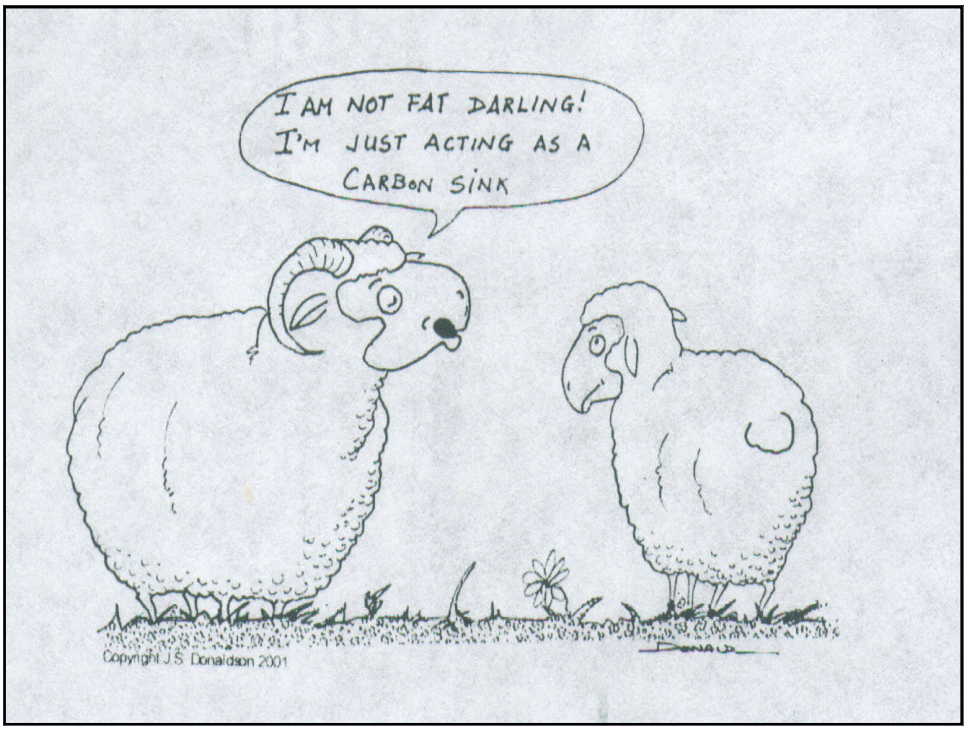
Soil Carbon Sequestration in Brazil

Telmo Amado
Manhattan – KS
December 18, 2007



Index

- Amazon Tropical Rain Forest
- Agribusiness overview – Brazilian Ethanol
- Carbon cycle under No-till system
- Innovate cropping system
- Final remarks

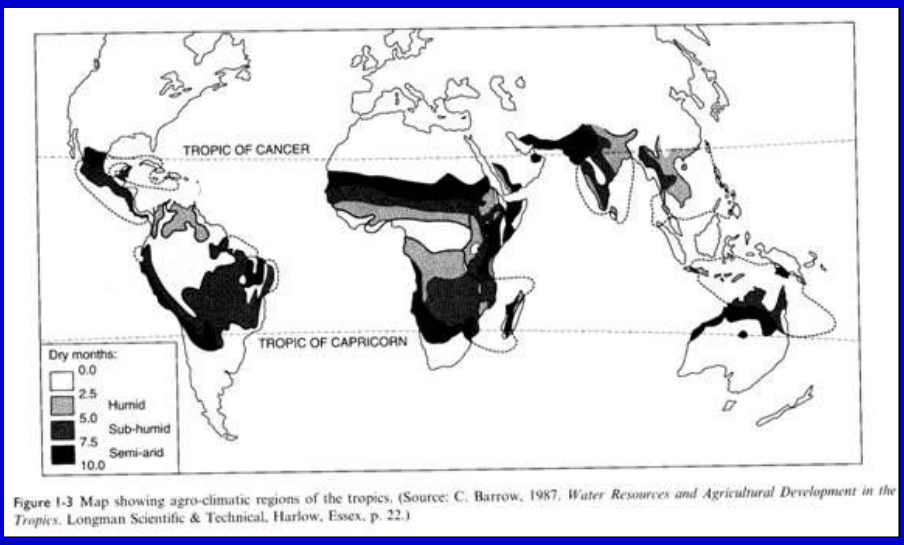
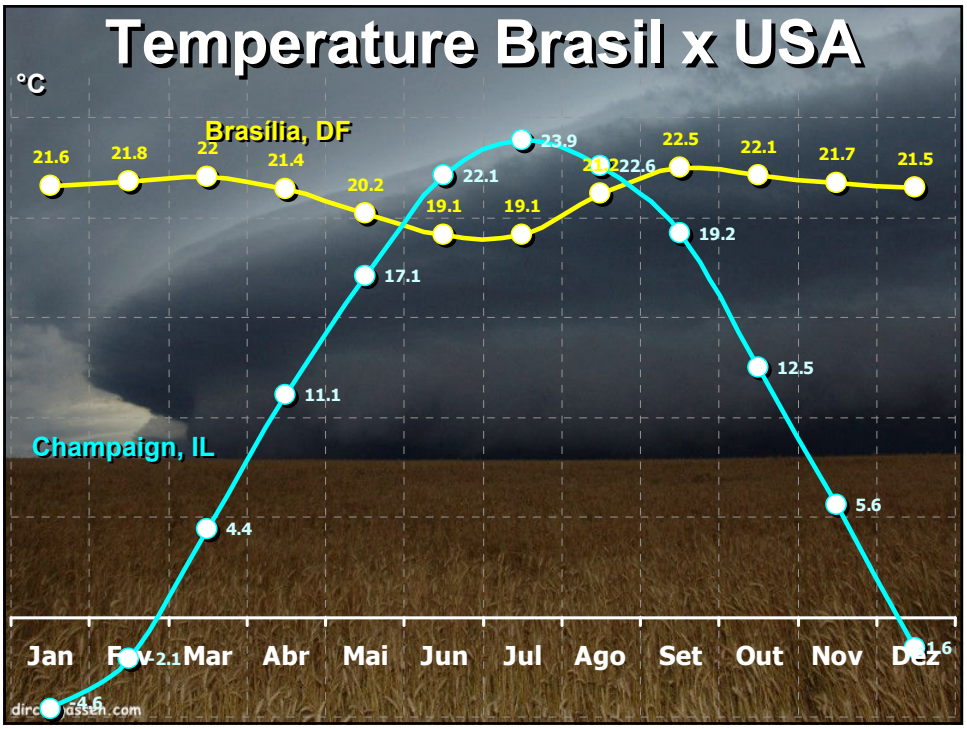
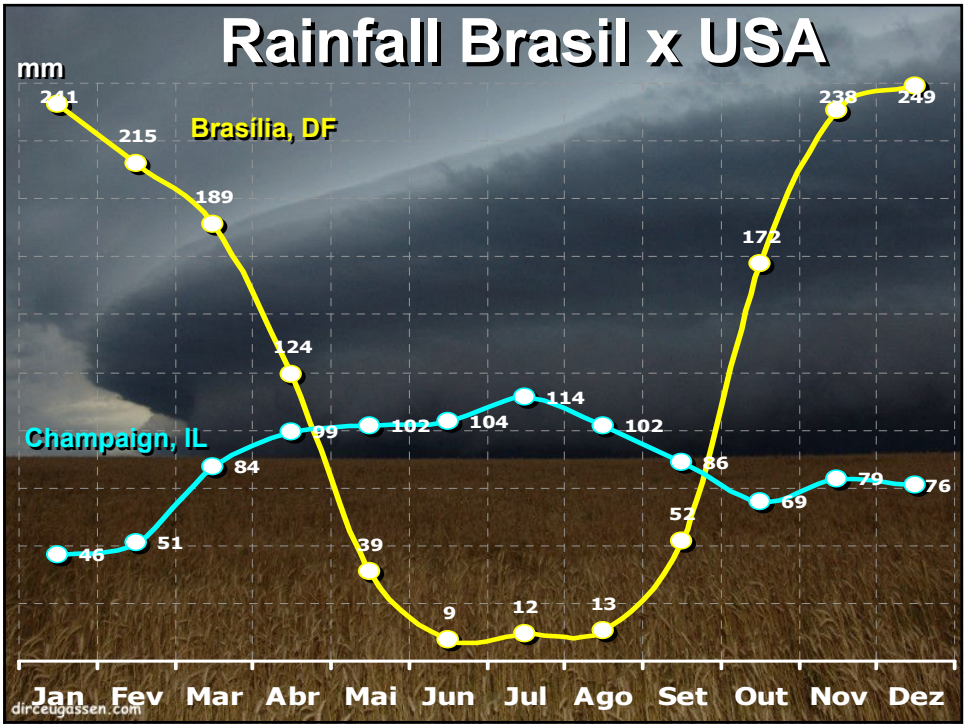


Figure 1-3 Map showing agro-climatic regions of the tropics. (Source: C. Barrow, 1987. *Water Resources and Agricultural Development in the Tropics*. Longman Scientific & Technical, Harlow, Essex, p. 22.)


Temperature Brasil x USA
°C
Brasília, DF
21.6
21.8
22
21.4
20.2
19.1
22.1
23.9
22.6
19.1
22.5
22.1
21.7
21.5
19.2
12.5
5.6
Champaign, IL
4.4
11.1
17.1
Jan
Fev
Mar
Abr
Mai
Jun
Jul
Ago
Set
Out
Nov
Dez
dirceugassen.com


Rainfall Brasil x USA
mm
Brasília, DF
241
215
189
124
39
9
12
13
52
172
238
249
Champaign, IL
46
51
84
99
102
104
114
102
86
69
79
76
Jan
Fev
Mar
Abr
Mai
Jun
Jul
Ago
Set
Out
Nov
Dez
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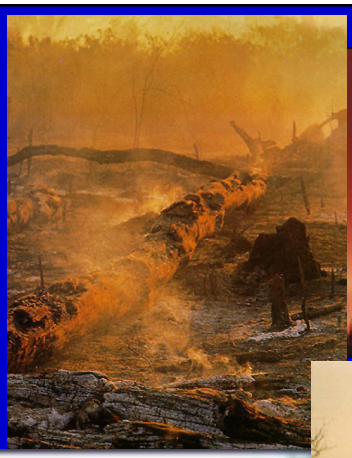
Amazonia at a glance ... The Natural System

- almost 6 million km^2 of contiguous tropical forests
- perhaps 1/3 of the planet's biodiversity
- abundant rainfall (2.2 m annually)
- 18% of freshwater input into the global oceans (220,000 m^3/s)
- over 100 G ton C stored in vegetation and soil
- a multitude of ecosystems, biological and ethnic diversity


Biodiversity...

Fire...



Fire...

Selective logging...

Source: Nobre, 2002

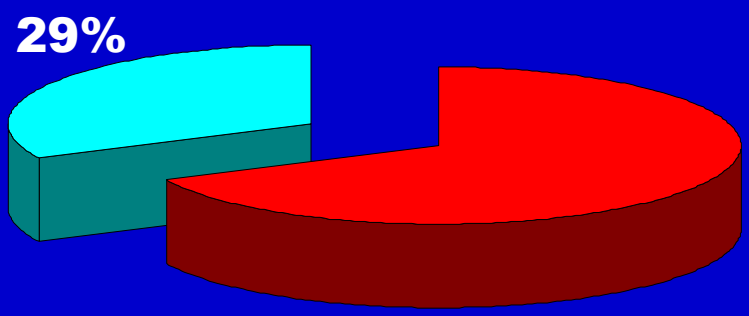
Brazilian agribusiness
General overview

Top 5 biggest world grain producers

Itens	Countries				
	China	USA	Brazil	Russian	Canadian
Total Surface (millions km²)	9,536	9,372	8,547	17,075	9,970
Population (millions)	1,300	278	175	147	31
Crop Area (ha – millions)	78	90	42	40	22
Grain production (ha – millions)	450	420	115	88	88

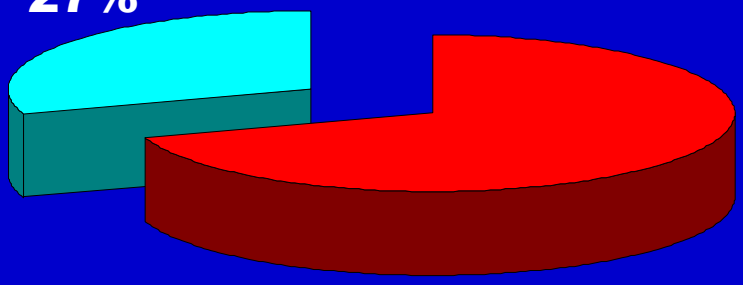
Source: Grolli, D., 2003 (Grãos Brasil, v. 10, p.12)

Contribution of the agribusiness in the Brazilian GDP



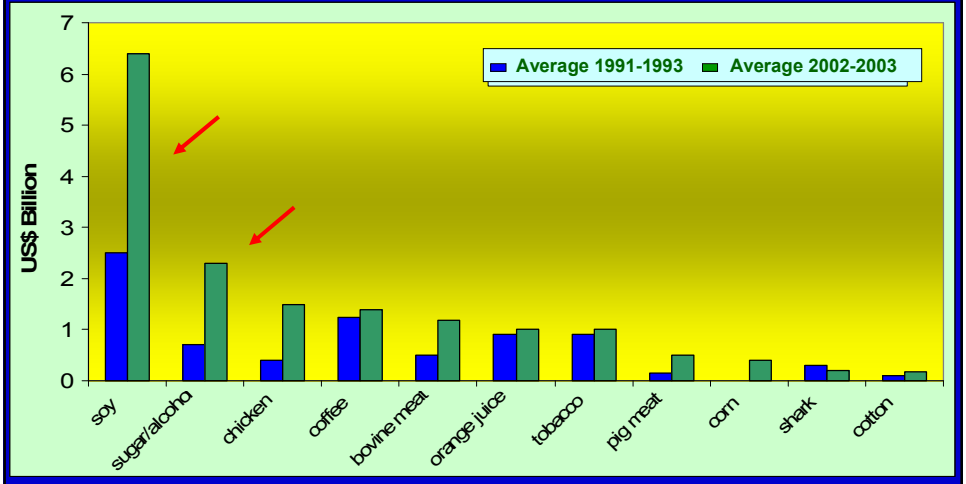
Source: IPEA, 2003

Agriculture contribution to the active economic population

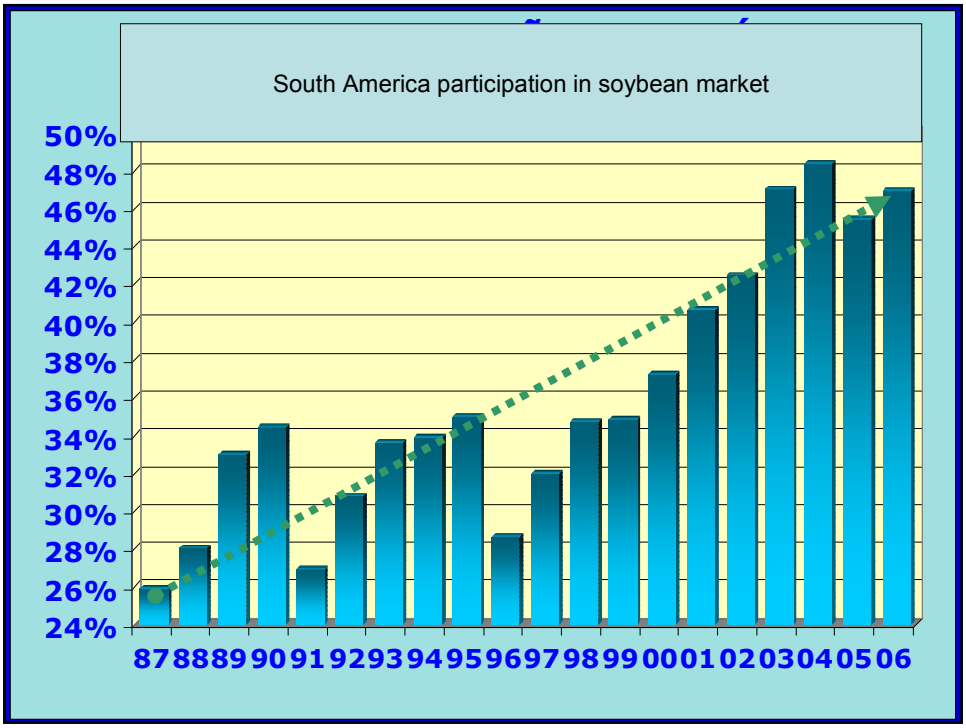


Source: IPEA, 2003

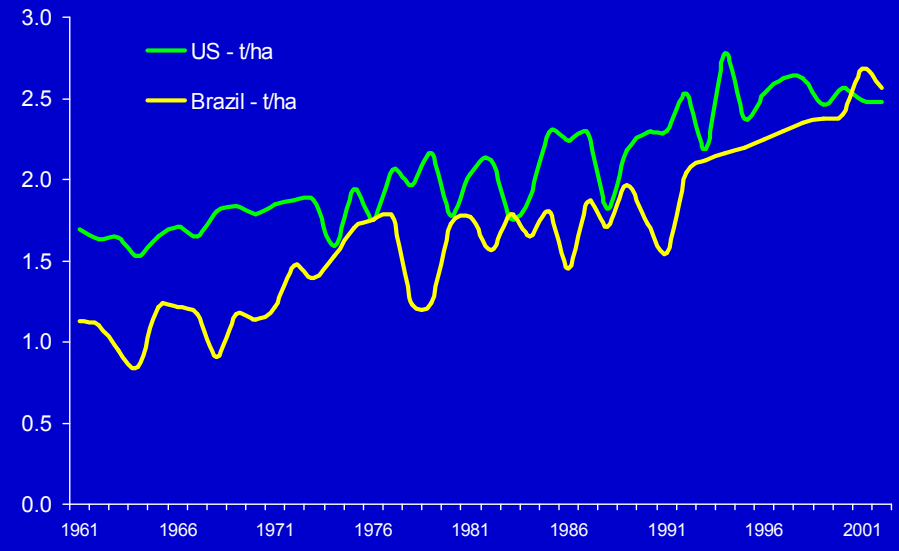
Main agricultural products exported.



Source: Ministry of the development, industry and external trade. MDIC, 2003.

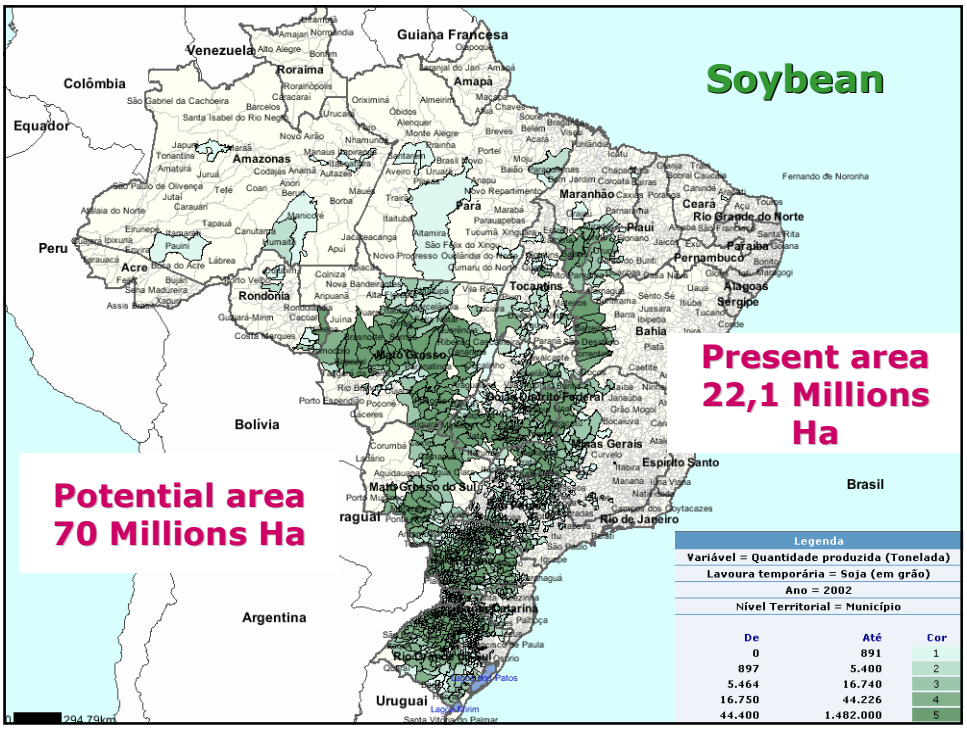


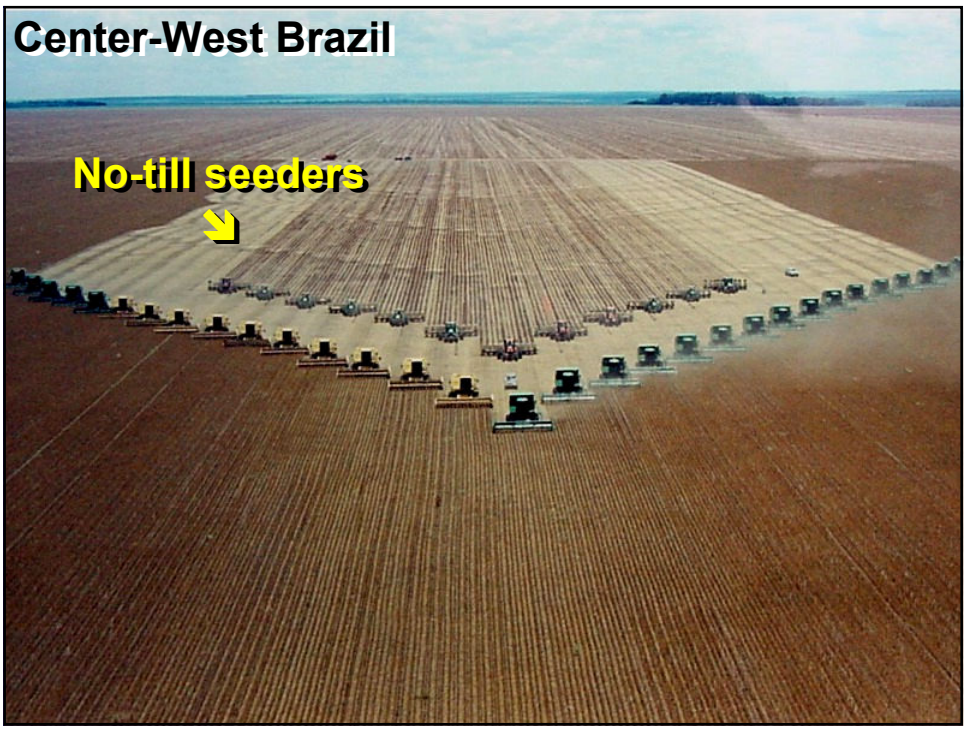
Soybean yields – US/Brazil



AgriStats, NASS

Brazilian agribusiness Future


Soybean
Present area
22,1 Millions
Ha
Potential area
70 Millions Ha
Guiana Francesa
Venezuela
Roraima
Colômbia
Amapá
Equador
Amazonas
Peru
Acre
Rondonia
Bolivia
Argentina
Uruguai
Maranhão
Ceará
Rio Grande do Norte
Piauí
Paraíba
Pernambuco
Alagoas
Sergipe
Bahia
Tocantins
Mato Grosso
Minas Gerais
Espirito Santo
Rio de Janeiro
Brasil
Legenda
Variável = Quantidade produzida (Tonelada)
Lavoura temporária = Soja (em grão)
Ano = 2002
Nível Territorial = Município
De Até Cor
0 891 1
897 5.400 2
5.464 16.740 3
16.750 44.226 4
44.400 1.482.000 5


Center-West Brazil
No-till seeders

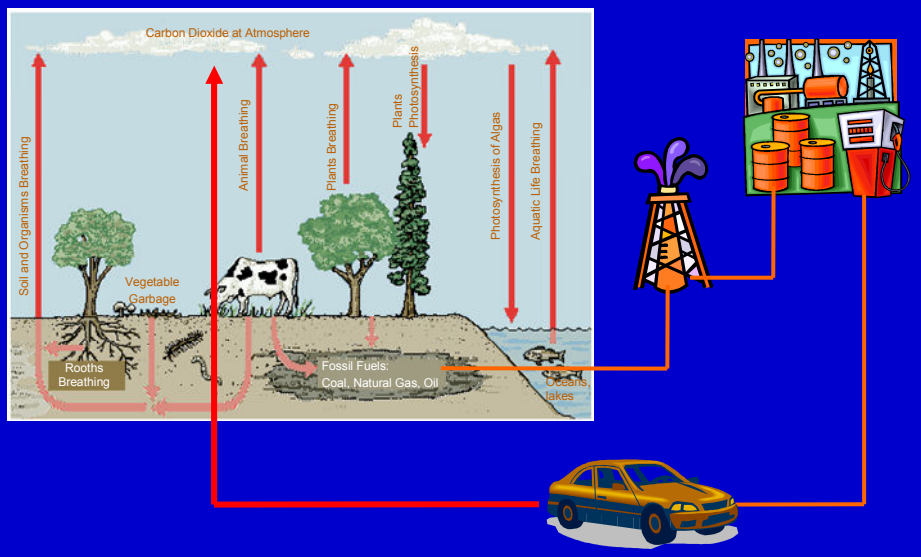
BRAZIL: Next decade projections

CROPS	ÁREA HECTARES	ÁREA HECTARES	VARIATION (%)
YEAR	2006/2007	2014/2015	2015/2007
GRAIN *	45.837.100	59.479.305	29.8%
COFFEE	2.309.741	2.656.202	15.0%
SUGAR CANE	6.188.600	9.282.900	50.0%
VEGETABLES AND FRUITS	12.200.000	15.250.000	25.0%
TOTAL UTILIZADO	66.535.441	86.668.408	30.3%
ÁREA AGRICULTÁVEL DISPONÍVEL	388.000.000	388.000.000	
PASTURE	220.000.000	220.000.000	0.0%
COMERCIAL FOREST	6.000.000	12.000.000	100.0%
CROPS	66.535.441	86.668.408	30.3%
TOTAL AVAILABLE	95.464.559	69.331.592	

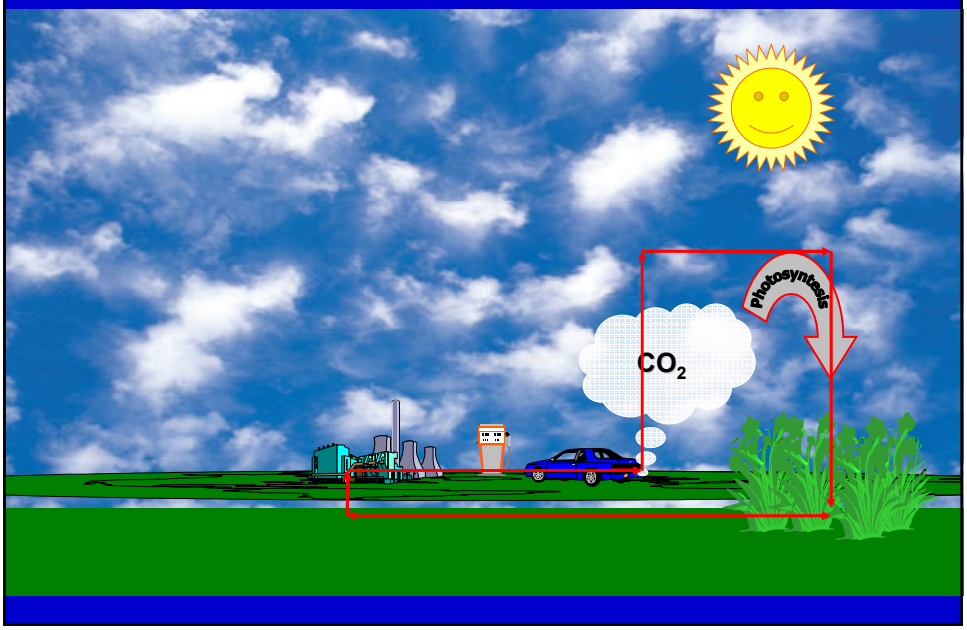
* INCLUSO ALGODÃO CAROÇO

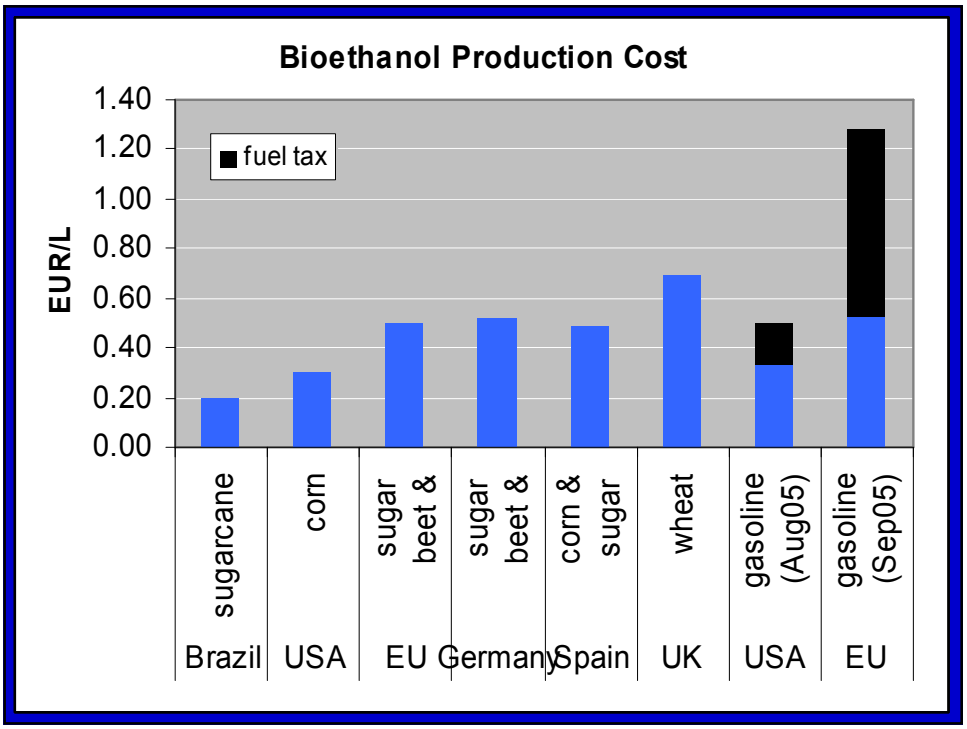
Elaboração e Projeções: Carlos Cogo Consultoria Agroeconômica

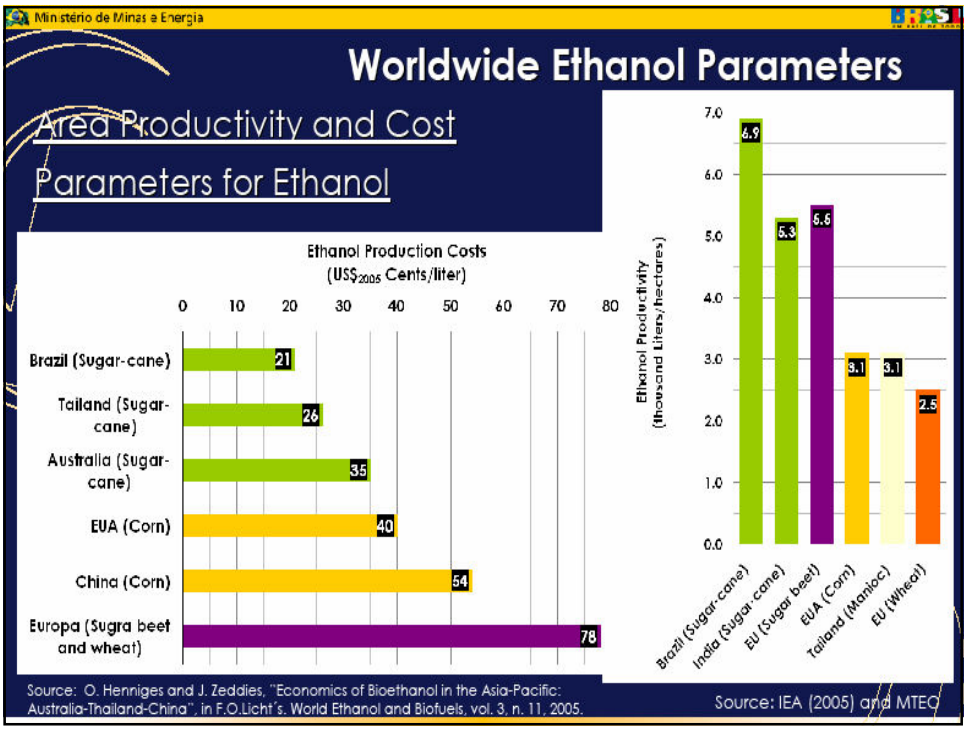
The Fossil Fuels

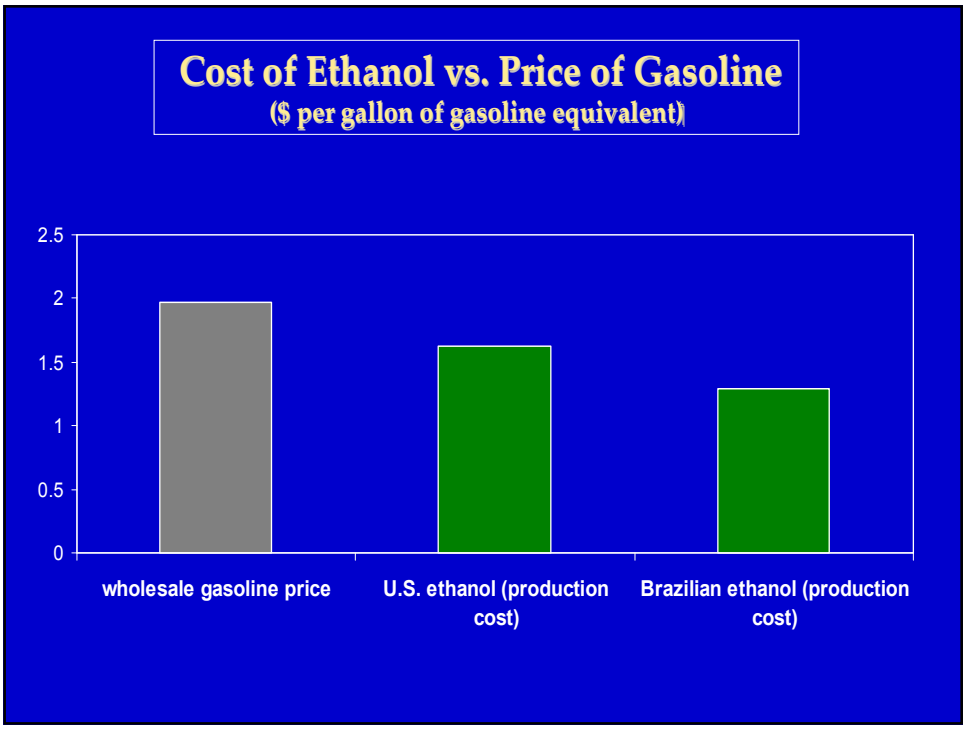


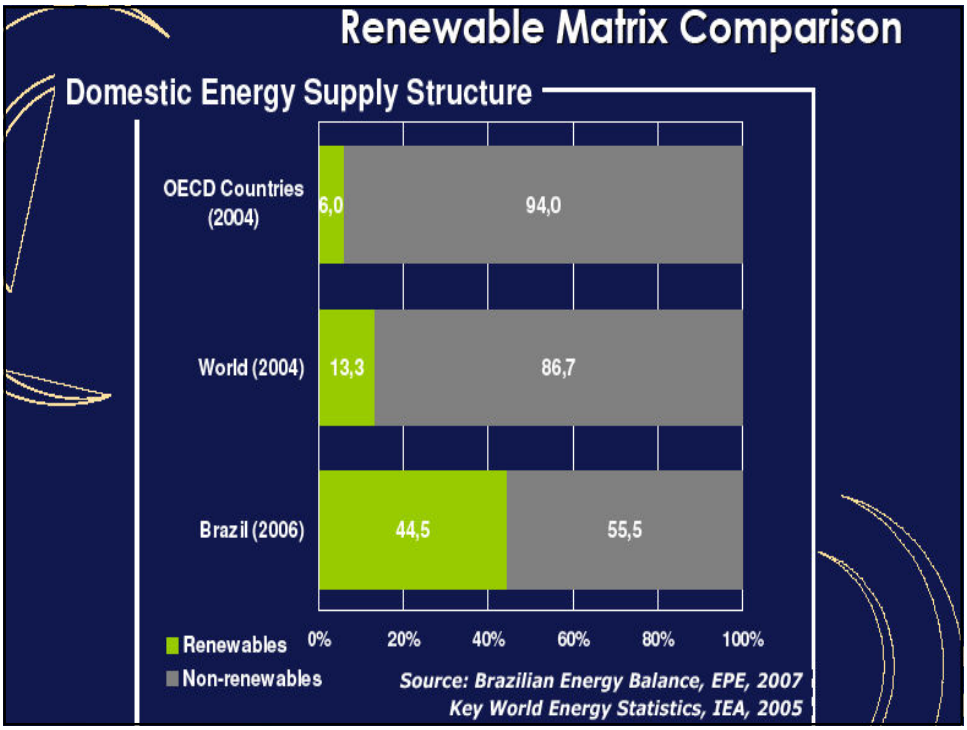
12. The Renewable Fuels

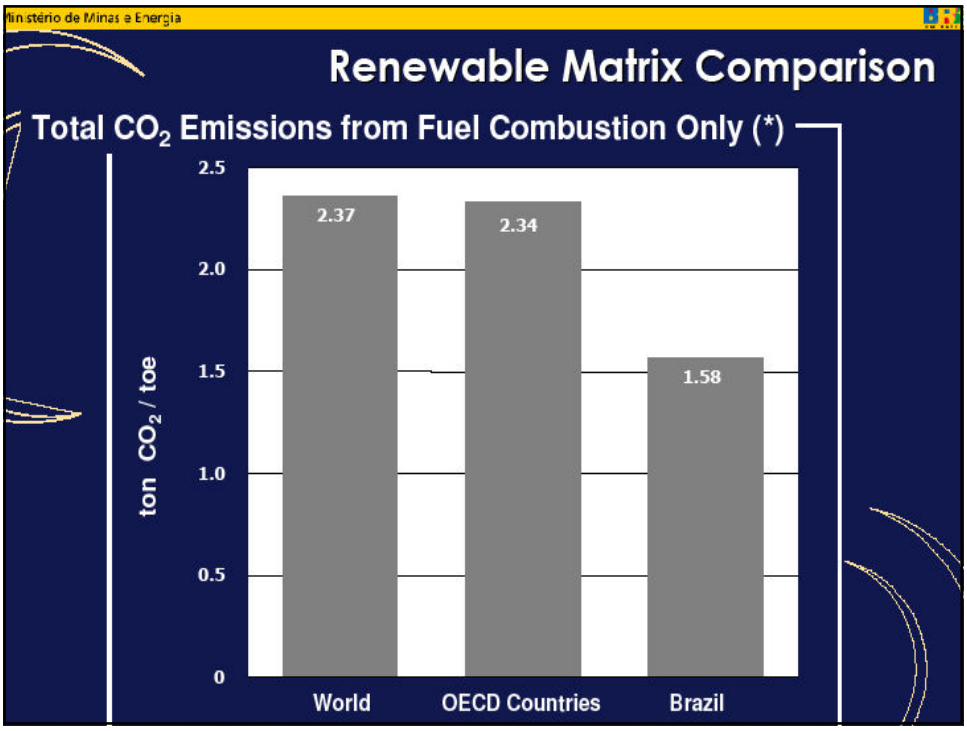



Bioethanol Production Cost
EUR/L
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
fuel tax
sugarcane
corn
sugar beet &
sugar beet &
corn & sugar
wheat
gasoline (Aug05)
gasoline (Sep05)
Brazil
USA
EU
Germany
Spain
UK
USA
EU


Ministério de Minas e Energia
Worldwide Ethanol Parameters
Area Productivity and Cost Parameters for Ethanol
Ethanol Production Costs (US$2005 Cents/liter)
0
10
20
30
40
50
60
70
80
Brazil (Sugar-cane)
21
Tailand (Sugar-cane)
26
Australia (Sugar-cane)
35
EUA (Corn)
40
China (Corn)
54
Europa (Sugra beet and wheat)
78
Source: O. Henniges and J. Zeddies, "Economics of Bioethanol in the Asia-Pacific: Australia-Thailand-China", in F.O.Licht's, World Ethanol and Biofuels, vol. 3, n. 11, 2005.
Ethanol Productivity (thousand Liters/hectares)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
6.9
5.3
6.6
3.1
3.1
2.5
Brazil (Sugar-cane)
India (Sugar-cane)
EU (Sugar beet)
EUA (Corn)
Tailand (Manioc)
EU (Wheat)
Source: IEA (2005) and MTEO


Cost of Ethanol vs. Price of Gasoline
($ per gallon of gasoline equivalent)
2.5
2
1.5
1
0.5
0
wholesale gasoline price
U.S. ethanol (production cost)
Brazilian ethanol (production cost)


Renewable Matrix Comparison
Domestic Energy Supply Structure
OECD Countries (2004)
6,0
94,0
World (2004)
13,3
86,7
Brazil (2006)
44,5
55,5
0%
20%
40%
60%
80%
100%
Renewables
Non-renewables
Source: Brazilian Energy Balance, EPE, 2007
Key World Energy Statistics, IEA, 2005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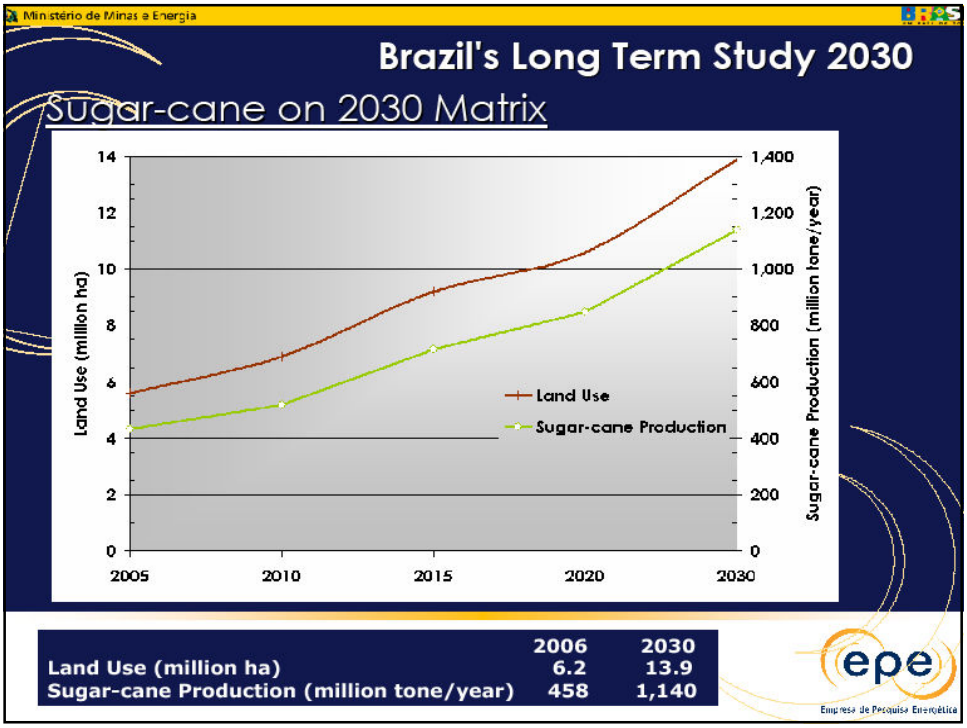
Renewable Matrix Comparison
Total CO_2 Emissions from Fuel Combustion Only (*)
ton CO_2 / toe
2.5
2.0
1.5
1.0
0.5
0
2.37
2.34
1.58
World
OECD Countries
Brazil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Brazil's Long Term Study 2030
Sugar-cane on 2030 Matrix
Land Use (million ha)
Sugar-cane Production (million tone/year)
Land Use
Sugar-cane Production
14
12
10
8
6
4
2
0
1,400
1,200
1,000
800
600
400
200
0
2005
2010
2015
2020
2030
Land Use (million ha) 2006 6.2 2030 13.9
Sugar-cane Production (million tone/year) 458 1,140
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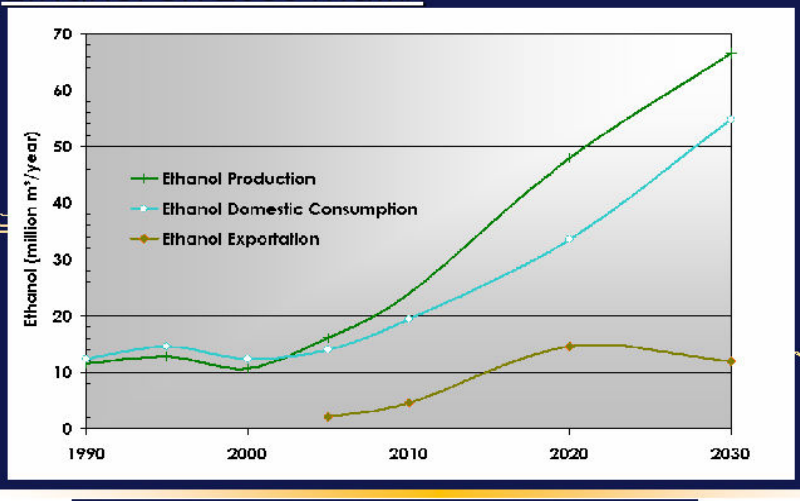
Brazil's Long Term Study 2030

Ethanol on 2030 Matrix



(million m³/year)	2006	2030
Ethanol Production	17.8	66.7
Ethanol Consumption	14.4	54.7
Ethanol Exportation	3.4	12.0

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The Brazil's History of Sugar-cane and Ethanol

On the beginnings

1532 Martim Afonso de Souza introduces sugar-cane in Brazil

1925 First ethanol vehicle tested in Brazil

PROALCOOL 1975 Created the Brazilian Ethanol Program

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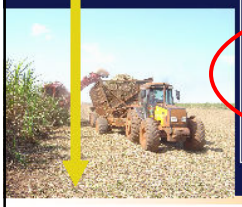
Stages of Brazilian Ethanol Program

2000 **Current phase**

- Crude oil international prices higher
- Flex fuel technology introduction
  - → *first flex fuel vehicles in 2003*
  - → *currently, flex fuel represent 78% of cars selling*
- Electricity from bagasse-based cogeneration advances commercialization
- Up to 25% of anhydrous ethanol added to gasoline (minimum percentage of 20%)
- Current Brazilian production (2006):
  - → *ethanol : 17.8 billions liters*
  - → *sugar : 30.9 millions ton*



30 years experience in research and implementing technology - chain management maturity

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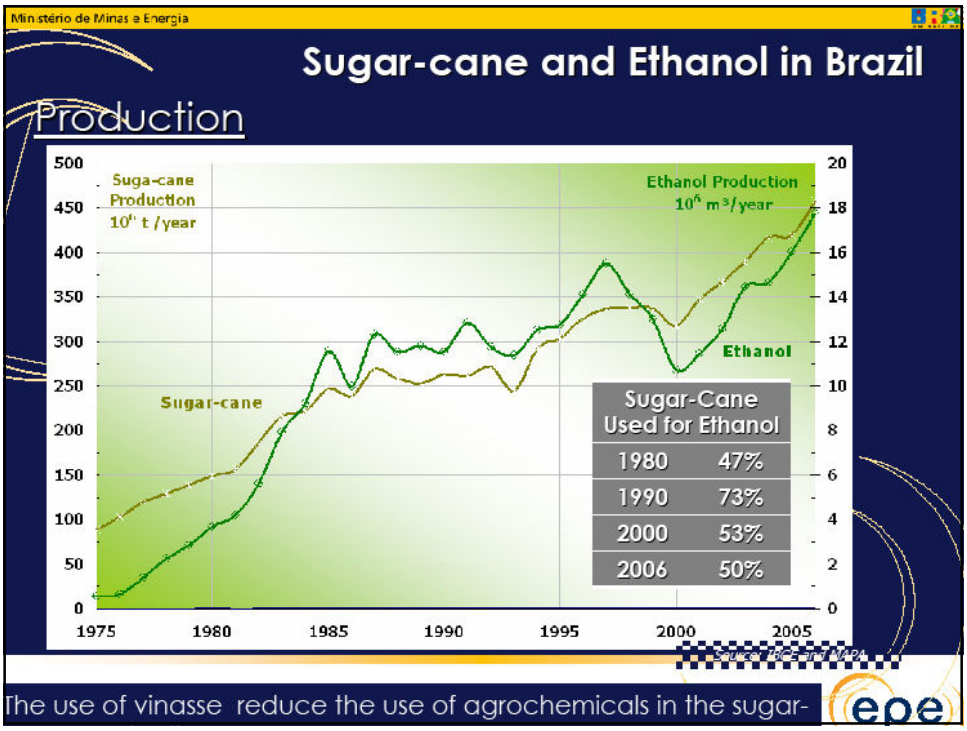
Ethanol in Brazil and USA

General View of Ethanol Brazil and USA

	BRAZIL (2006/2007)	USA (2005/2006)
Production Units	385	97
Raw material	Sugar-cane	Corn
Area for Ethanol Production (million hectares)	3.2	6.3
Raw material Production for Ethanol (million tones)	229	53
Raw material Productivity (tone/hectare)	74	8.5
Ethanol Production (million m^3)	17.8	18.5
Ethanol Productivity (liters/hectare)	6,800	3,000
Ethanol participation in Otto Cycle Engines Domestic Consumption	40%	3%
Importations (million m^3)	0	2.81
Exportations (million m^3)	3.4	0
Production Cost (US$/liter)	0.22	0.4
Importation Tax	0%	46%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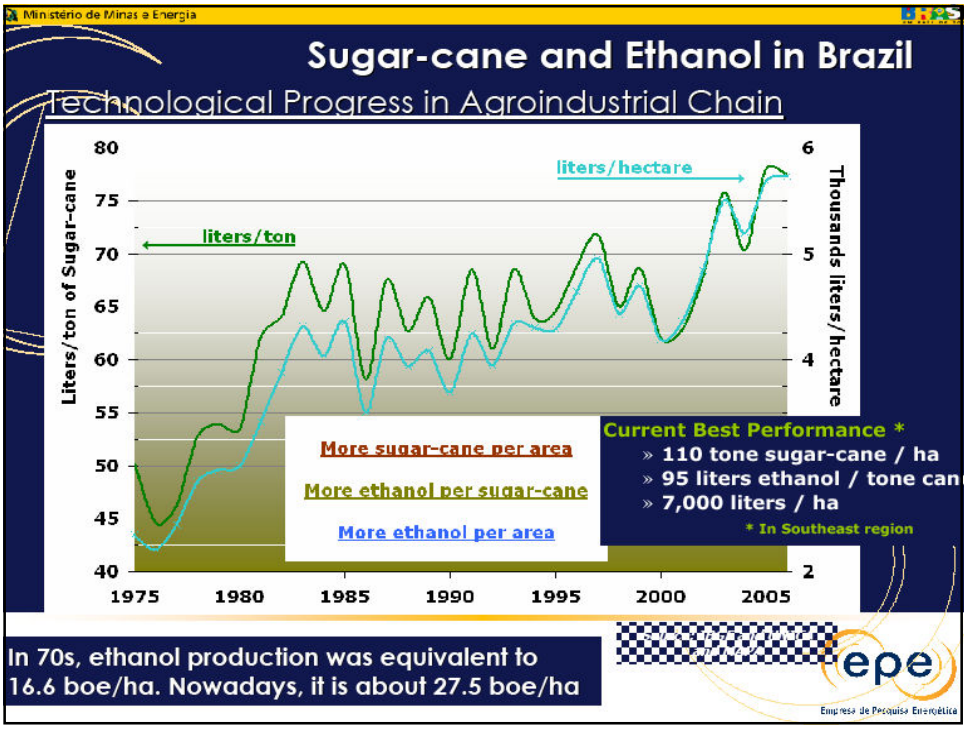
Sugar-cane and Ethanol in Brazil
Production
Suga-cane Production 10^6 t /year
Ethanol Production 10^6 m^3/year
Sugar-cane
Ethanol
Sugar-Cane Used for Ethanol
1980 47%
1990 73%
2000 53%
2006 50%
The use of vinasse reduce the use of agrochemicals in the sugar-
epe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Sugar-cane and Ethanol in Brazil
Technological Progress in Agroindustrial Chain
Liters/ton of Sugar-cane
Thousands liters/hectare
liters/hectare
liters/ton
More sugar-cane per area
More ethanol per sugar-cane
More ethanol per area
Current Best Performance *
» 110 tone sugar-cane / ha
» 95 liters ethanol / tone can
» 7,000 liters / ha
* In Southeast region
In 70s, ethanol production was equivalent to 16.6 boe/ha. Nowadays, it is about 27.5 boe/ha
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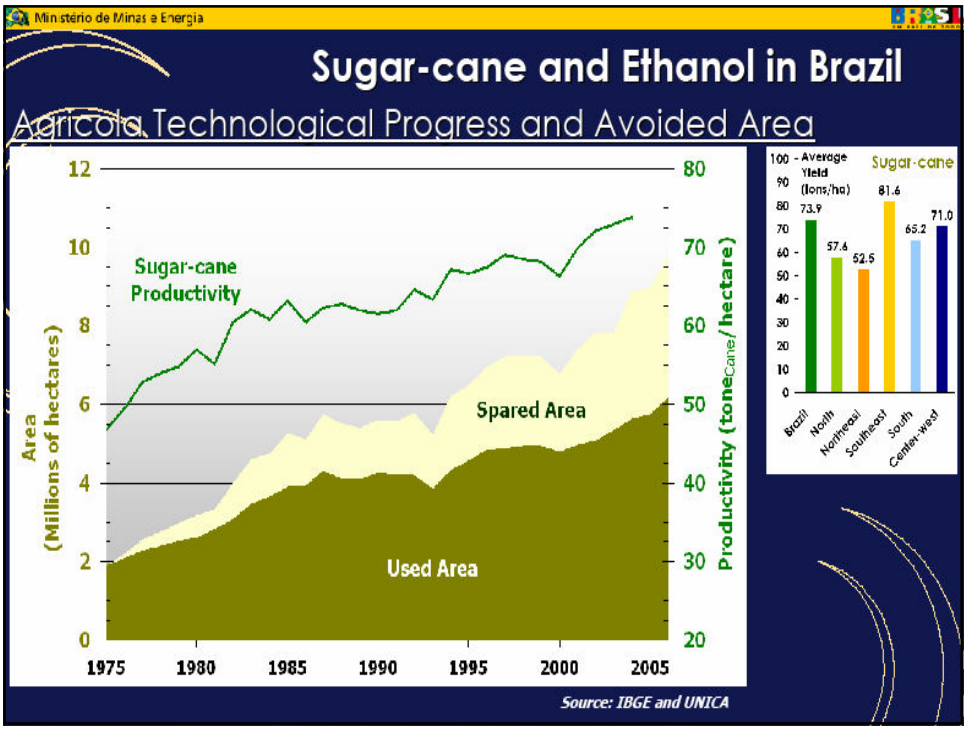
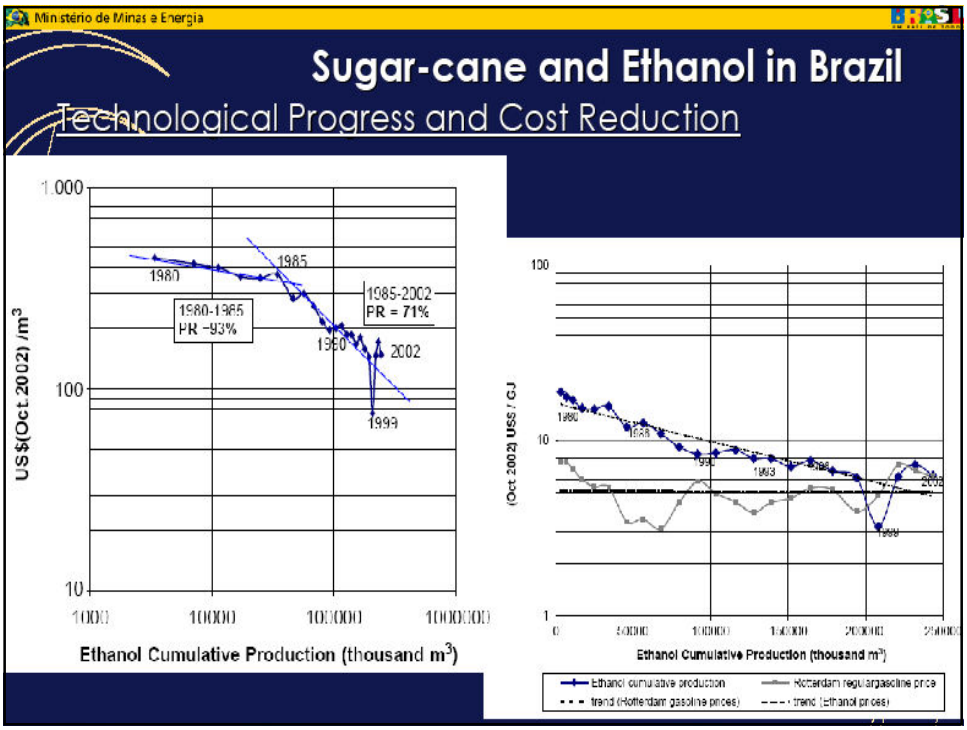

Ministério de Minas e Energia
Sugar-cane and Ethanol in Brazil
Agricola Technological Progress and Avoided Area
Area (Millions of hectares)
Productivity (tonneCane/hectare)
Sugar-cane Productivity
Spared Area
Used Area
1975
1980
1985
1990
1995
2000
2005
Average Yield (tons/ha)
Sugar-cane
73.9
57.6
52.5
81.6
65.2
71.0
Brazil
North
Northeast
Southeast
South
Center-west
Source: IBGE and UNICA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Sugar-cane and Ethanol in Brazil
Technological Progress and Cost Reduction
US$(Oct.2002) /m3
1980
1985
1990
1999
2002
1980-1985
PR -93%
1985-2002
PR = 71%
Ethanol Cumulative Production (thousand m3)
(Oct 2002) US$ / GJ
Ethanol Cumulative Production (thousand m3)
Ethanol cumulative production
Rotterdam regular gasoline price
trend (Rotterdam gasoline prices)
trend (Ethanol prices)

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Sugar-cane and Ethanol in Brazil

- Ethanol Business:
  - ⇒ represent US$ 35 billion per year (2006);
  - ⇒ has created more than 6 million jobs until now;
  - ⇒ generated incomes in rural areas, reducing the exodus to cities;
- One unit of ethanol creates 156 times more jobs than one equivalent unit of oil.

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Sugar-cane and Ethanol in Brazil

- In the last 30 years: 40 % reduction in Brazilian oil consumption;
- From 1975 until today: Brazil has saved US$ 121 billion (imported oil avoided)
- It does not have governmental subsidies nowadays;

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Countries Ethanol Policies

United States of America

- ⇒ Gasoline consumption above 530 billion liters/year
- ⇒ Ethanol production 18.5 billion liters/year from corn
- ⇒ Mandatory ethanol use (2012): 20% gasoline substitution for ethanol (28.35 billion liter/year)

Japan

- ⇒Gasoline consumption above 65 billion liters/year
- ⇒Mix of 3% ethanol and biodiesel in gasoline authorized by law (2010): 10% ethanol mix in gasoline in whole country (6.5 billion liter/year)

European Union

- ⇒2.5% of Biofuels in 2005 e 5.75% by 2010
- ⇒Target 20% by 2020

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Brazilian Biomes and the Agro-frontier

Brazilian Biomes and the Sugar-cane Farmer Area

Higher Potential Area for Energy Crops

Tropical Savanna – 204 10^6 ha

Source: EMBRAPA. 2006

In Tropical Savanna, 137 million hectares can be used for agricultural purposes, and 90 million hectares represent the

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Sugar-cane as an Effective Energy Source

Sugar-cane has a high energetic contents

153 kg juice (sucrose) → 608 x 10^3 kcal

276 kg bagasse (50% humidity) → 598 x 10^3 kcal

165 kg straw (15% humidity) → 512 x 10^3 kcal

1 ton sugar-cane
1,718 x 10^3 kcal

1 crude oil barrel
1,386 x 10^3 kcal

1 ton sugar-cane = 1.2 crude oil barrel

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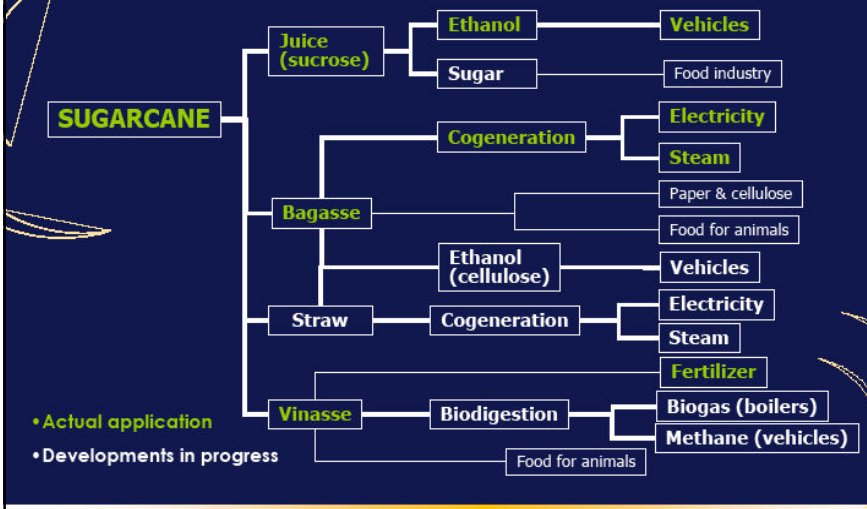
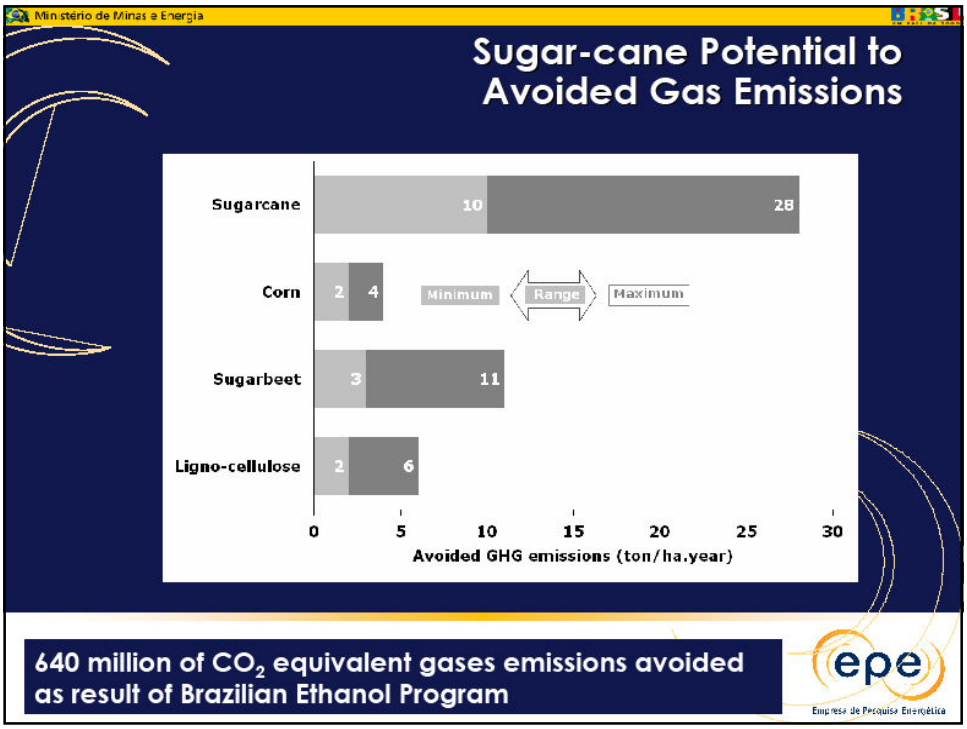
Sugar-cane and by-products technology structure



- Actual application
- Developments in progress

Sugar-cane and by-products provide both cleaner fuel and electricity

epe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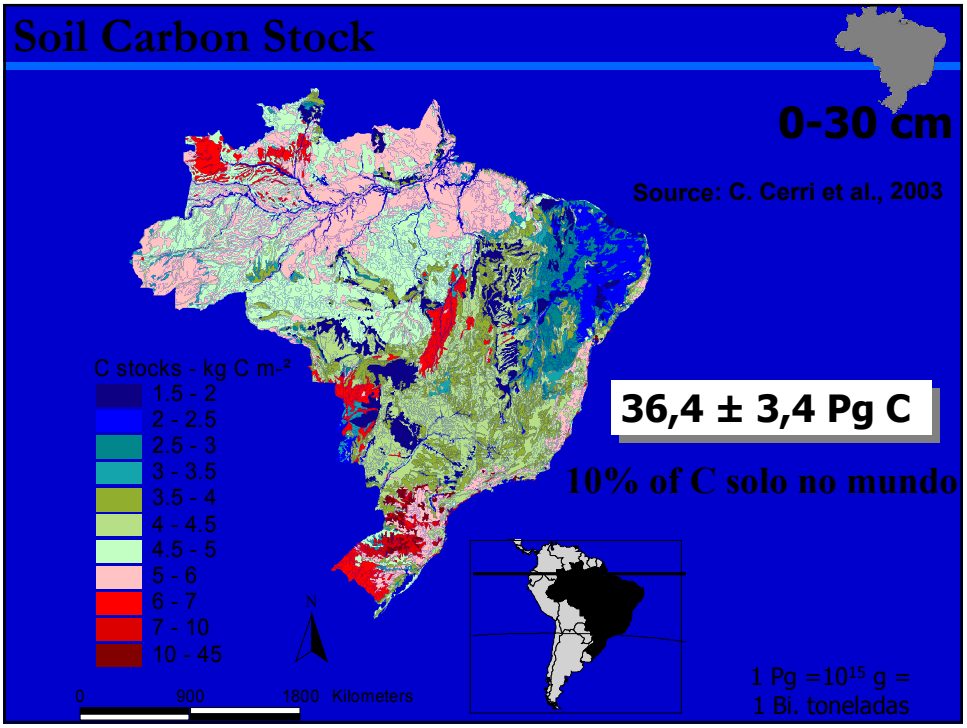
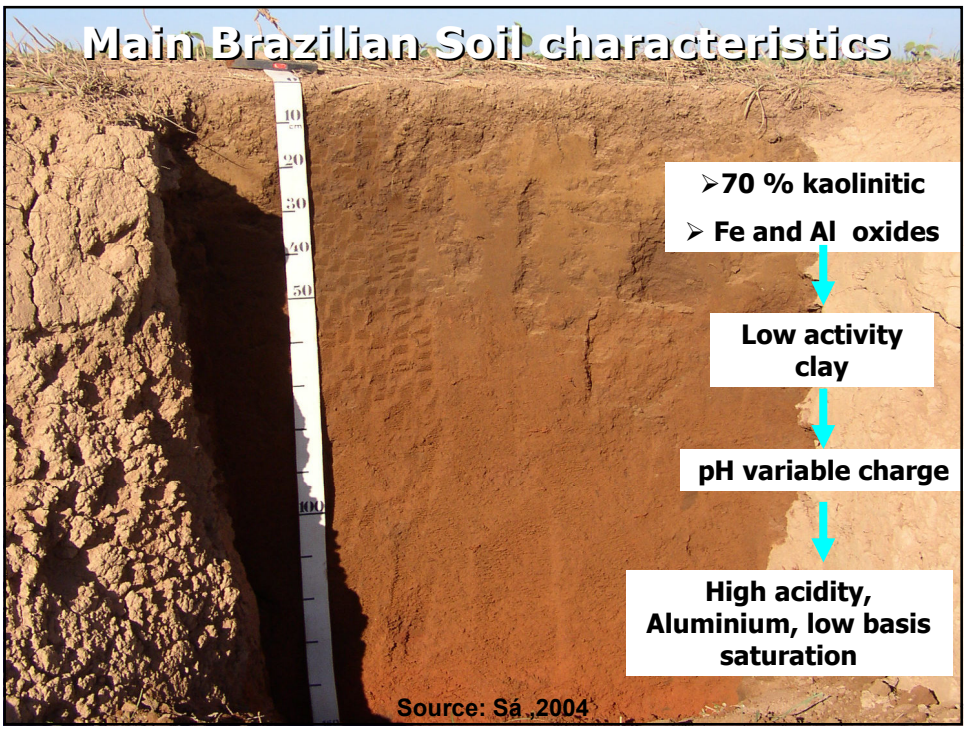
Sugar-cane Potential to Avoided Gas Emissions
Sugarcane
10
28
Corn
2
4
Minimum
Range
Maximum
Sugarbeet
3
11
Ligno-cellulose
2
6
0
5
10
15
20
25
30
Avoided GHG emissions (ton/ha.year)
640 million of CO_2 equivalent gases emissions avoided as result of Brazilian Ethanol Program
epe
Empresa de Pesquisa Energética

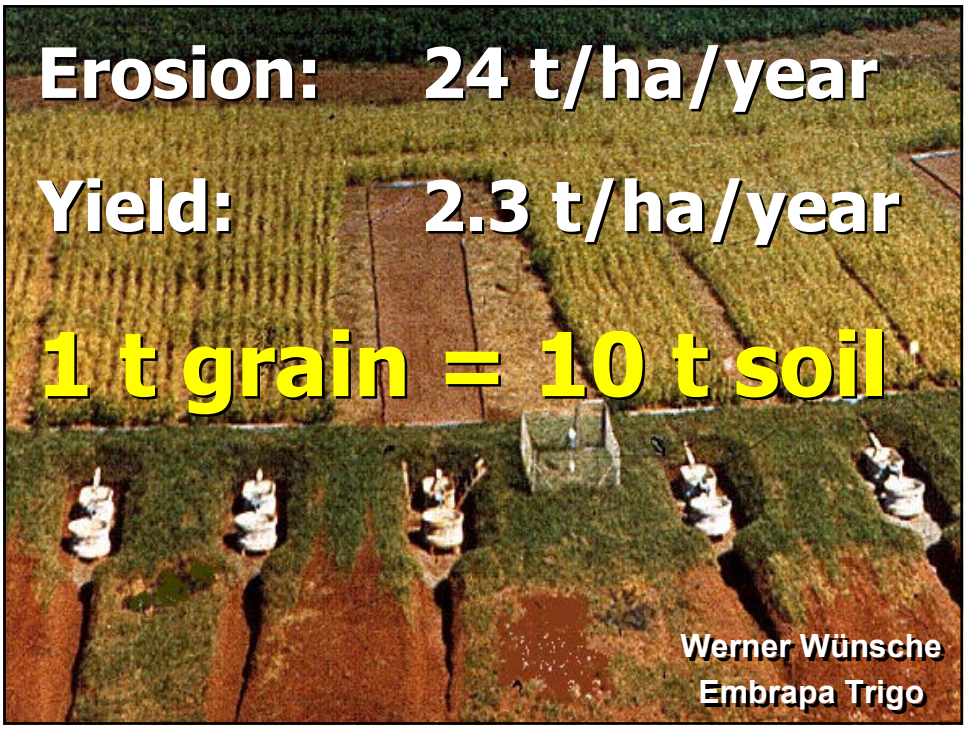

Soil Carbon Stock
0-30 cm
Source: C. Cerri et al., 2003
C stocks - kg C m-²
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
5 - 6
6 - 7
7 - 10
10 - 45
N
0
900
1800 Kilometers
36,4 ± 3,4 Pg C
10% of C solo no mundo
1 Pg =10¹⁵ g =
1 Bi. toneladas


Main Brazilian Soil characteristics
➢70 % kaolinitic
➢ Fe and Al oxides
Low activity clay
pH variable charge
High acidity, Aluminium, low basis saturation
Source: Sá ,2004

EROSION

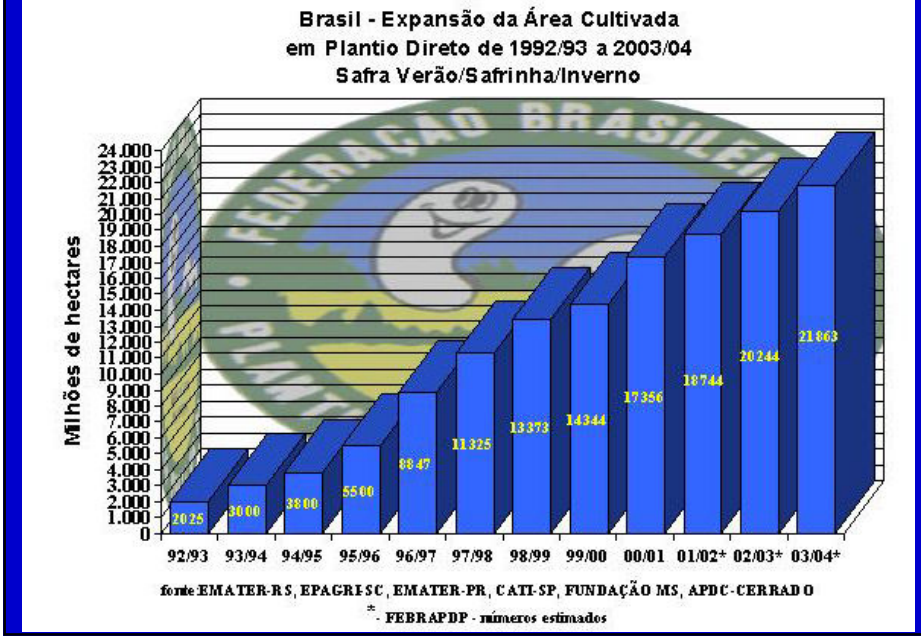

Fonte: Moryja, 2005


16 1 2003


Erosion: 24 t/ha/year
Yield: 2.3 t/ha/year
1 t grain = 10 t soil
Werner Wünsche
Embrapa Trigo

NO-TILL

Brazil NT area



Animal traction No-till

No-till animal traction

Fonte: Moryja, 2005

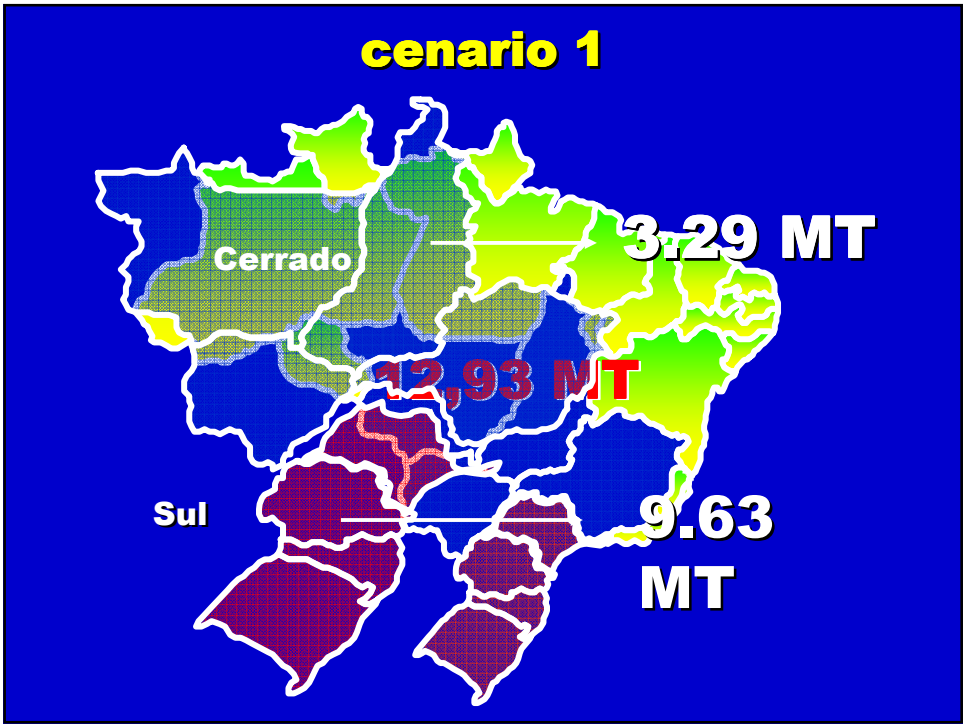
Fonte: Moryja, 2005

No-till smallholders

Country	Área (ha)	Nº Farmers
Brazil	173.000	38.000
India	130.000	26.000
Pakistan	80.000	5.500
Ghana	45.000	100.000
Bangladesh	10.000	30.000
Paraguai	6.500	2.300

(Wall, P., 2002)

Ag Soil Carbon Sequestration



Some soil carbon sequestration rates

Region		Rate
		Mg ha^{-1} yr^{-1}
Brazil — Tropical (West-Central BR)	Range	0.04 – 0.63
	Mean	0.39
Brazil — Subtropical (Southern BR)	Range	0.04-0.97
	Mean	0.58
Temperate (USA)	Range	0.1-0.5
	Mean	0.34
GLOBAL	Mean	0.57

Tropical: Corazza et al. (1999), Silva et al. (2001), Leite et al. (2001)
Subtropical: Bayer et al. (2000a,b), Lovato (2001), Amado et al. (2001), Freixo et al. (2002)
Temperate: Lal et al. (1999); West & Marland (2002)
Global: West & Post (2002)

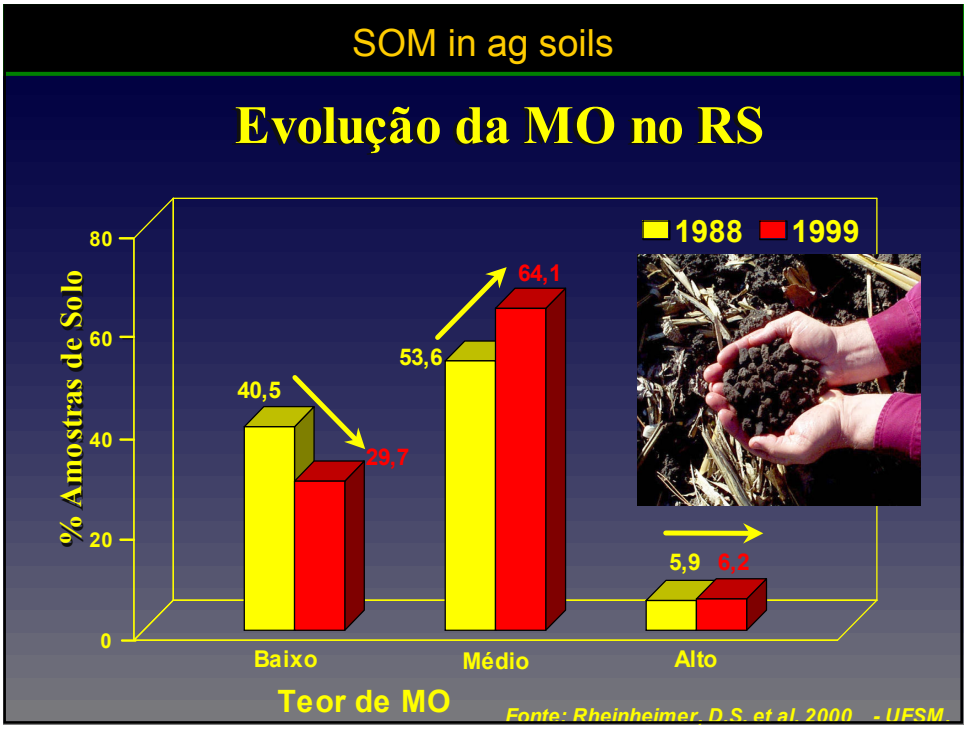
Bayer, 2007

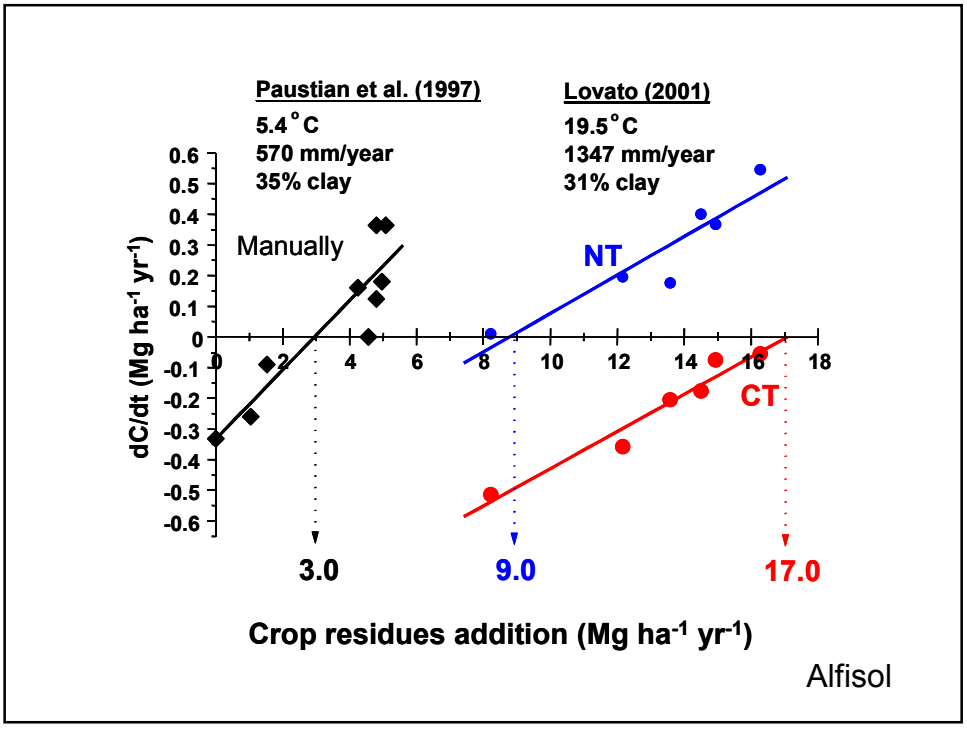
Carbon Sequestration

State	Soil	Crops	Rate	Reference
	% Clay		Mg ha^{-1} ano^{-1}	
GO	35	P/S-M	0,30	Bayer et al., 2006
MS	65	P/S-M	0,60	Bayer et al., 2006
SP	60	A/S-A/M	0,23	Leite et al., 2004
Solos tropicais			0,35	Bayer et al., 2006
PR	argiloso	T/S	0,32	Castro-Filho et al., 1998
PR	argiloso	S/T/M	0,43	Castro-Filho et al., 1998
RS	22	A/M	0,52	Lovato et al., 2004
RS	57	T/S	0,16	Amado et al., 2006
RS	57	T/S-A/S-A+E/M/N	0,51	Amado et al., 2006
Solos subtropicais			0,48	Bayer et al., 2006
Solos temperados			0,34	West and Marland, 2002

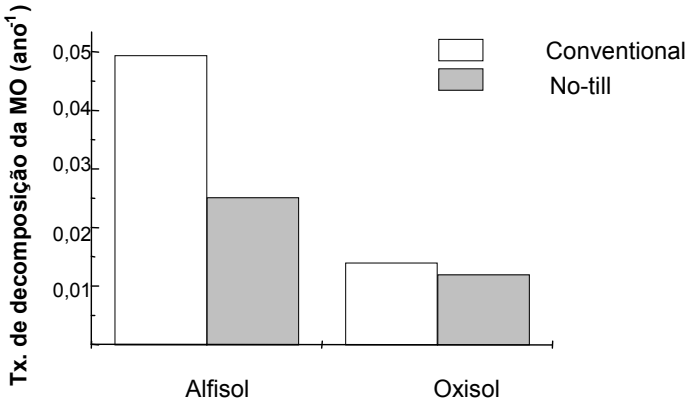
Bayer, 2007

SOM in ag soils

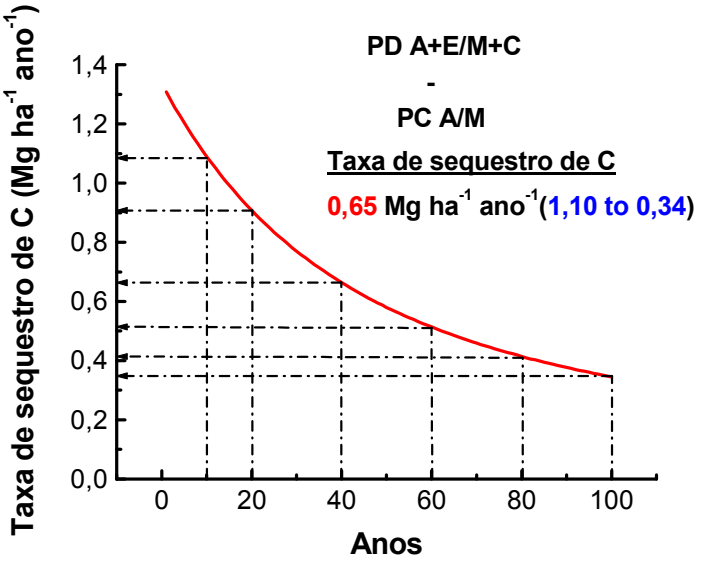




Rate of SOM mineralization x Soil Type



Temperatura (ºC)	**19,4**	**21,2**
Precipitação (mm/ano)	**1550**	**1620**
Argila (g kg^{-1})	**220**	**620**
Fe_2O_3 (g kg^{-1})	**103**	**211**



Mielniczuk et al. (em elaboração)

C accumulation in subsoil layers of mature no-till

Soil	Reference System	C sequestration		Paper
		0-20	0-100	
		---- Mg ha^{-1} ano^{-1} ----		
No-till				
Alfisol	PC	0,65	1,05	*Zanatta et al. (2005)*
Alfisol	PC	1,22	1,95	*Dieckow et al. (2005)*
Oxisol	PC	0,52 *	0,98	*Sisti et al. (2004)*
Oxisol	PC	0,20	0,27	*Conceição et al. (2006)*
Oxisol	PC	0,82	1,36	*Jantalia et al. (2007)*
Oxisol	PC	0,83	2,28	*Corazza et al. (1999)*
Oxisol	PC	0,21 *	0,52	*Jantalia et al. (ñ pub)*
Pasture				
Alfisol	PC	0,91 **	3,23	*Omonode et al. (2006)*
Oxisol	PC	0,76 **	3,13	*Omonode et al. (2006)*
Oxisol	PC	0,43	1,92	*Corazza et al. (1999)*
Oxisol	Cerrado	1,14	2,53	*Silva et al. (2004)*

* 0-30 cm ** 0-15 cm

Mechanisms of C stabilization in no-tillage soils

-**Molecular recalcitrance**
-**Chemical protection**
-**Physical protection**

→ Very important in variable charge soils

Chemical and physical protection

Very important mechanisms in variable charge soils

Soil Quality Indicator

SOM fraction	Tillage Systems		Δ%	Δ Mg ha^{-1}
	CT	NT		
Particulate SOM	5.19	7.06	36	1.87
Mineral-associate SOM	25.22	30.90	23	5.68

75% of the total soil C sequestration

Bayer et al. (2003)

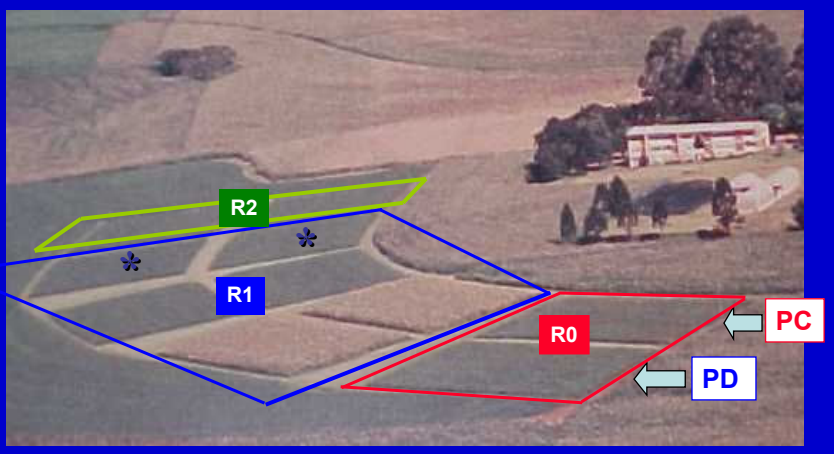
Brazil:

Soil: clay Rhodic Hapludox (Oxisol).

The treatments selected were:

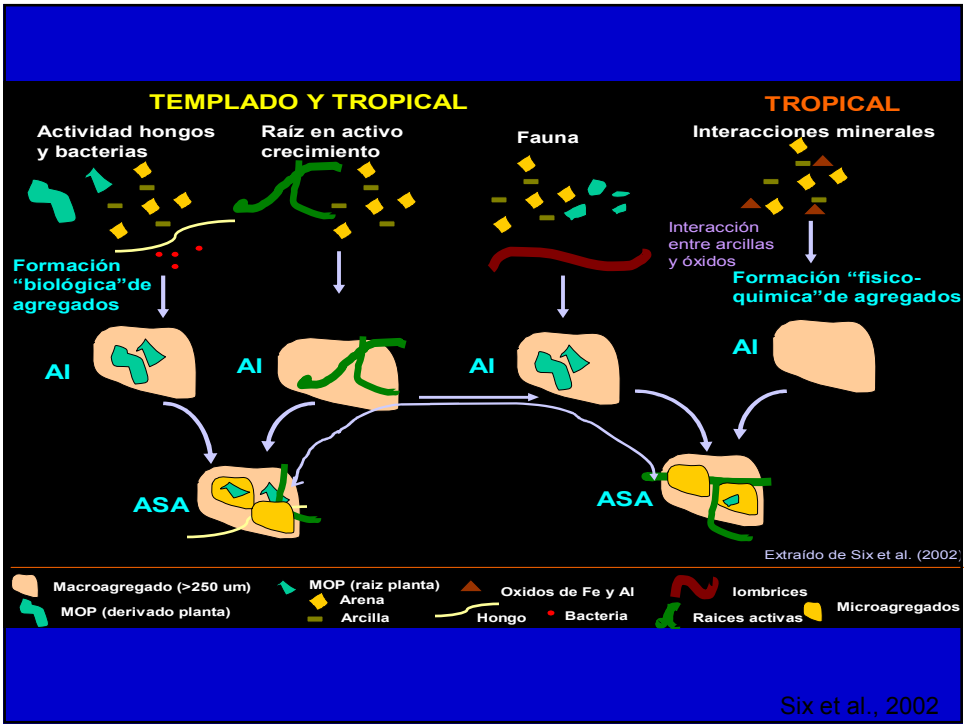
1) Intensive crop system under CT and NT

Rotation: Black oat/soybean/black oat + vetch/maize/radish oil (*Raphanus sativus L.*)/wheat/soybean



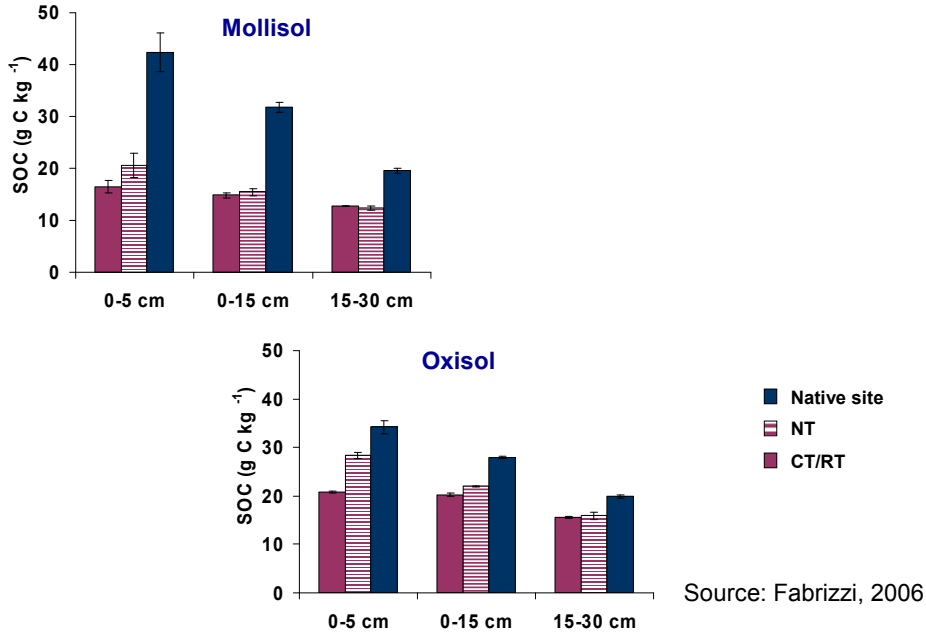
Vista geral do experimento de manejo do solo e culturas. FUNDACEP, Cruz Alta.

Slide: Campos, 2006



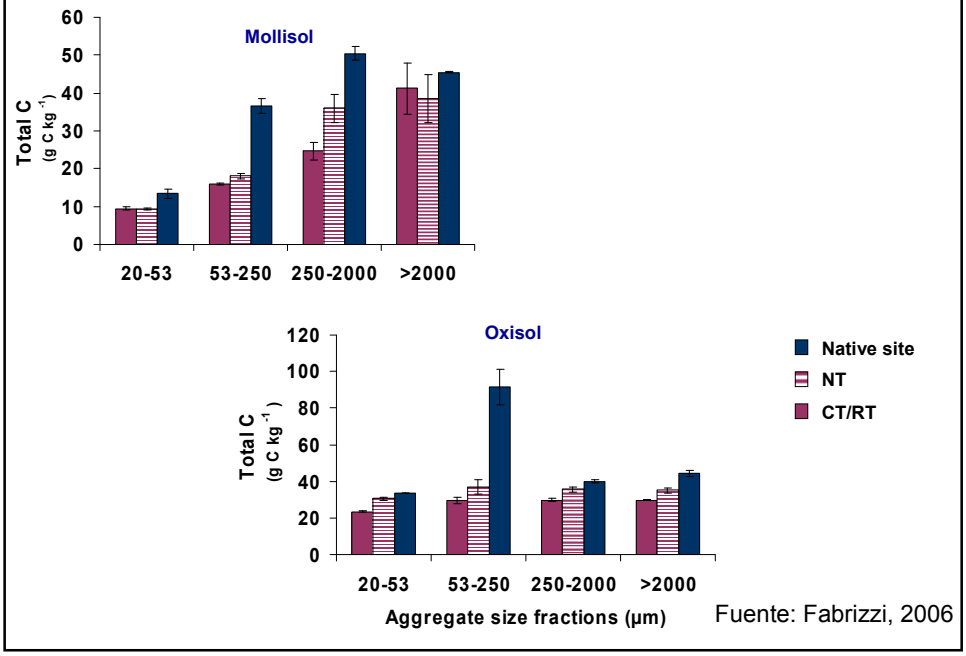
Six et al., 2002

SOIL ORGANIC C

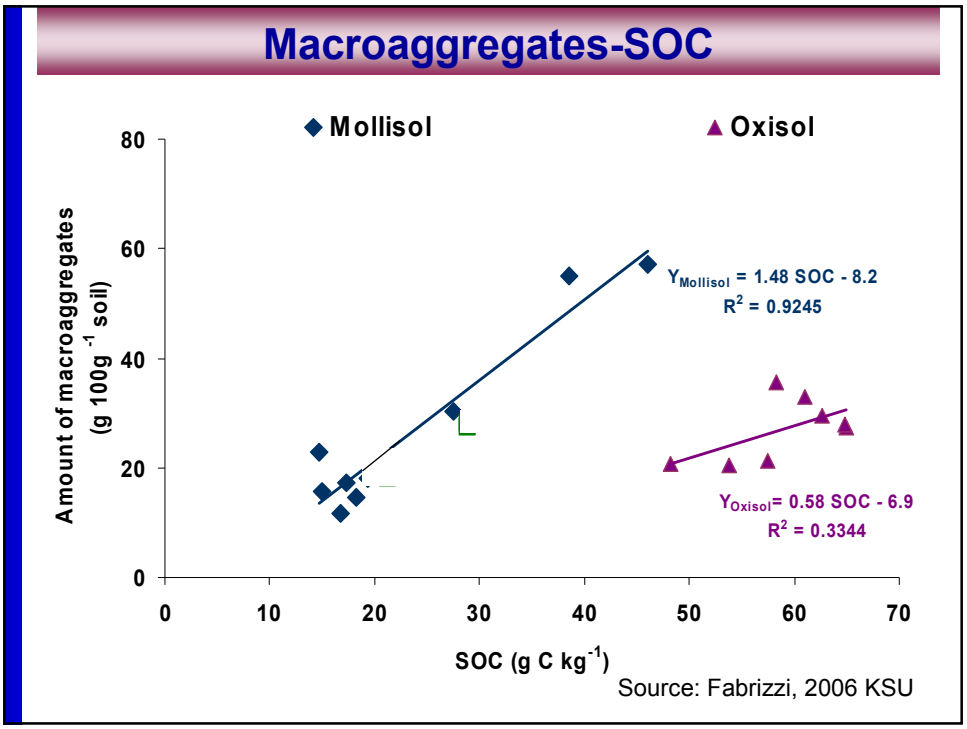


Source: Fabrizzi, 2006

Aggregate-associated C



Fuente: Fabrizzi, 2006



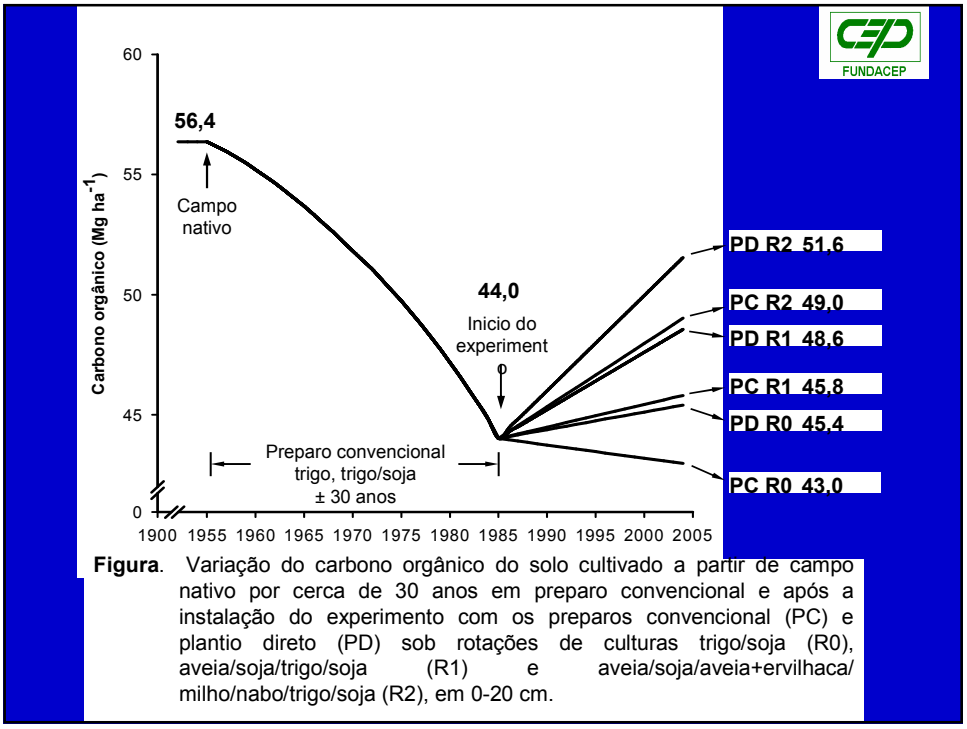
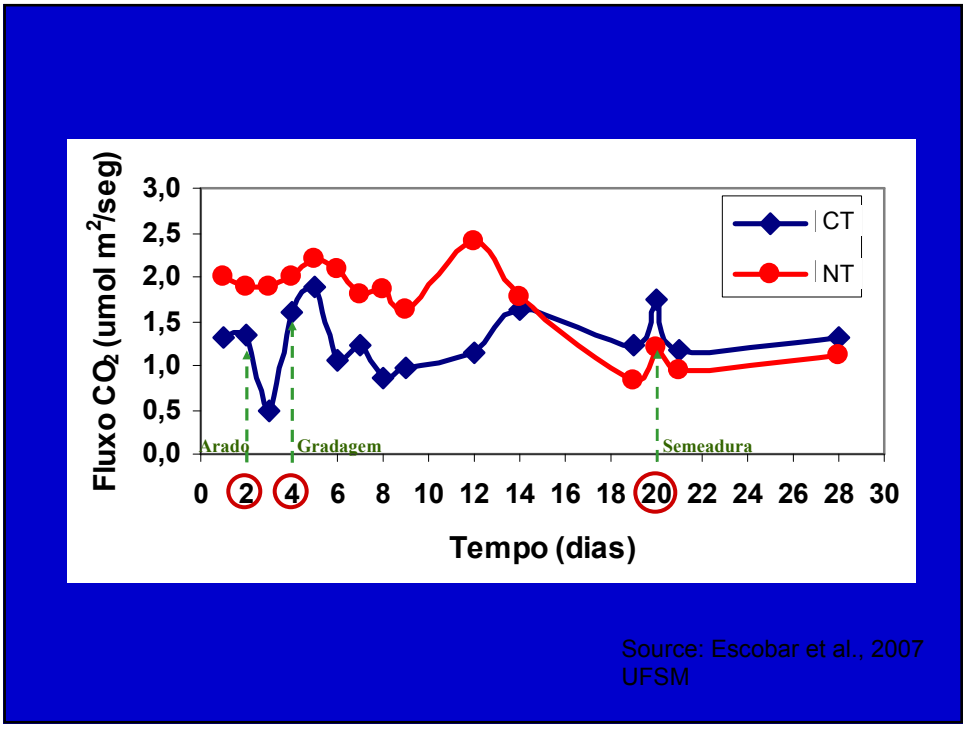


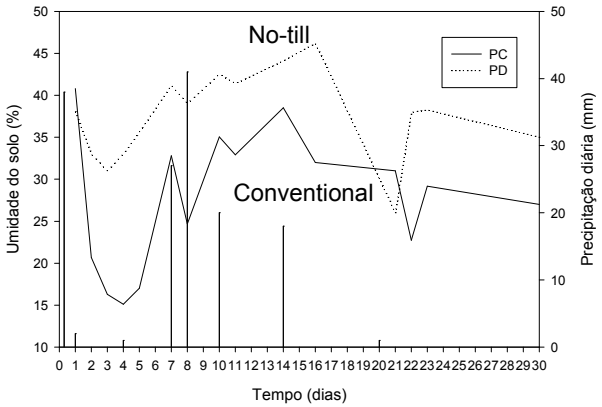
Figura. Variação do carbono orgânico do solo cultivado a partir de campo nativo por cerca de 30 anos em preparo convencional e após a instalação do experimento com os preparos convencional (PC) e plantio direto (PD) sob rotações de culturas trigo/soja (R0), aveia/soja/trigo/soja (R1) e aveia/soja/aveia+ervilhaca/ milho/nabo/trigo/soja (R2), em 0-20 cm.



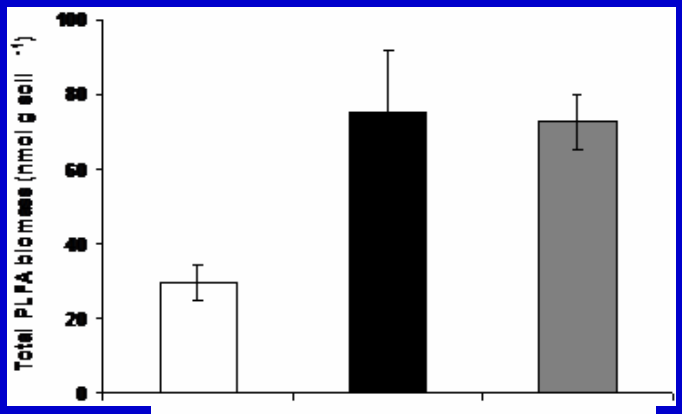
Source: Escobar et al., 2007
UFSM

Soil Mostuire

Umidade do solo e precipitação

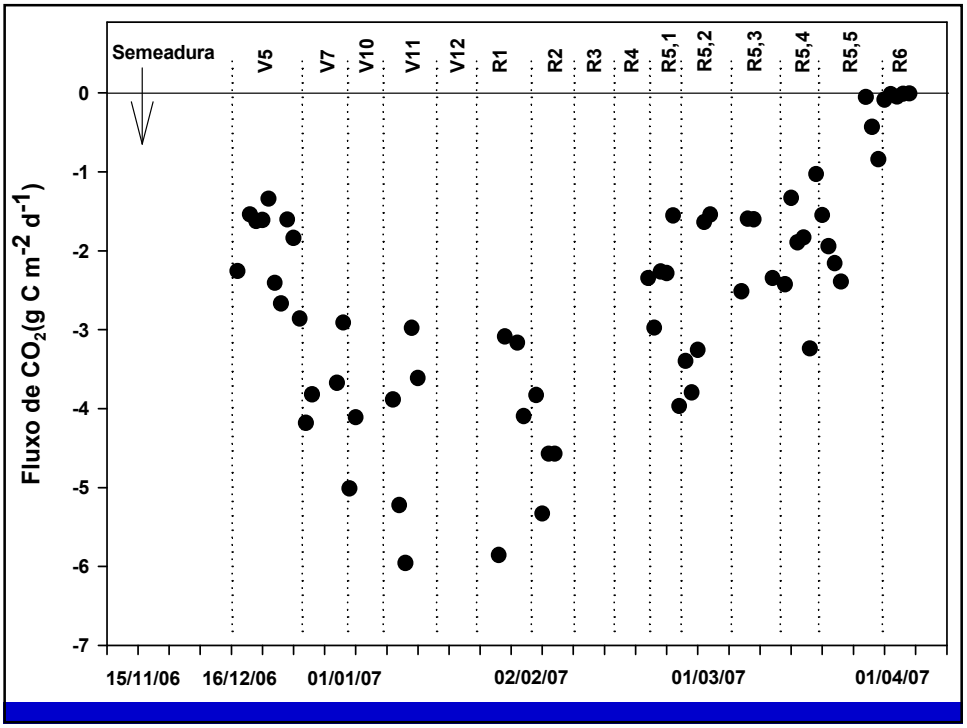


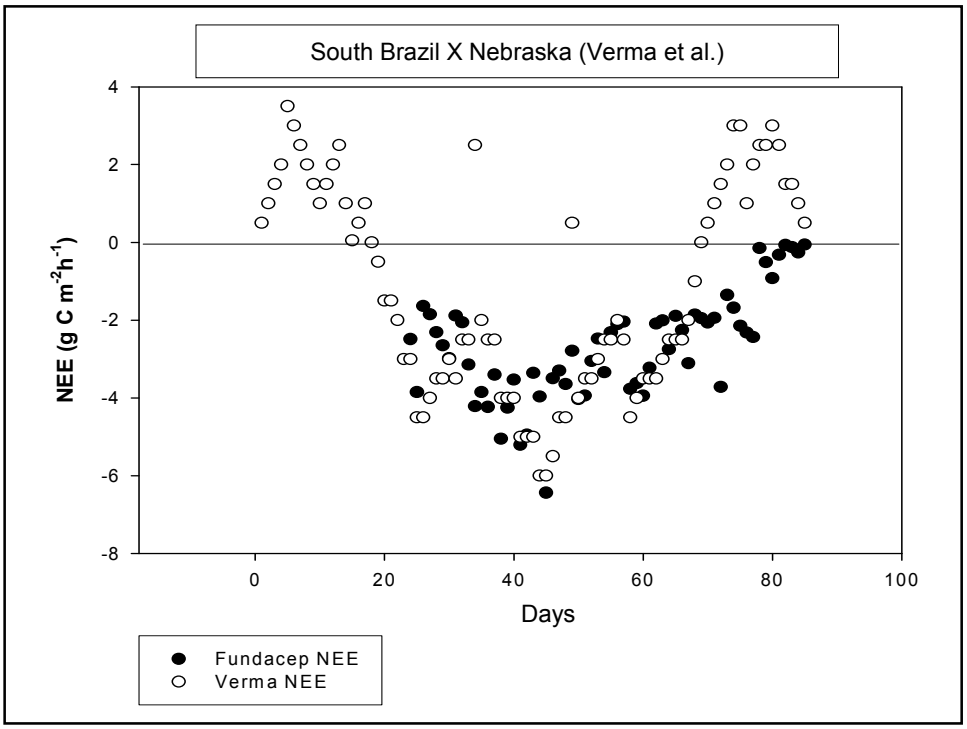
Dia 2 – Aração, Dia 4 – Gradagem, Dia 22 - Semeadura



PD - 60% Microbial biomass

Source: Fabrizzi, 2006


Semeadura
V5
V7
V10
V11
V12
R1
R2
R3
R4
R5,1
R5,2
R5,3
R5,4
R5,5
R6
0
-1
-2
-3
-4
-5
-6
-7
Fluxo de CO_2(g C m^{-2} d^{-1})
15/11/06
16/12/06
01/01/07
02/02/07
01/03/07
01/04/07



Soybean Ecosystem C Balance

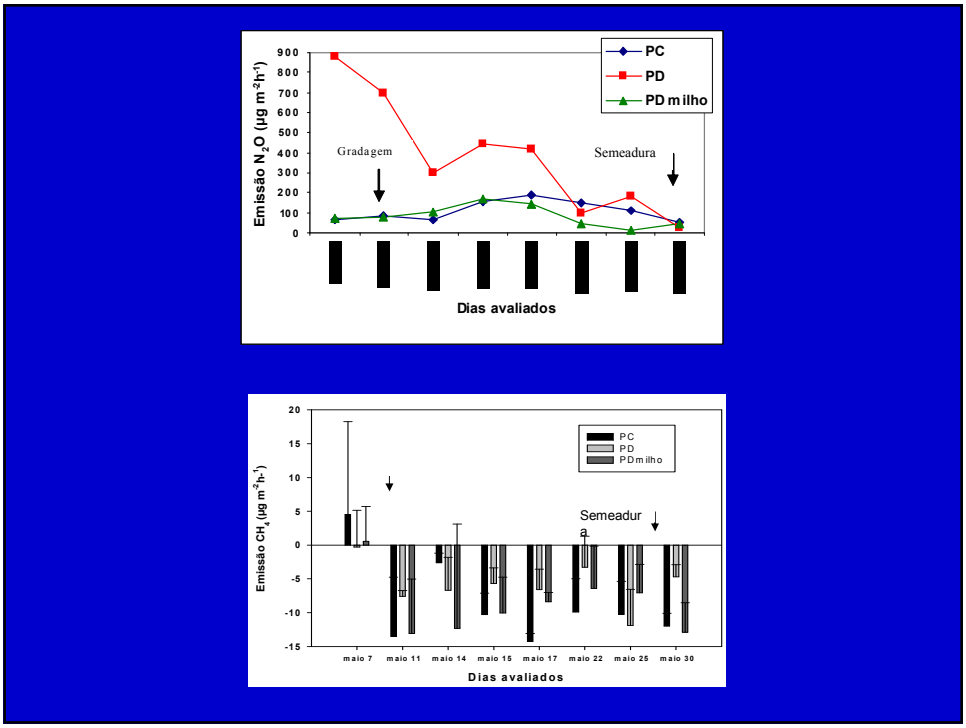
Soybean	Yield	C grain	CO2 Flux	CO2 flux-C grain
		---------- g m^{-2} ----------		
2006/07	321.3	150,95	-158.05	-7.10

Verma et al. (2005) +/- 45 g C m^{-2}

Conclusion: Carbon sequestration? Not with soybean

NT soybean neutral balance

Escobar, 2007



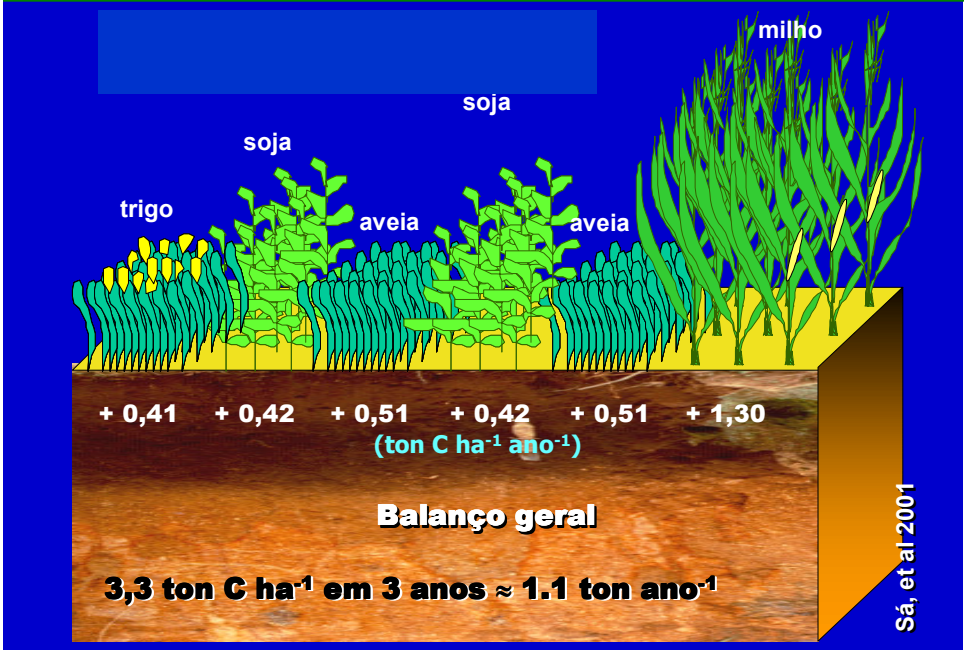
GWP = [Cost C]+[Δ C solo + N-N_2O x 126,9 + CH_4 x 8,4)

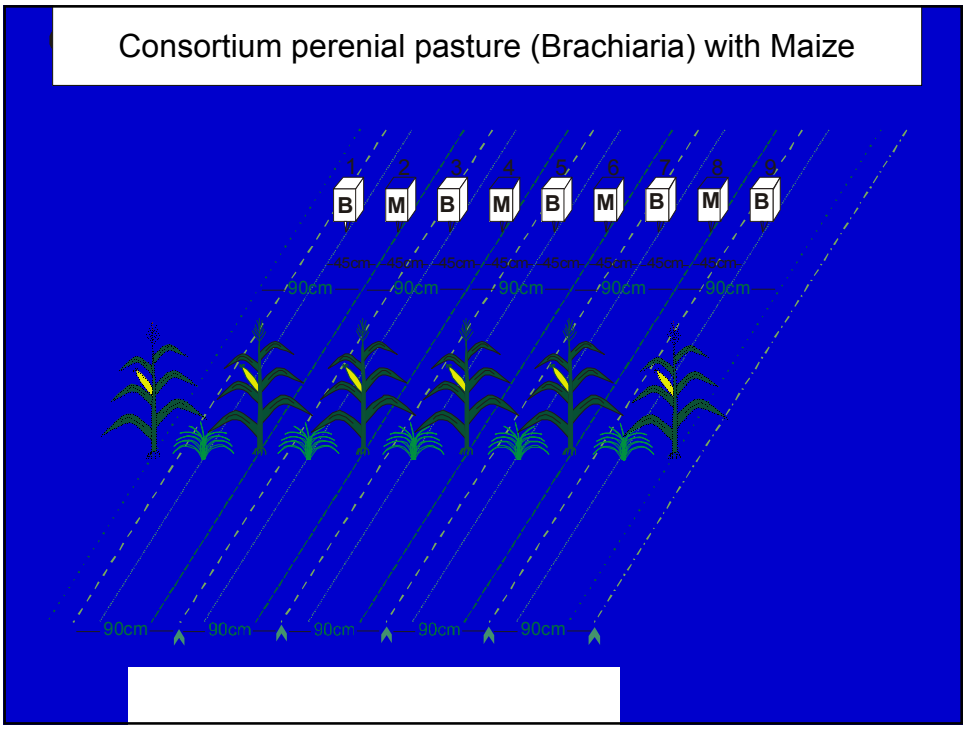
Treatment	Cost C-CO_2	TOC	N_2O	CH_4	GWP
	----------Kg CE ha^{-1} ano^{-1}----------				
Conventional Tillage					
Oat/Maiz	224,6	+28	30,2	0,032	+283
Vetch/Maiz	224,6	+10	35,9	0,097	+270
No-Till					
Oat/M	199,2	+45	-5,6	-0,024	+239
Vetch/M	199,2	-505	61,2	-0,033	-244
O+V/M+C	161,9	-350	100,4	0,001	-88
LabLab+M	161,9	-590	85,3	0,028	-343
Guandu+M	161,9	-780	101,0	0,056	-517

Gomes (2006)

Innovate cropping systems

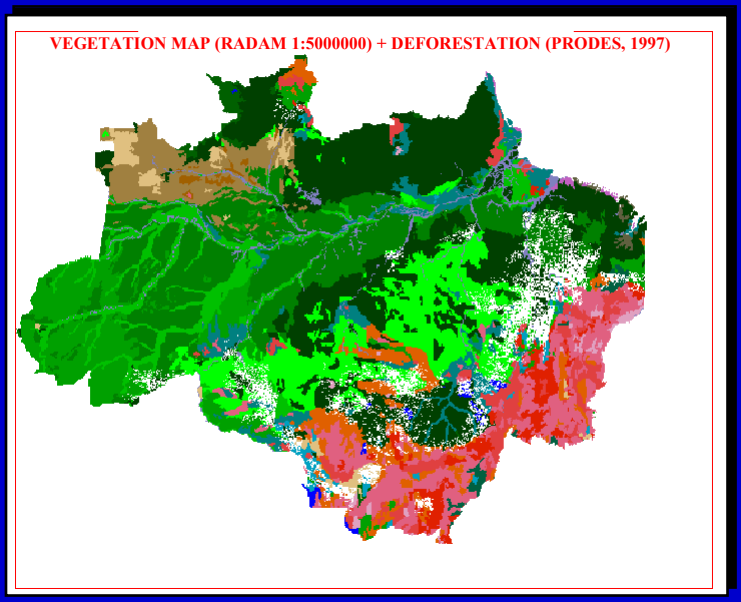
Intensive cropping system




Consortium perenial pasture (Brachiaria) with Maize
1 2 3 4 5 6 7 8 9
B M B M B M B M B
45cm 45cm 45cm 45cm 45cm 45cm 45cm 45cm
90cm 90cm 90cm 90cm 90cm
90cm 90cm 90cm 90cm 90cm


25 14:43


2 14:58



Current patterns of deforestation in white color

Methodologies / Current issues in SOM research

- **Standardization of soil sampling depth**
  - 1.0 meter (C sequestration in deeper layers)
  - 0.30 m (IPCC metodology)
  - 0.20 m (Century model)
- **Equivalent mass rather than equivalent depth approach**
- **Improvement of the physical fractionation procedures**
- **Isotopic techniques (crop rotation systems)**
  - Compartments of SOM and their dynamics