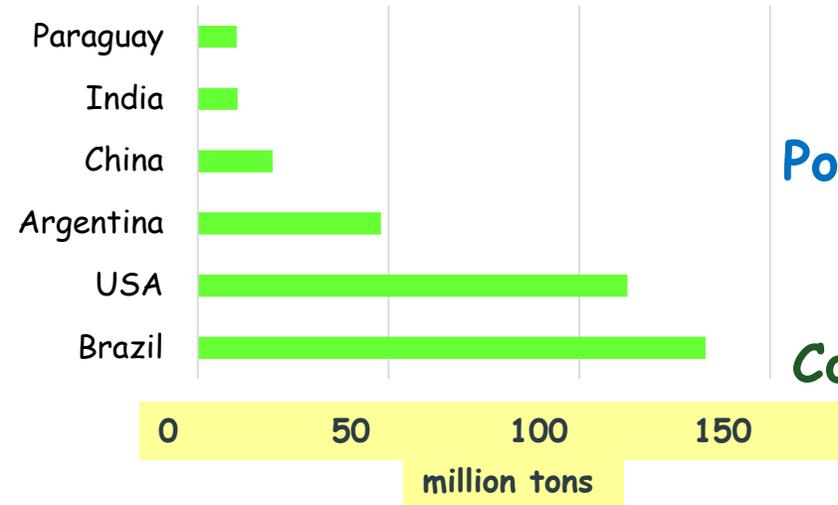
Brazil is the first world soybean producer



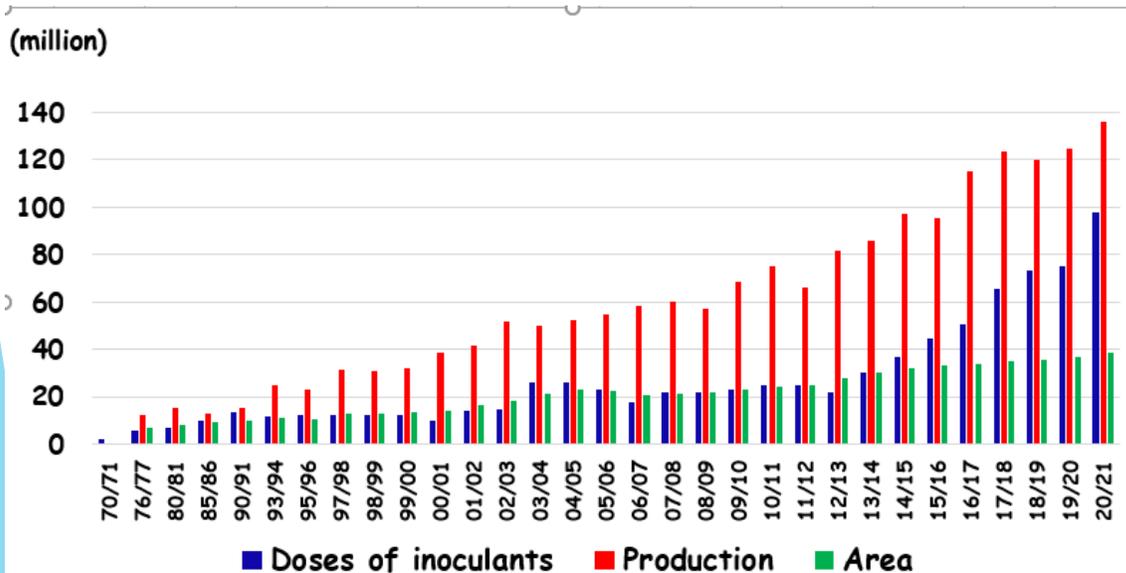
Position achieved only due to the biological nitrogen fixation



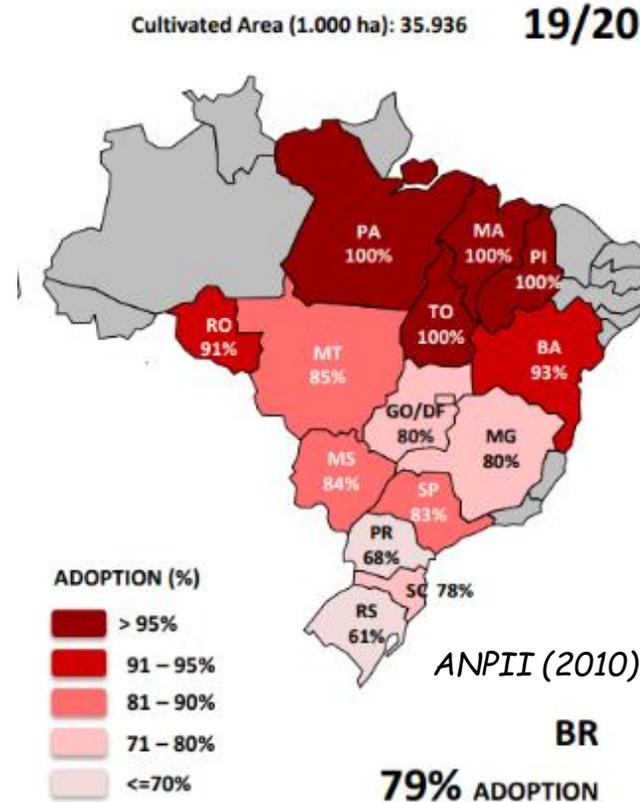
Contribution of BNF: Brazil (>90%); USA (50%); China (50%)



Farmers know about the benefits, farmers use



Hungria & Nogueira, Chapter (2022)



Little N-fertilizers industries working for the farmers



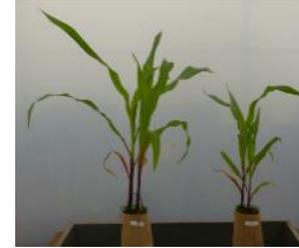
And when the farmers see the benefits, they want more!!!

1998-2004

Azospirillum brasilense



BNF



Phytohormones

Hungria et al.,
Plant Soil (2010)



+24%



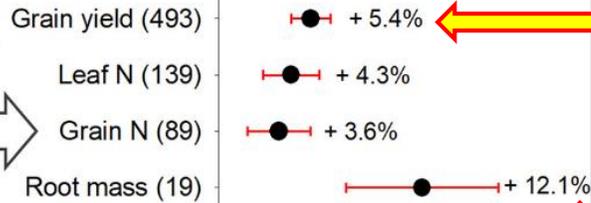
+19%



Inoculant in
2009

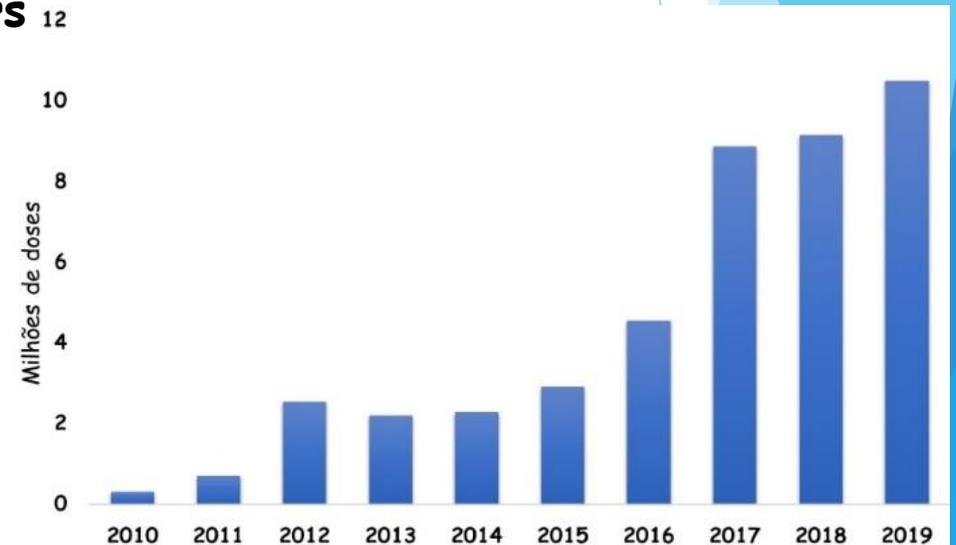


Maize attributes



Effect of inoculation (%)

10 years



Barbosa et al., Appl. Soil Ecol. (2022)

Santos et al., Rev. Bras. Cienc. Solo (2021)

More roots improve efficiency of use of chemical fertilizers by the plants

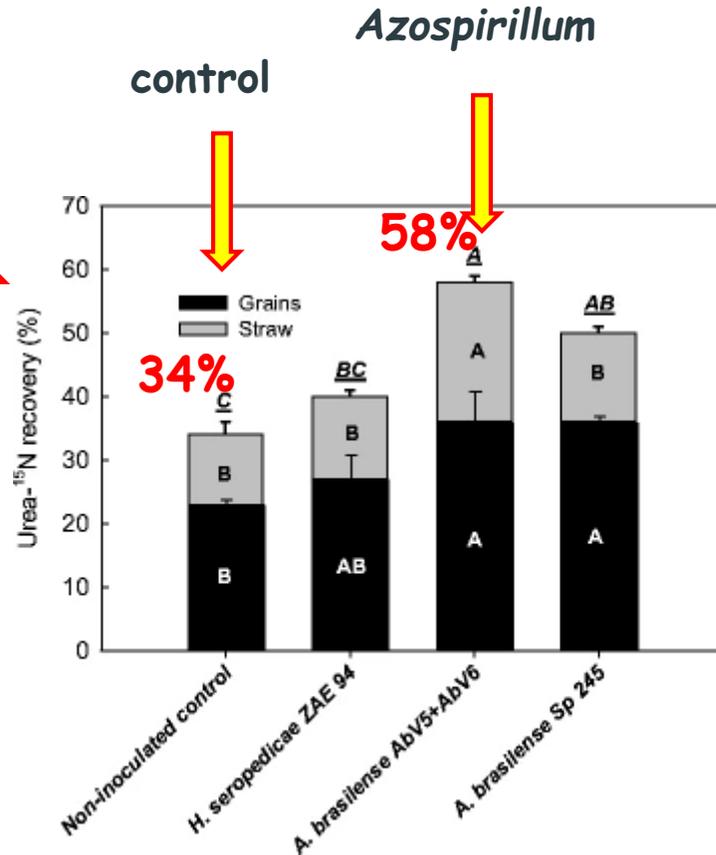
Nitrogen

Azospirillum brasilense



Phytohormones (IAA)

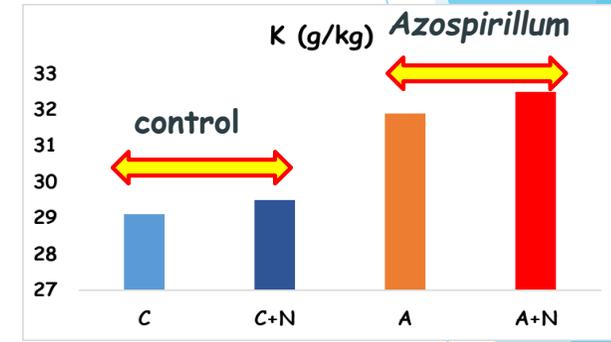
+70%



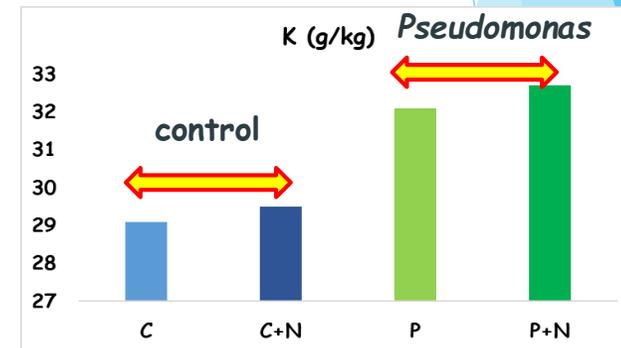
100 kg/ha of ¹⁵N

Martins et al., Plant and Soil (2018)

Potassium



Azospirillum brasilense



Pseudomonas fluorescens

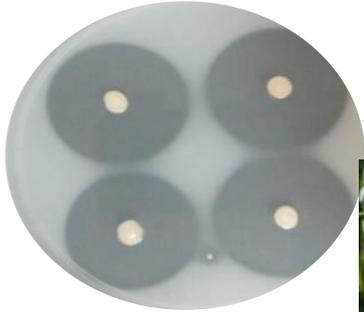
80 kg /ha of K₂O

Hungria et al., Plant and Soil (2021)

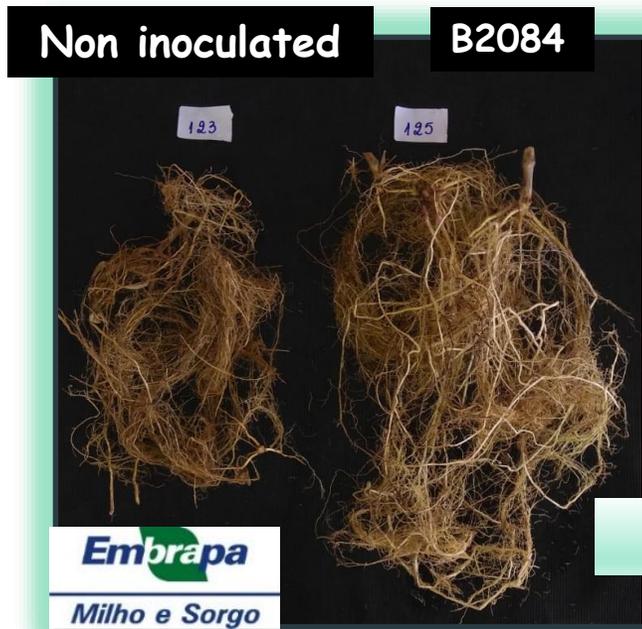
Phosphorus

Solubilization and uptake of phosphorus

- ✓ CNPMS B2084: *Bacillus subtilis*
- ✓ CNPMS B119: *Bacillus (Priestia) megaterium*



Ribeiro et al. Braz. J. Microbiol. (2018)



Inoculant in 2019

2021



maize



soybean



sugarcane

4 million hectares

And we realized that there is advantage in using more than one microorganism!!!

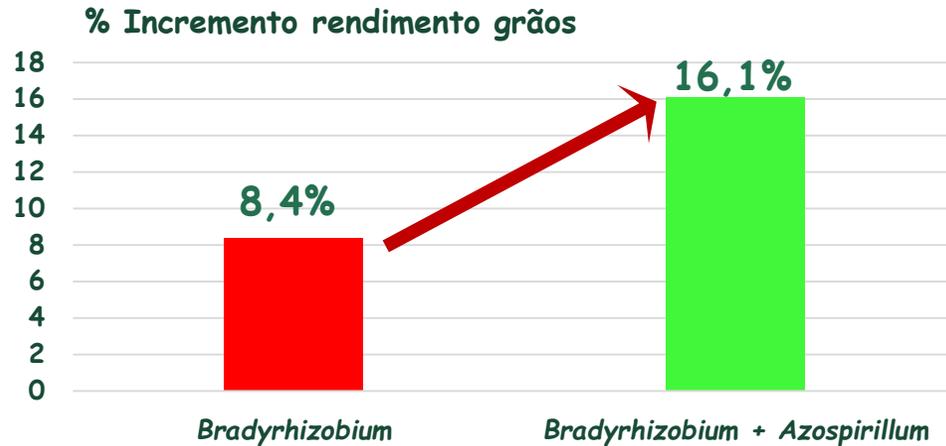
Co-inoculation !!!!! rhizobia + *Azospirillum brasilense*

"industry" of N-fertilizer

"industry" of phytohormones



Hungria et al., *Biol. Fertil. Soils*, 2013



Inoculant
2013/14

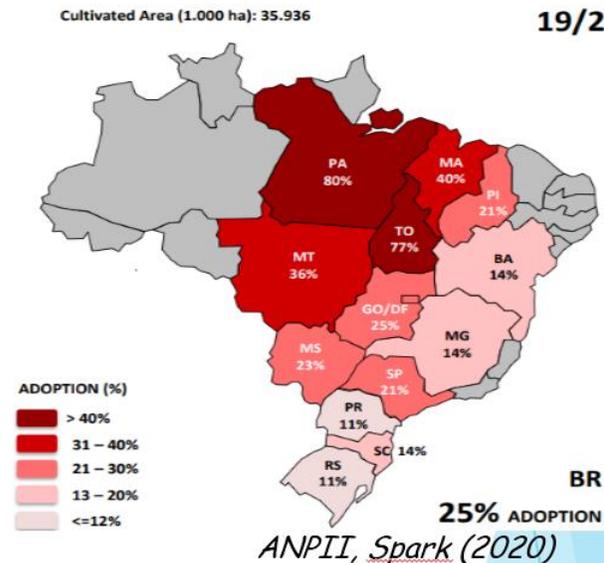
5 years

- 51 publications,
- 39 sites-field trials

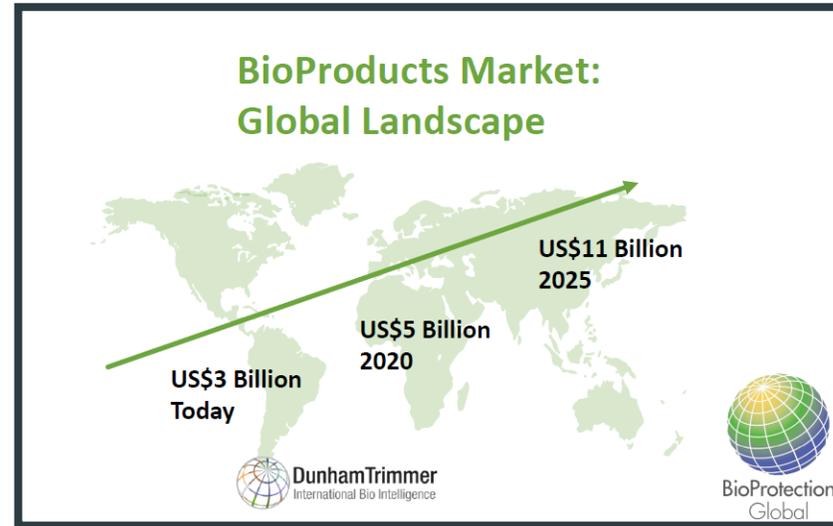
Barbosa et al., *Applied Soil Ecol.* (2021)

root dry weight: +11%
 nodule number: +5.4%
 nodule dry weight: +10,6%
 N in grains: +3.2%
 yield: +3.6%

5 years

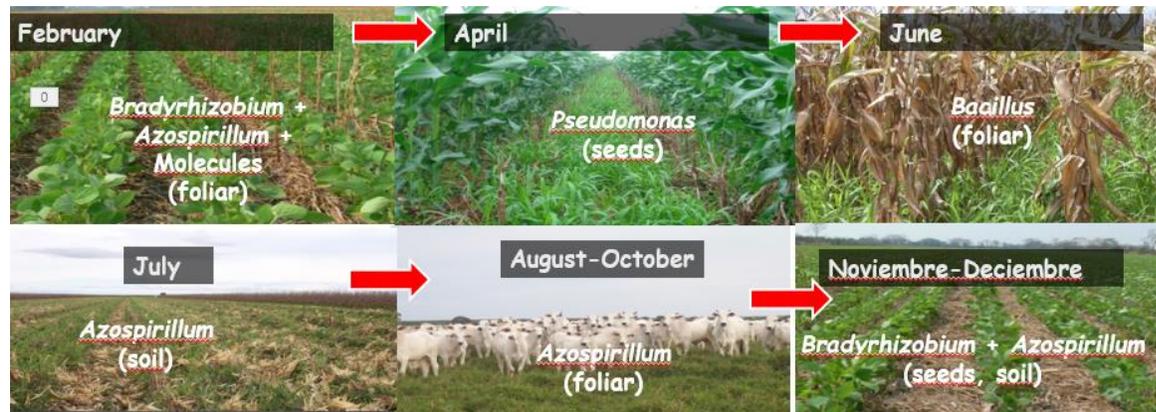
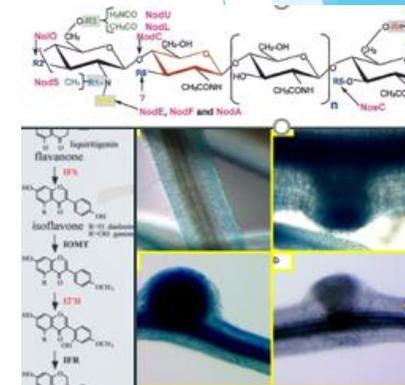


The Future



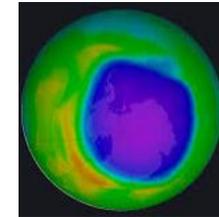
2020-2025
Chemicals: 3.4%
Biologicals: 15%

1) Use of multifunctional microorganisms + microbial molecules

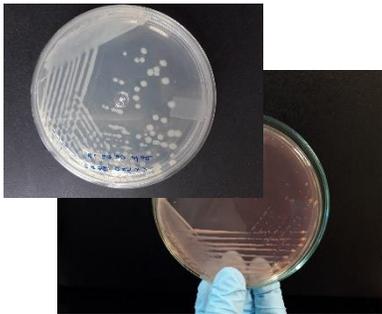


2) Microorganisms for integrated systems

3) Microorganisms to mitigate the emission of GHG



Nitrogen (Brazil): soybean, common bean, maize, brachiarias = 228 million Mg de CO₂-e

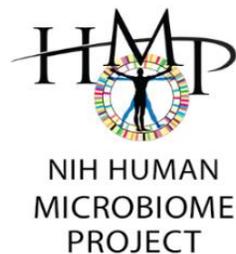
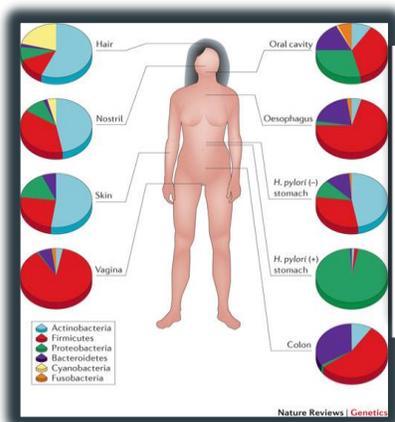


Lower cost, human health

4) Microorganisms as social services

5) A brilliant microbial future is expected in agriculture

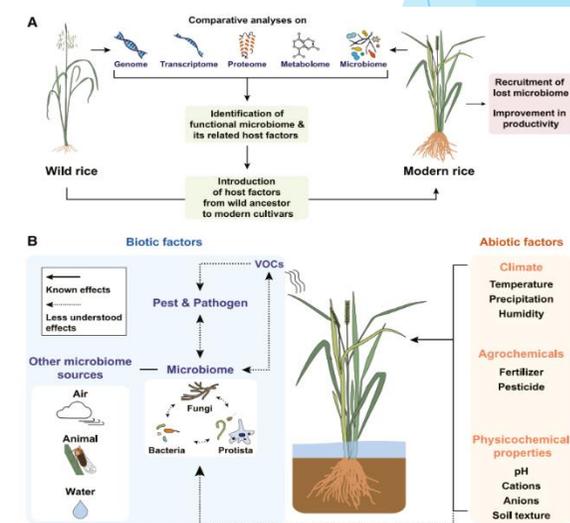
Human microbiome



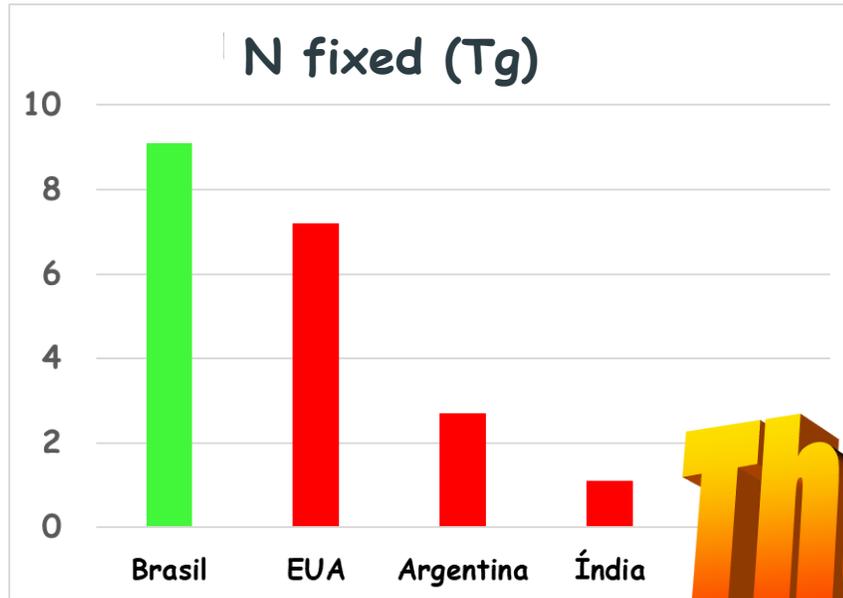
Plant microbiome

- Control of abiotic stresses;
- Control of diseases;
- Maximize plant nutrition.

Kim & Lee, *Phytobiomes J.* (2020)



Beautiful stories are built with lots of efforts: research + industry + legislation + farmers



Herridge et al., Plant and Soil (2022)



Thank you!!!!

2021/22

(~40.70 million ha, 3,016 kg/ha)

ea \$ /kg N

~US\$ 41.92 billion/year

~US\$ 1,320/second!!!

~204 million ton of CO₂-equivalents

