World Soil Issues and Sustainable Development: An agenda for Action
40 years ISRIC – World Soil Information
(Anniversary Seminar, 9th March 2006, Wageningen)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

Carlos C. Cerri,

Carlos E. P. Cerri, David Powlson, Niels H. Batjes,

Martial Bernoux, Keith Paustian, Eleanor Milne, Charles W. Rice

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas (GHG) Emissions

TOPICS

General Considerations

- Importance of soil organic carbon
- Carbon balance and sequestration
- The tropics
- Carbon sequestration and international effort

Soil Organic Carbon / GHGs in the tropics

- Known knows
- Known unknowns
- Unknown unknowns

Final Considerations

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas (GHG) Emissions

TOPICS

General Considerations

- Importance of soil organic carbon
- Carbon balance and sequestration
- The tropics
- Carbon sequestration and international effort

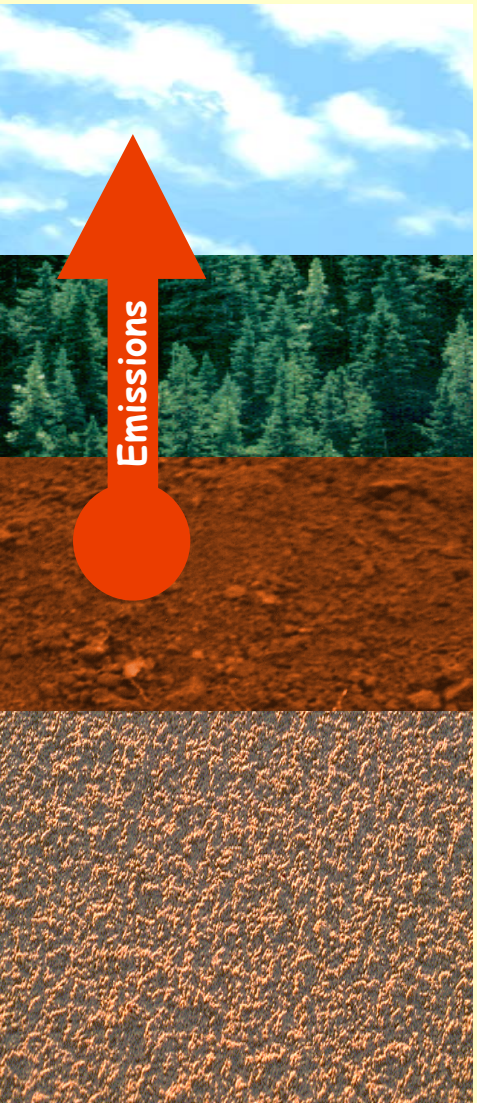
Soil Organic Carbon / GHGs in the tropics

- Known knows
- Known unknowns
- Unknown unknowns

Final Considerations

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

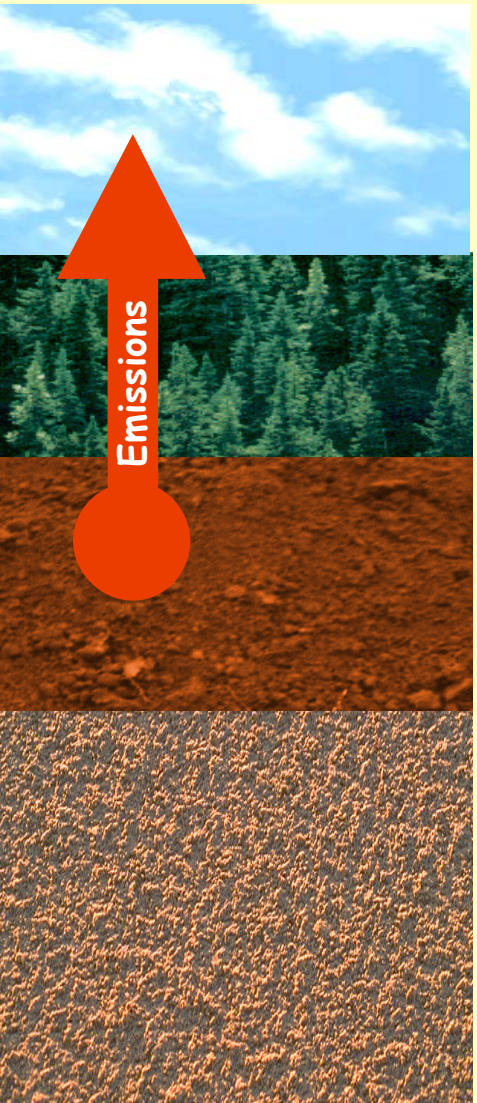
Importance of SOC at global scale



	Pg
Atmosphere	730 + Δ
Vegetation	470-655
Soil (0-30cm)	~700
Soil (1m)	1500-2000

Values in Gt C (1Gt = 10^9 t = 1 Pg)

Importance of SOC at global scale

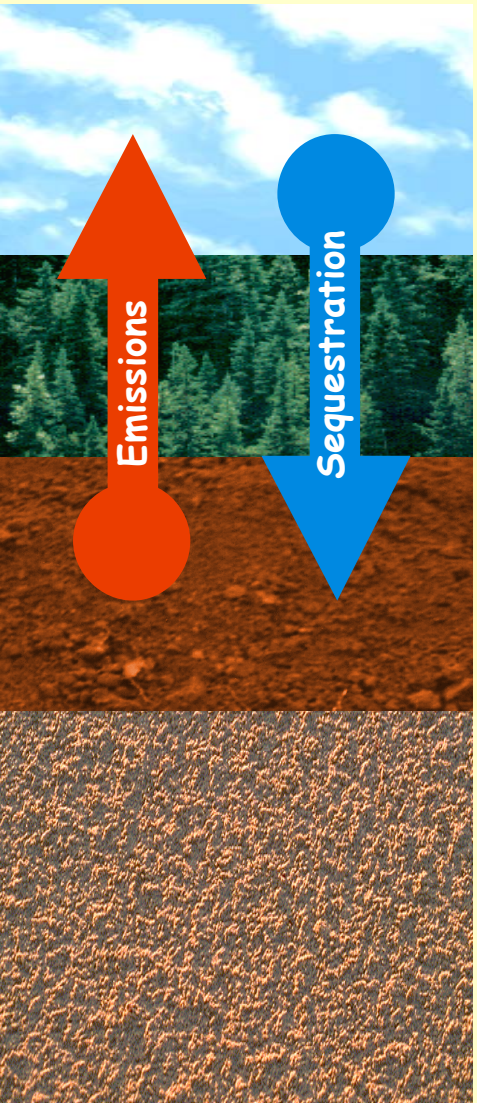


	Pg
Atmosphere	730
Vegetation	470-655
Soil (0-30cm)	~700
Soil (1m)	1500-2000

Values in Gt C (1Gt = 10^9 t = 1 Pg)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

Importance of SOC at global scale

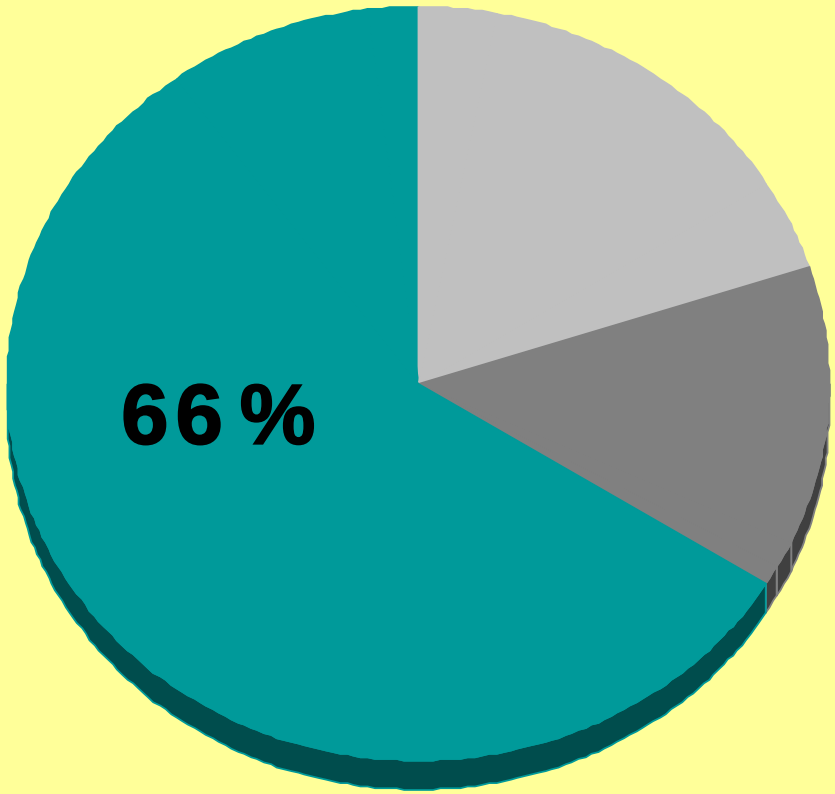


	Pg
Atmosphere	730 - Δ
Vegetation	470-655
Soil (0-30cm)	~700
Soil (1m)	1500-2000

Values in Gt C (1Gt = 10^9 t = 1 Pg)

Importance of LULUCF to the radiative forcing

Radiative forcings* by main sector

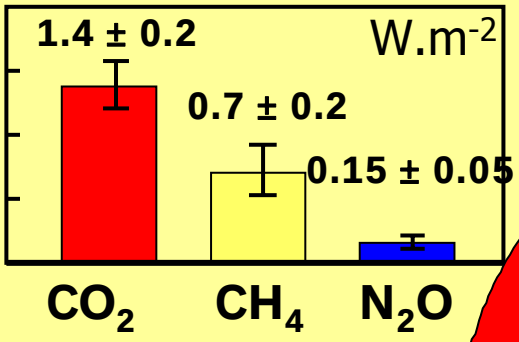


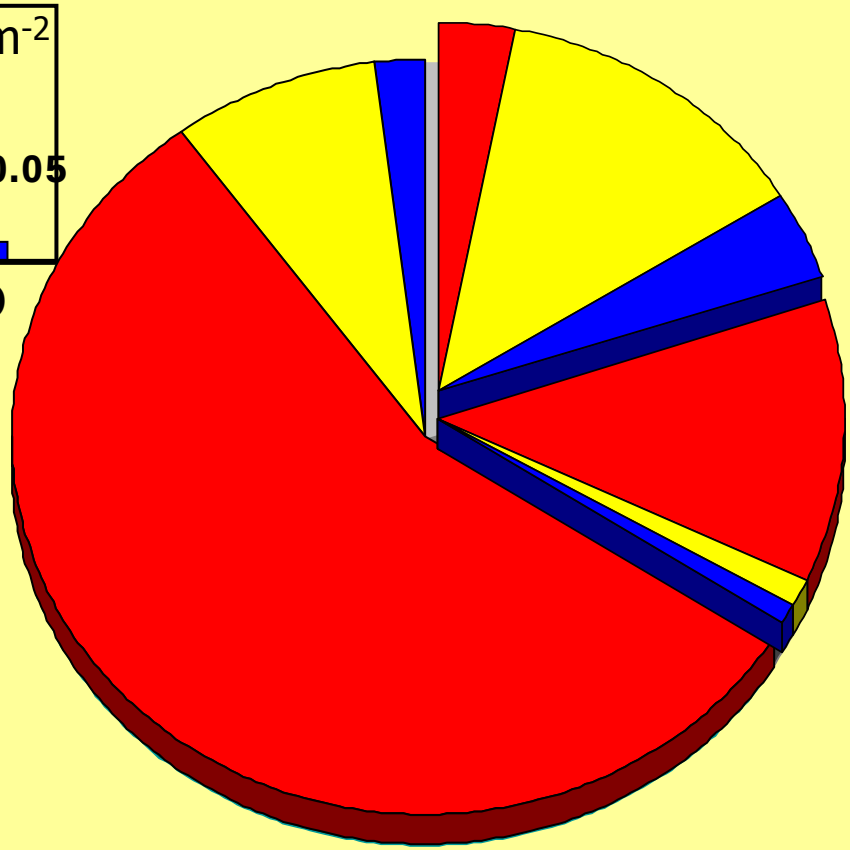
IPCC-SAR, 1996

* Change in the energetic balance of the Earth

Importance of LULUCF to the radiative forcing

Radiative forcings* by main sector





Industries cement And Fuel

Agriculture 20 %

CO_2	5 %
CH_4	50 %
N_2O	70 %

Land Use Change 14 %

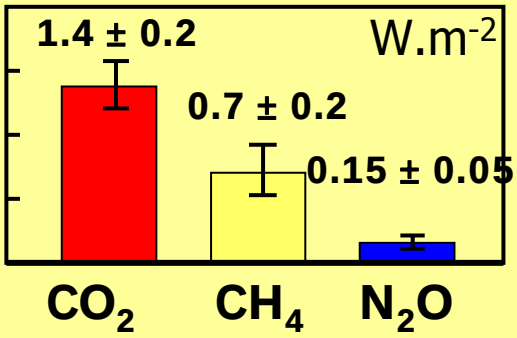
CO_2	17 %
CH_4	5 %
N_2O	10 %

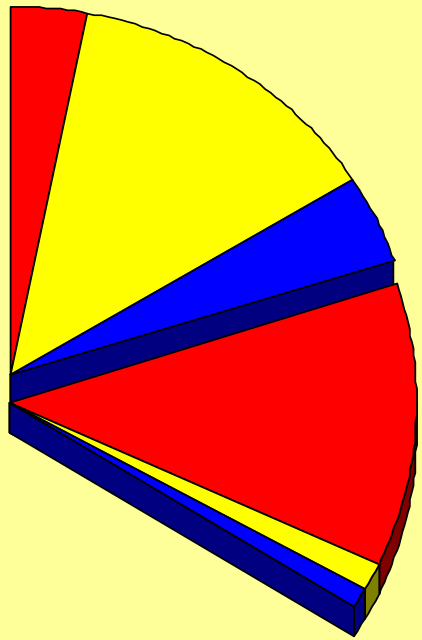
IPCC-SAR, 1996

* Change in the energetic balance of the Earth

Importance of LULUCF to the radiative forcing

Radiative forcings* by main sector





Agriculture
20 %

CO_2	5 %
CH_4	50 %
N_2O	70 %

LULUCF

CO_2	22 %
CH_4	55 %
N_2O	80 %

Land Use Change
14 %

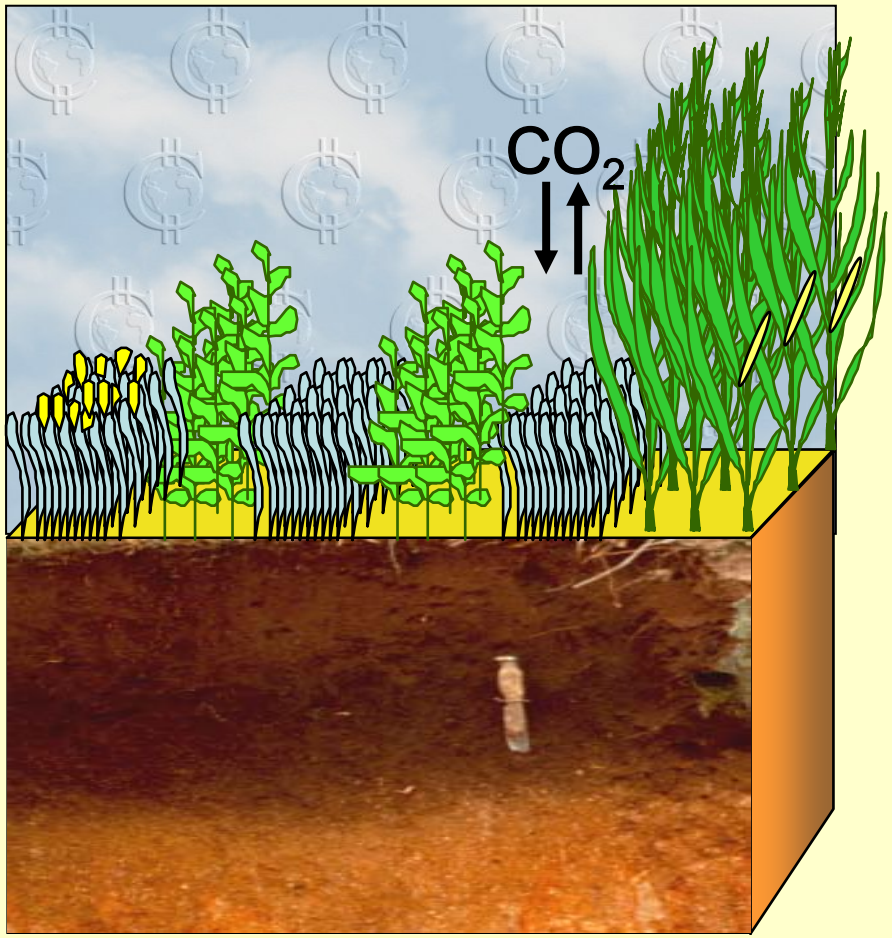
CO_2	17 %
CH_4	5 %
N_2O	10 %

IPCC-SAR, 1996

* Change in the energetic balance of the Earth

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

Carbon Balance at the plot scale



ΔC plant (aerial)

ΔC plant (root)

ΔC litter

ΔC soil

ΔC soluble

ΔC particulate

C soluble ⇄

C particulate ⇄

Time

Old System t_0 New System

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

LULUCF	
CO_2	22%
CH_4	55%
N_2O	80%

Carbon Sequestration at the plot scale

→ It must be computed all 3 gases and reported using the same equivalent

Global Warming Potential (GWP)

CO_2	CH_4	N_2O
1	23	296

CO_2 Equivalent

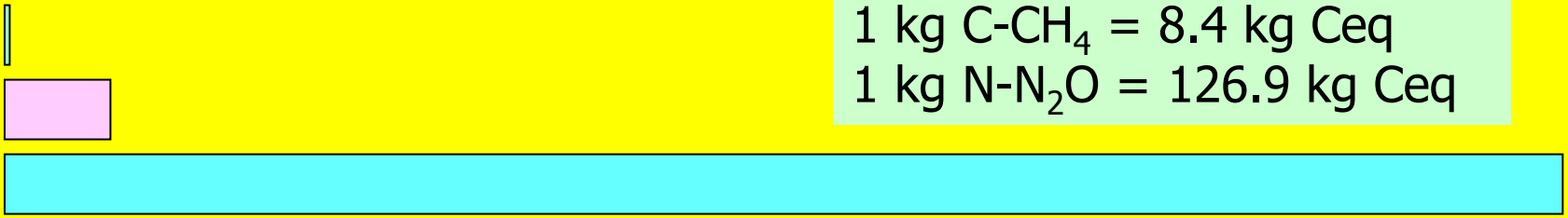
1 kg CH_4 = 23 kg CO_2eq

1 kg N_2O = 296 kg CO_2eq

C Equivalent

1 kg C-CH_4 = 8.4 kg Ceq

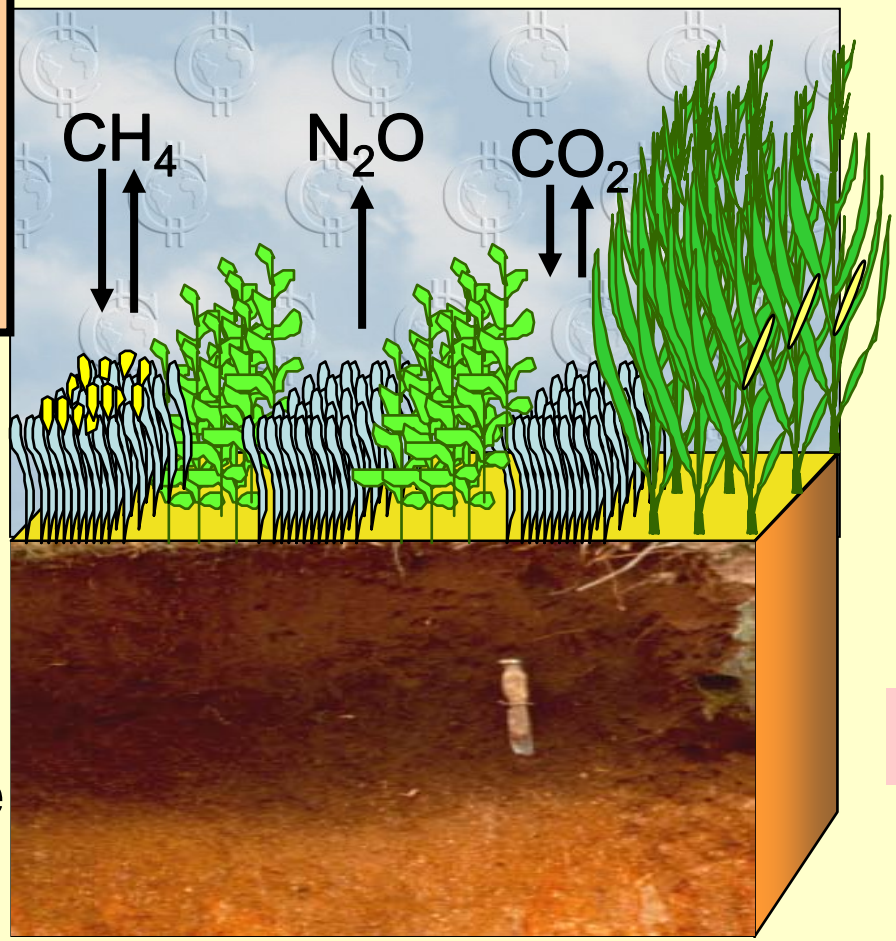
1 kg N-N_2O = 126.9 kg Ceq



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

C sequestration ≠ C balance

LULUCF	
CO_2	22%
CH_4	55%
N_2O	80%



- ΔC plant (aerial)
- ΔC plant (root)
- ΔC litter
- ΔC soil
- ΔC soluble
- ΔC particulate

ΔC gases (CH_4, N_2O)

C soluble ⇄

C particulate ⇄

Time

Old System t_0 New System

Versus Alternative system

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

The Tropics

- Rates of land use change is greatest in the tropics
- Feed 70% of the population (Lal and Sanchez 1992)
- Increasing demand for land will be met by converting forest and pasture (C release)
- ~ 26% of global SOC stocks are in the tropics (Batjes 1996)
- Relatively little information on soils and how they react to land use change

Carbon sequestration and international effort

- The Kyoto Protocol - CO_2 emissions can be offset against carbon removal from the atmosphere
- 1st commitment period: 2008 – 2012
- Article 3.3: forestry activities
- Article 3.4: management of agricultural soils
- Changes before 2008?
- UNFCCC -Inventories of CO_2 emissions from LUC
- Soils sources/sinks C?

Carbon sequestration and international effort

Kyoto Protocol

We need more scientific knowledge

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas (GHG) Emissions

TOPICS

General Considerations

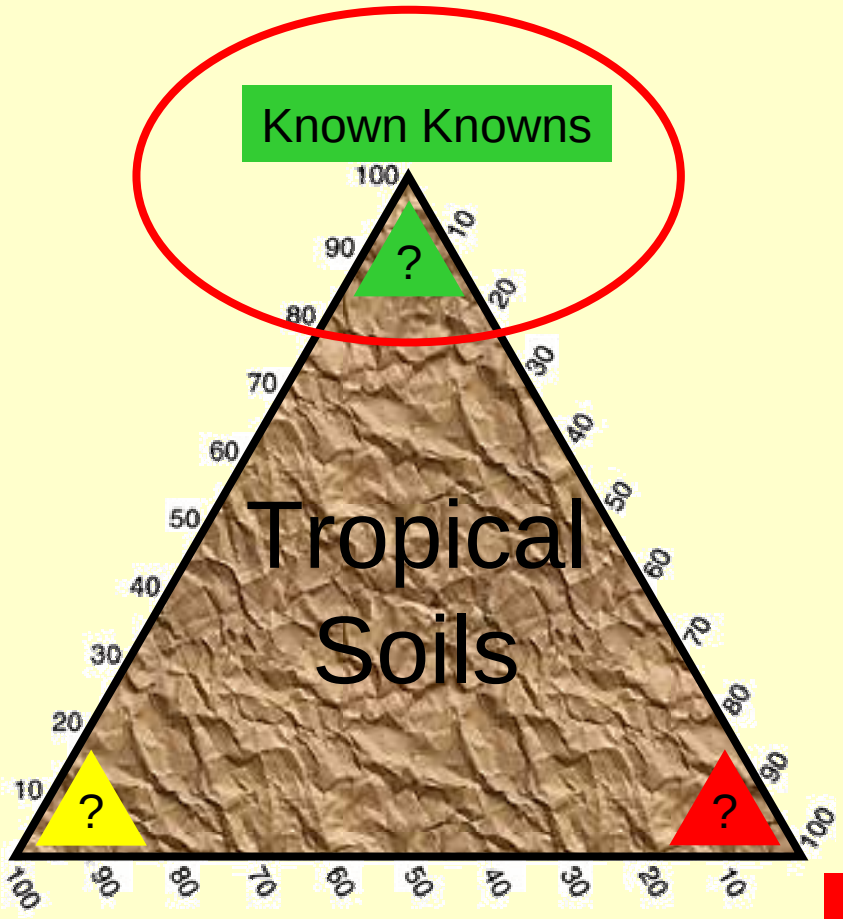
- Importance of soil organic carbon
- Carbon balance and sequestration
- The tropics
- Carbon sequestration and international effort

Soil Organic Carbon / GHGs in the tropics

- Known knows
- Known unknowns
- Unknown unknowns

Final Considerations

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions



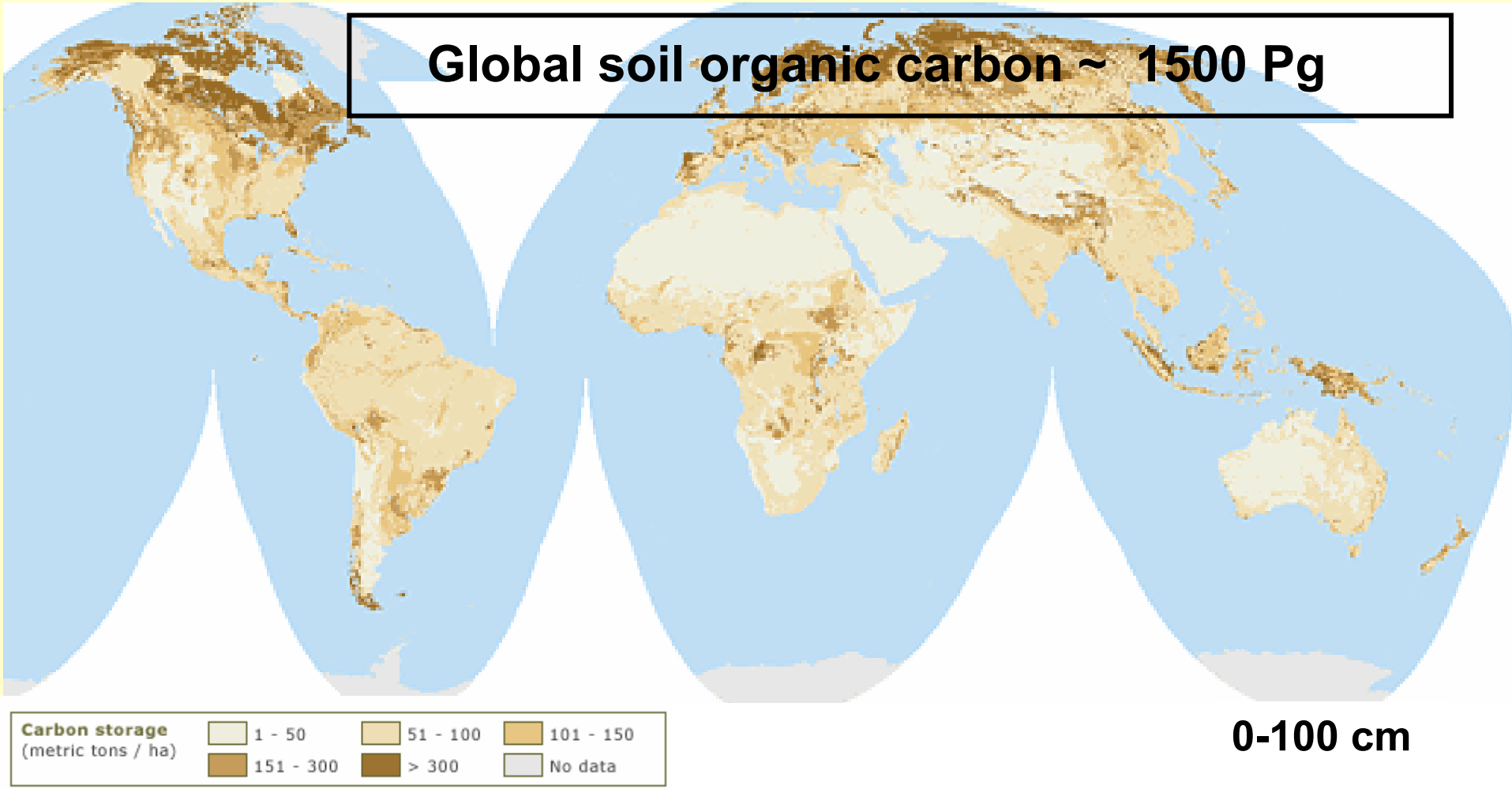
Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

Global distribution of soil organic carbon: native condition

Global soil organic carbon ~ 1500 Pg



0-100 cm

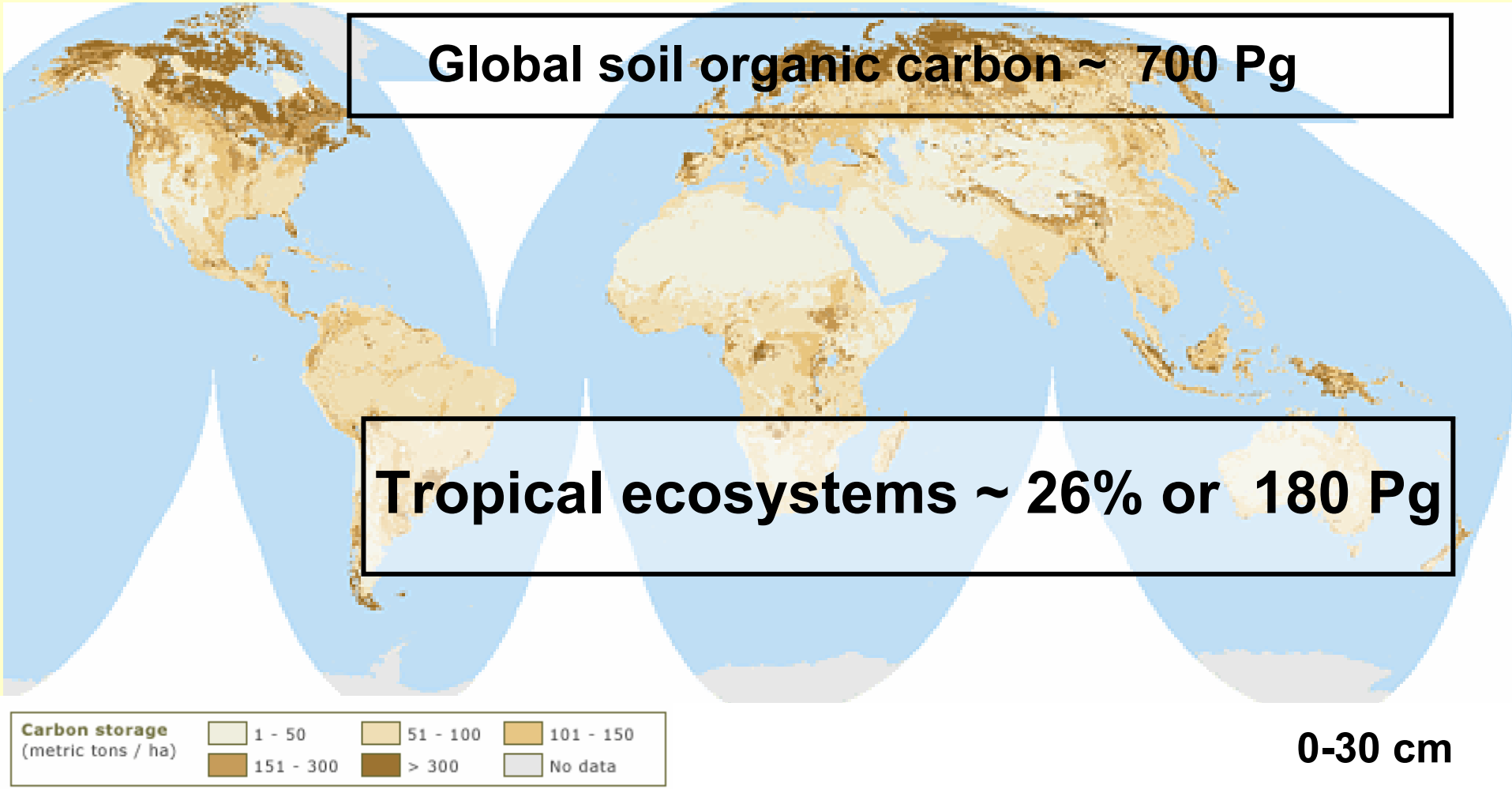
WRI, 2000 (FAO, 1995 & Batjes, 1996)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

Global distribution of soil organic carbon: native condition



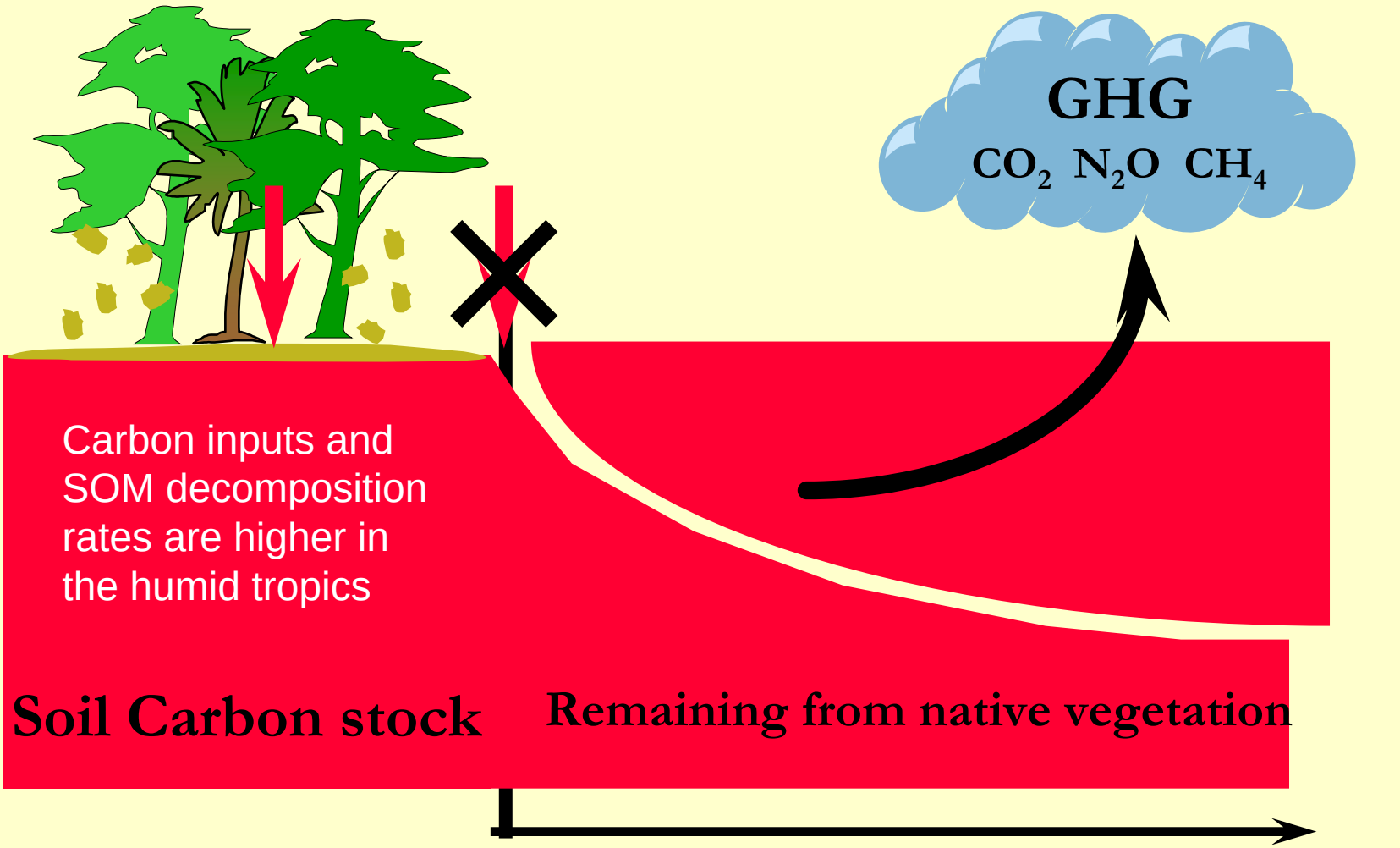
WRI, 2000 (FAO, 1995 & Batjes, 1996)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

Decline in SOM ⇨ GHG emissions



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Sources of GHG emissions

Known knowns

Agriculture and land use change

Fossil fuel combustion	Global	G H G (%)	Brazil	Fossil fuel combustion
78%	22	CO_2	75	25%
	55	CH_4	91	
	80	N_2O	94	

GHG in Brazil

	Global ranking
Only fossil fuel combustion:	17th
Fossil fuel combustion + Agriculture and land use change	5th

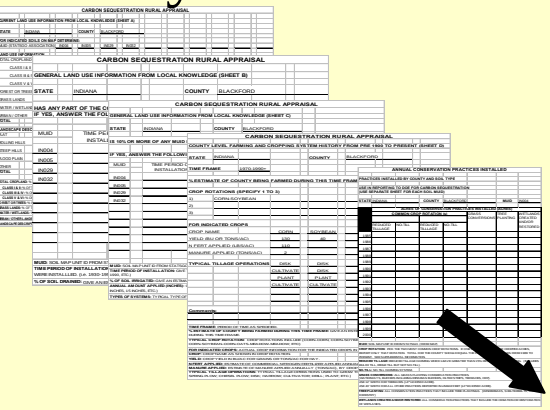
Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

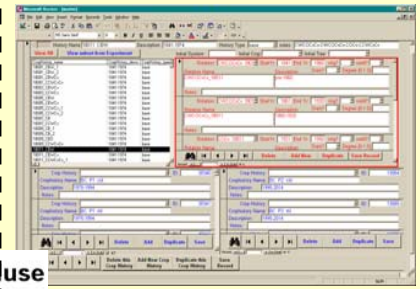
Survey data

Soil carbon modelling

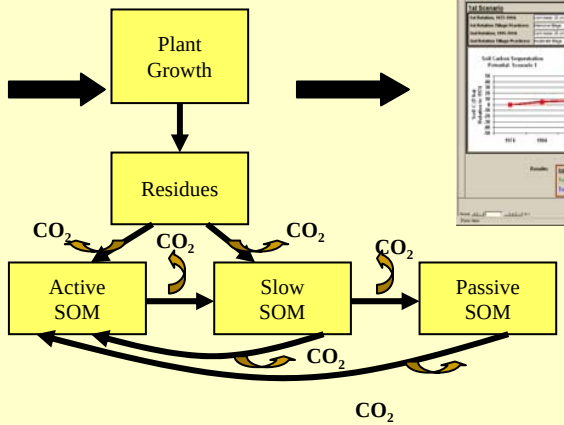


Dynamic soil C modelling tool

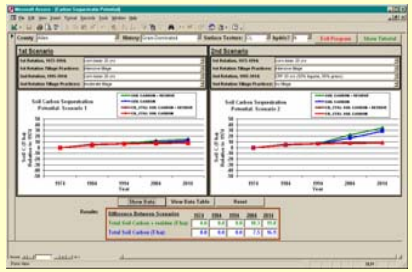
Input database



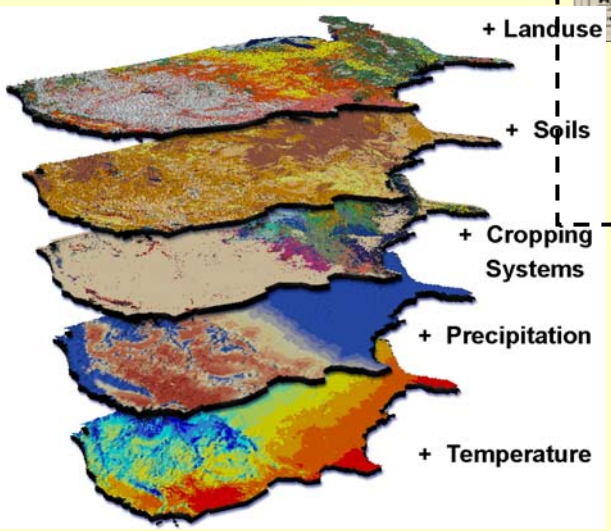
Simulation models

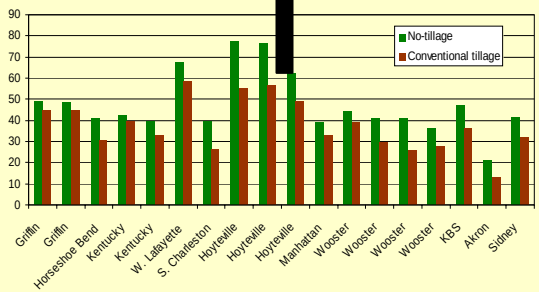


Output database



Spatial data



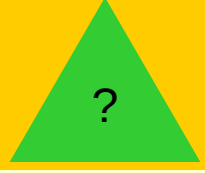


Long-term experiments

Process-knowledge

After: Easter et al. (2005)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions



Known knowns

- **Estimates of soil organic carbon (SOC) stocks for the Brazilian Amazon obtained from different studies (Cerri et al. 2006, *AEE subm*.)**

Source	Soil layer (cm)	SOC stocks (Pg)
Moraes et al. (1995)	0-20	21
Batjes & Dijshoorn (1999)	0-30	25
Bernoux et al. (2002)	0-30	22.7 ± 2.3
Batjes (2005)	0-30	23.9 - 24.2
GEFSOC project*		
Century	0-20	32.6
RothC	0-20	27.0
IPCC	0-30	26.9

* Estimates for the year 2000 and includes land use changes and management practices

- **Estimates of SOC stocks and changes remain fraught with uncertainty, irrespective of scale.**
  This uncertainty should be quantified (Falloon and Smith, 2003).

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

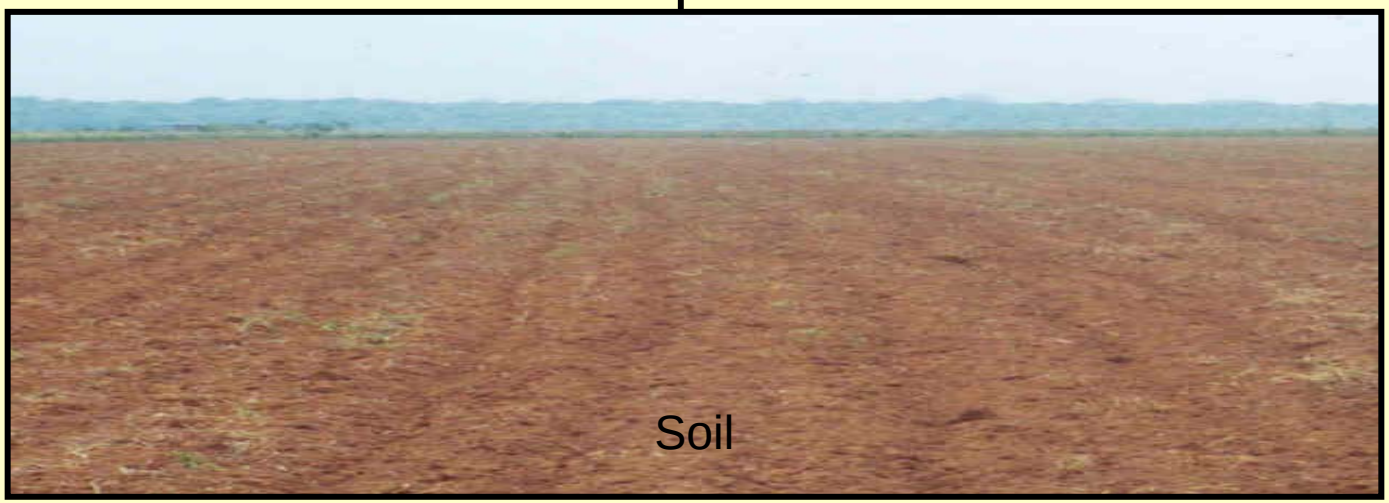
?

Known knowns

food

fiber

biomass

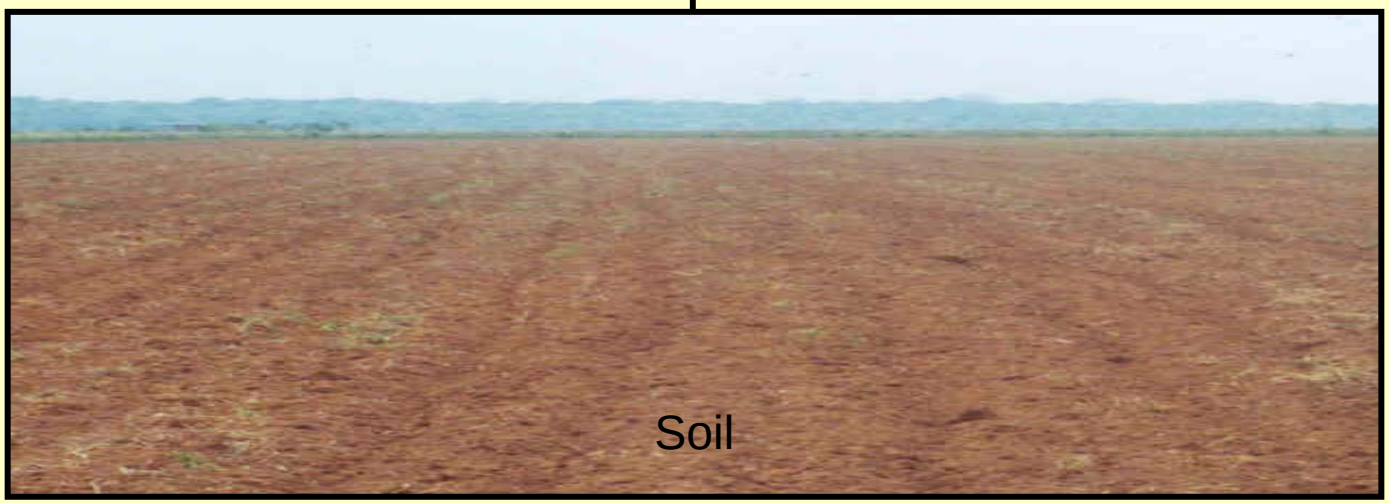


Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

energy



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

energy

Ethanol

sugarcane

Biodiesel

soybean

Castor-oil plant

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

~~Global warming~~

CO_2

Fotosynthesis

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

Biodiesel and the Carbon Cycle

Reduced Smog And CO_2

Transesterfication Process

Used or Waste Oil

Oil Extraction and Use

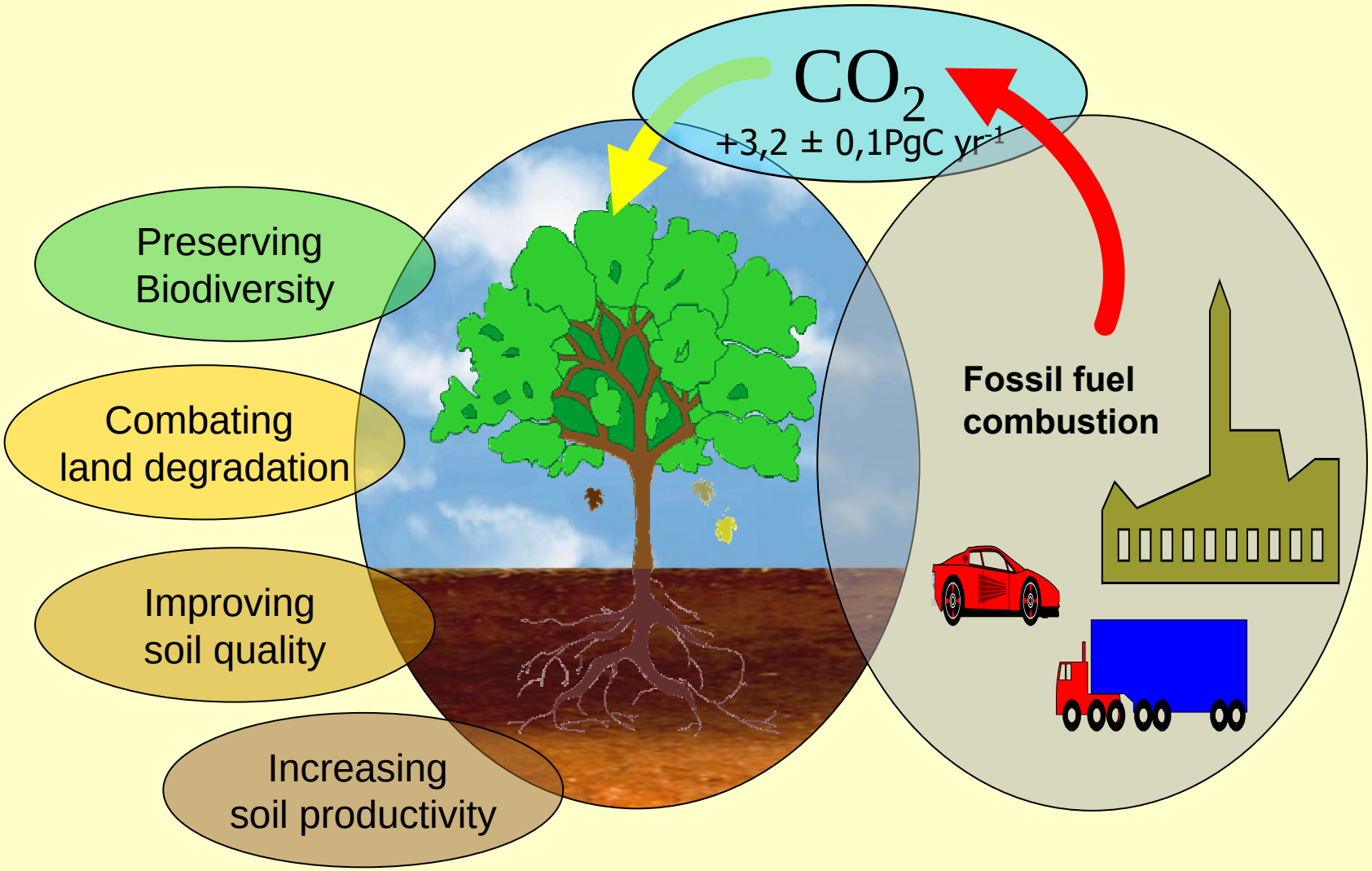
CO_2 in the Atmosphere

Oil seed (ie. Canola)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

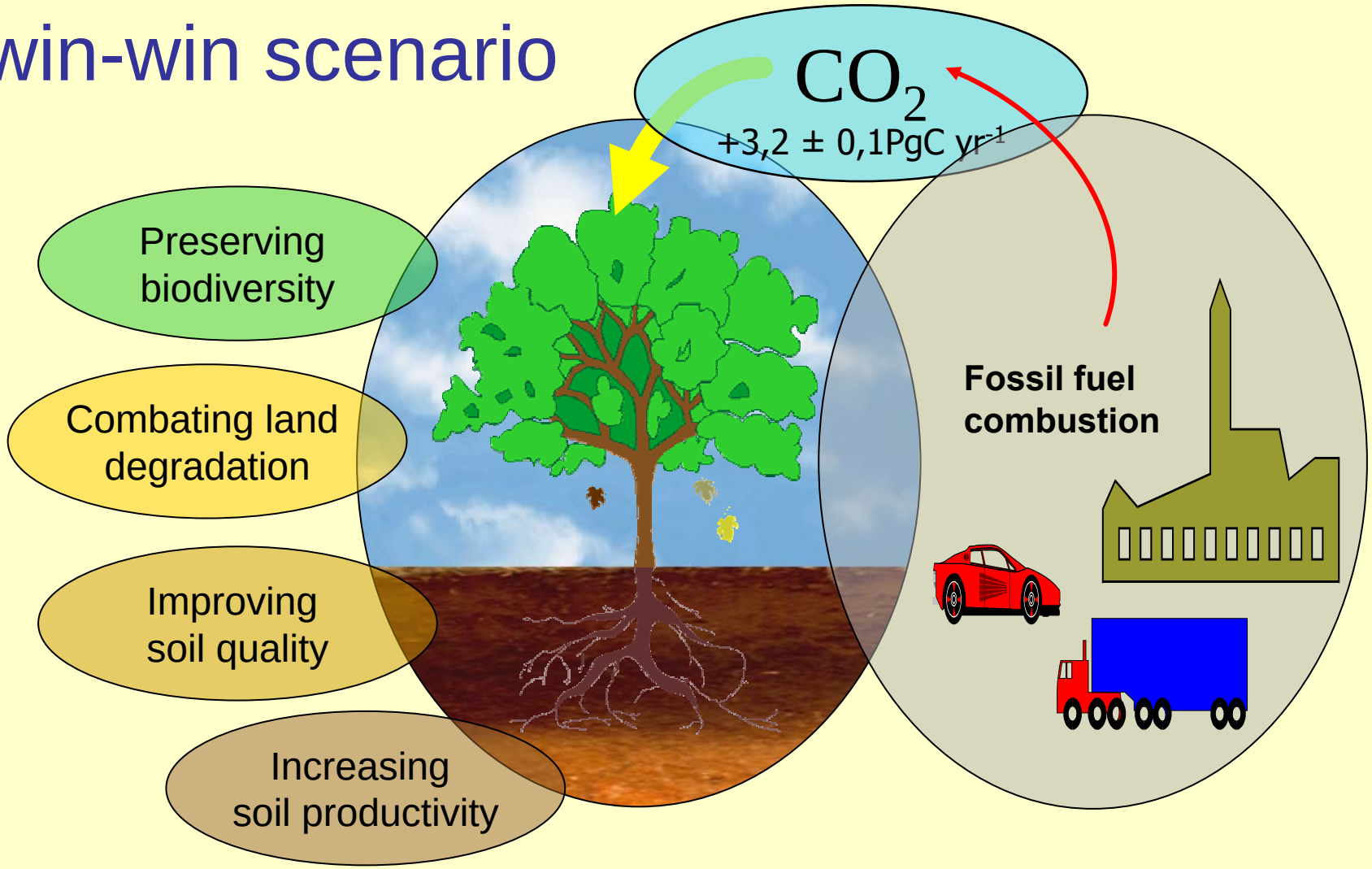


Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known knowns

win-win scenario



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

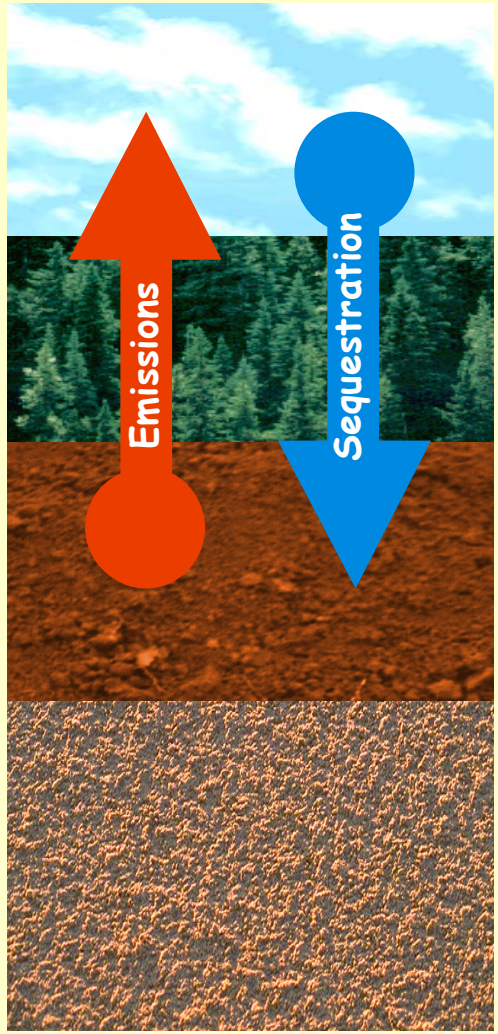
?

Known knowns

Known knows….most known is

Soil organic matter is much more than a potential sink for storing excess CO_2 biologically,

it is most useful when it decays (Janzen 2006)



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

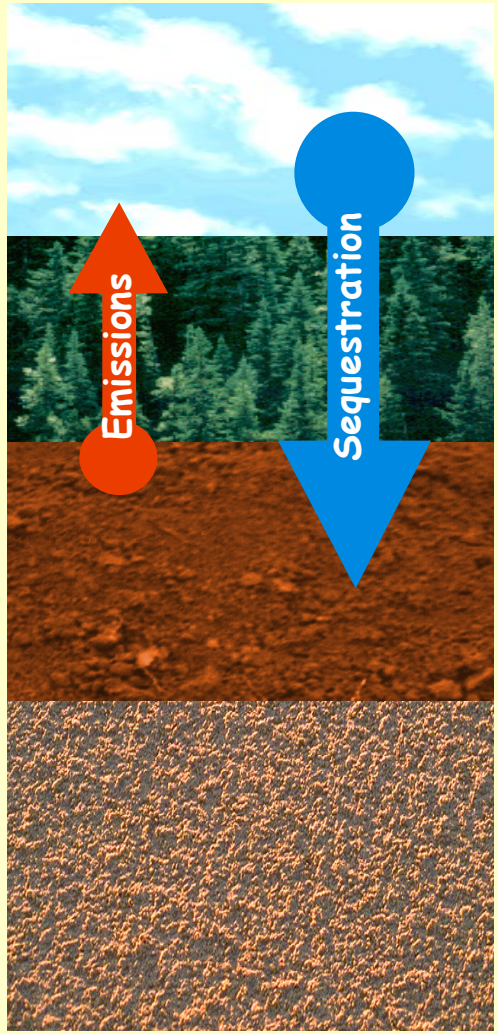
?

Known knowns

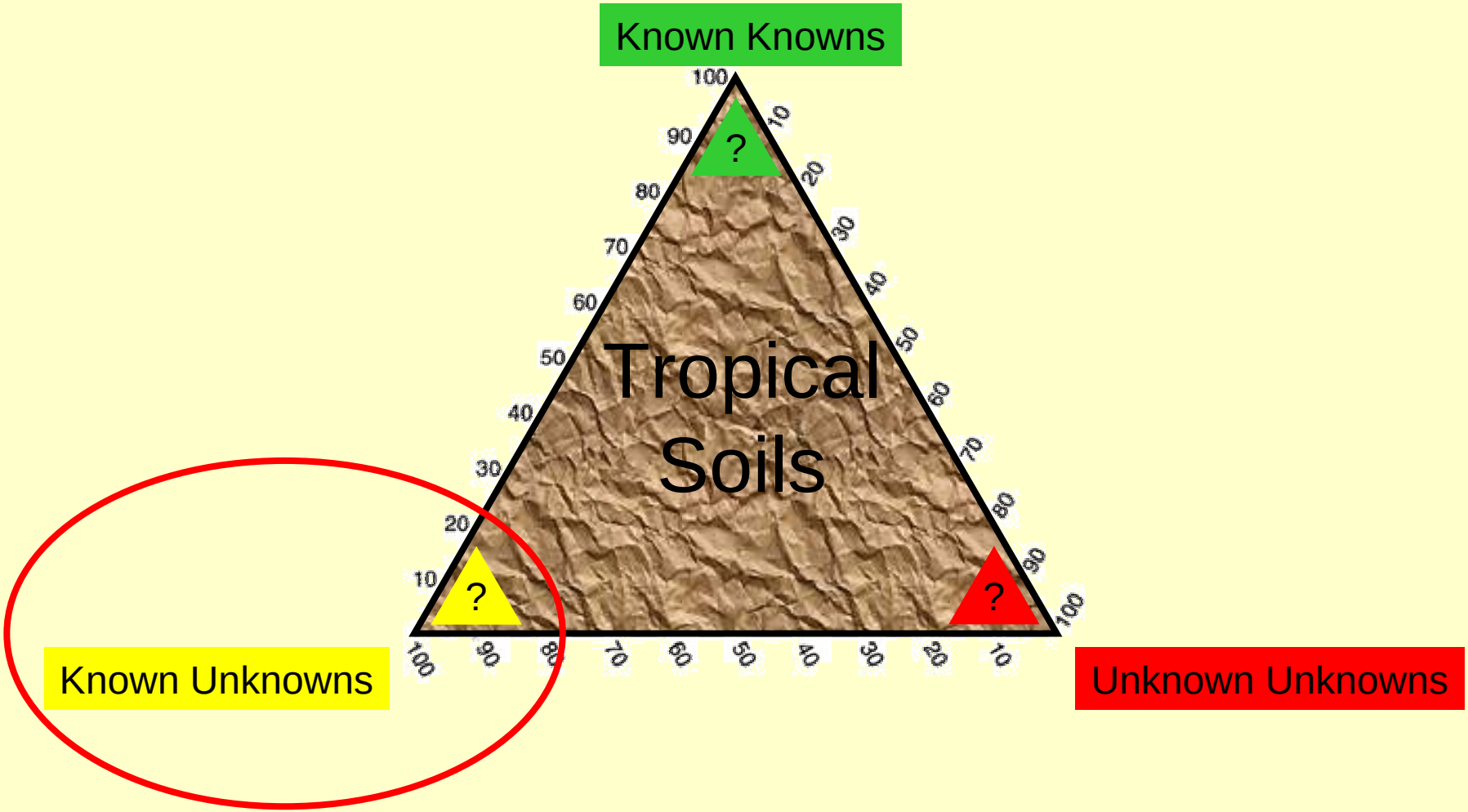
Known knows….most known is

Soil organic matter is much more than a potential sink for storing excess CO_2 biologically,

it is most useful when it decays (Janzen 2006)



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

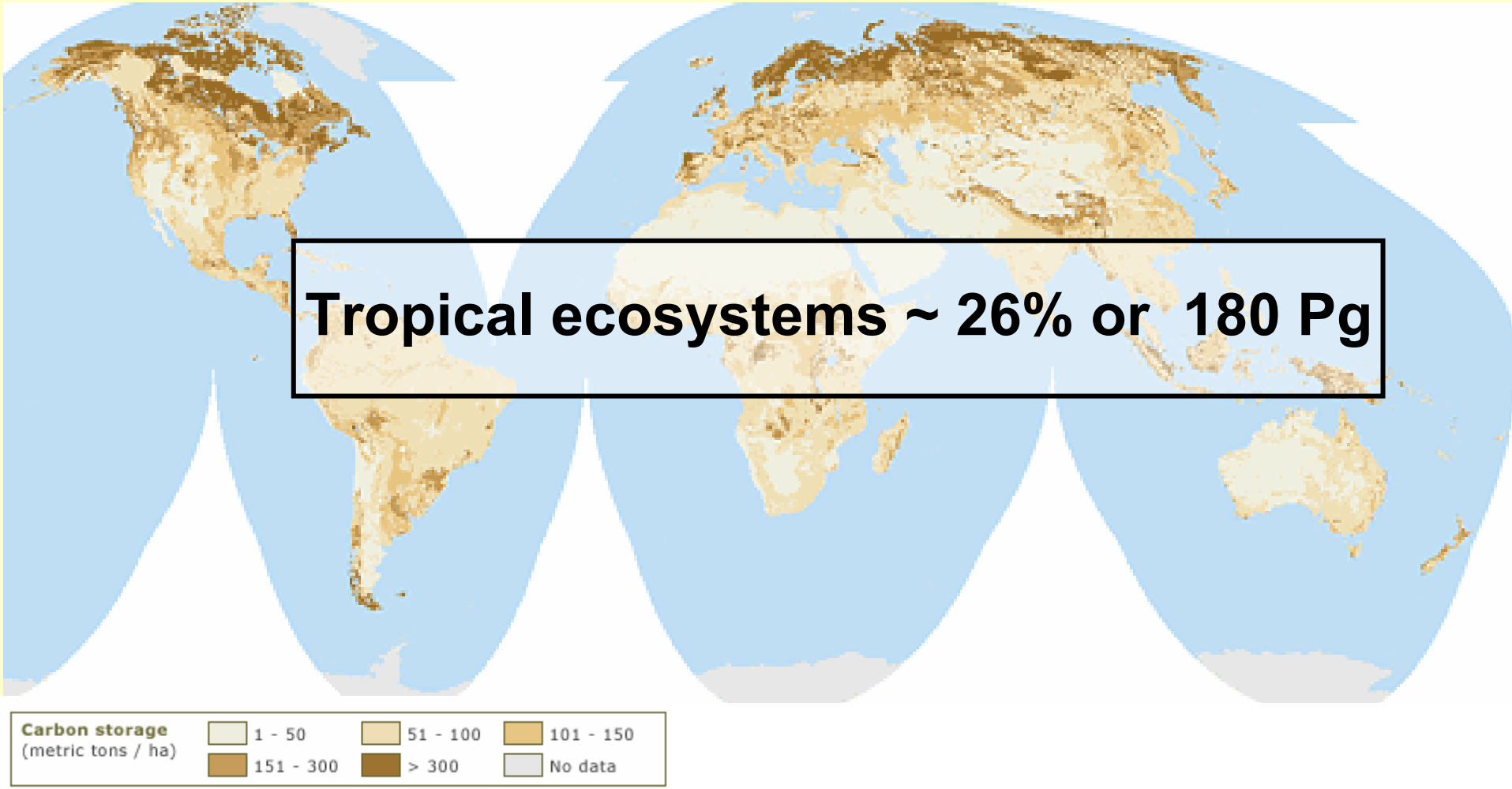


Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known Unknowns

Global distribution of soil organic carbon: native condition

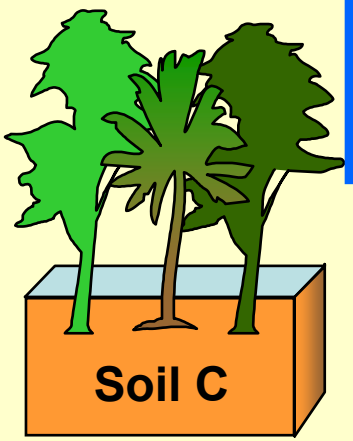


WRI, 2000 (FAO, 1995 & Batjes, 1996)

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

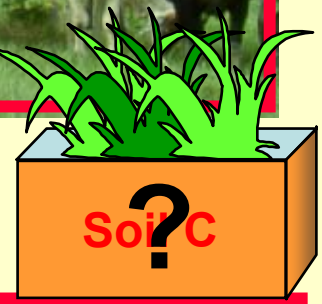
Known Unknowns



Known

Slash & burn

Crop/Pasture installation



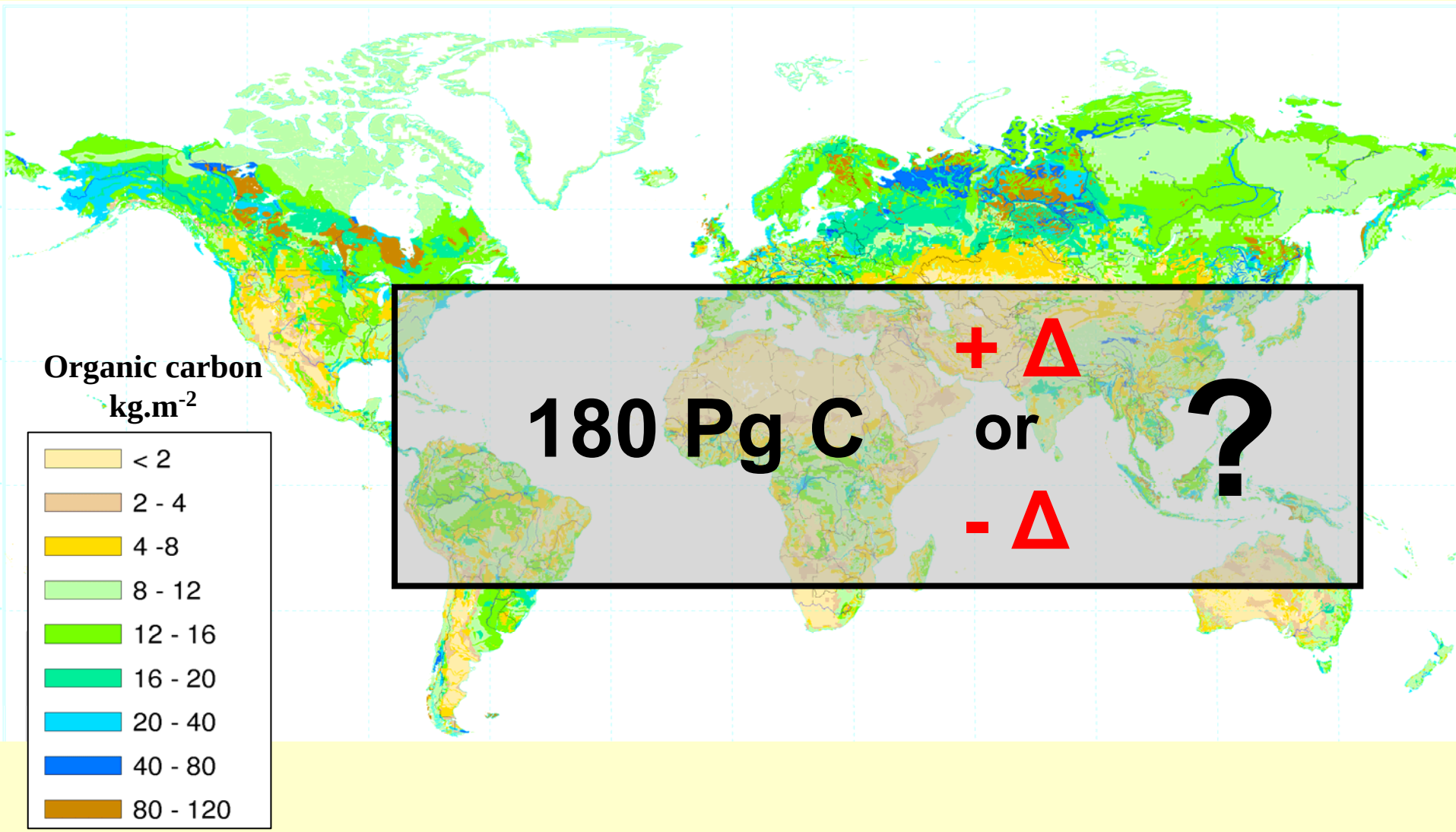
Unknown

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known Unknowns

Global distribution of soil organic carbon: anthropgenic use



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

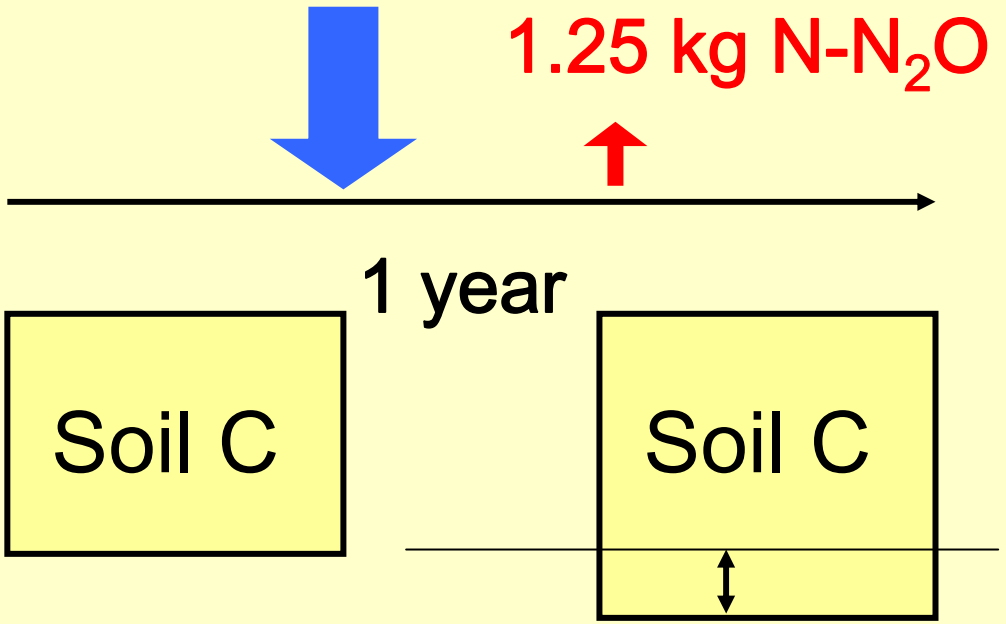
?

Carbon sequestration/GHG: full account

Known Unknowns

Example of N_2O

100 Kg N ha^{-1}



Δ C > 158 kg ha^{-1} yr^{-1} to have a benefit

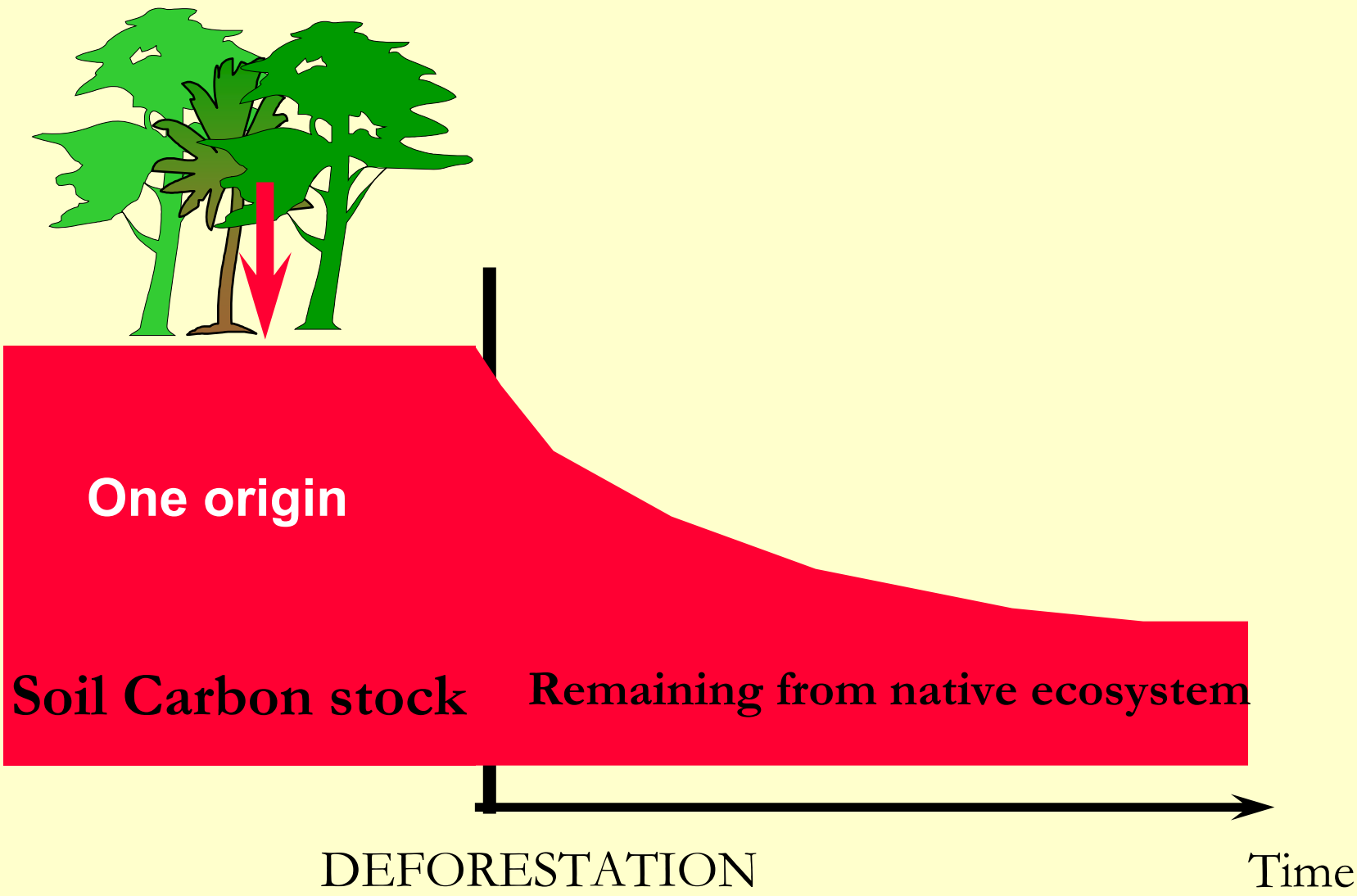
N_2O emissions can be greatly influenced by land management and difficult to predict

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

SOC origin

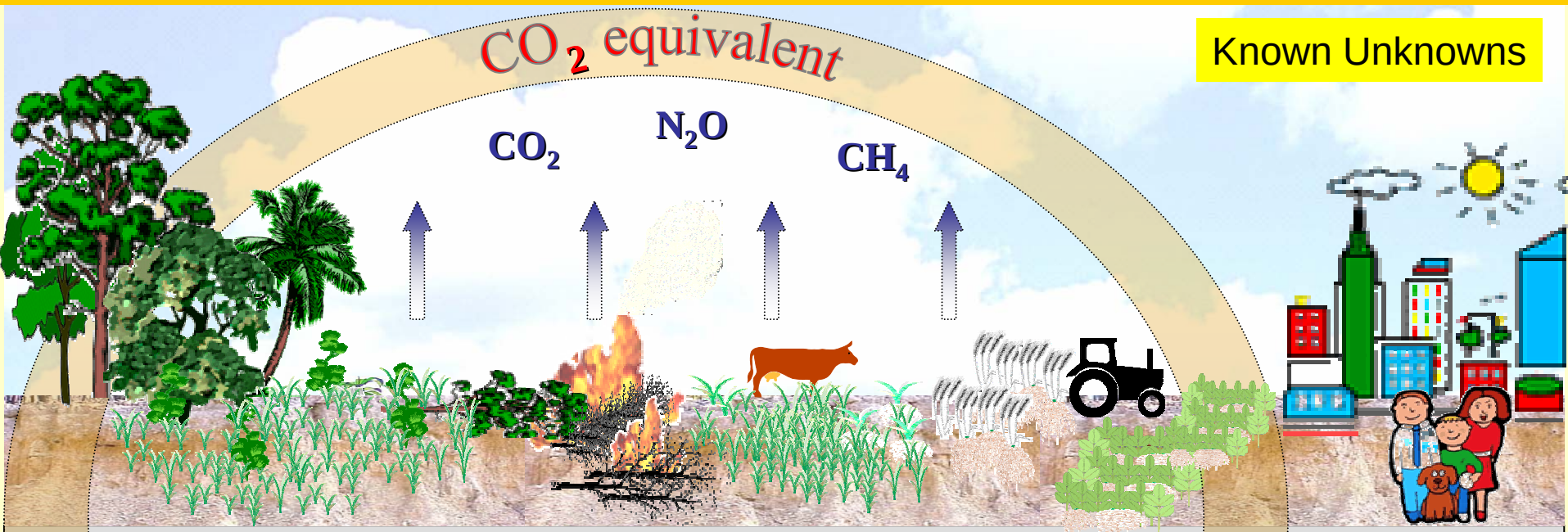
Known Unknowns



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Known Unknowns



Forest
Dense Cerrado
Cerrado
Savanna

Slash

Burn

Pasture

Agriculture

In soil:
Organic matter dynamic
C and N stocks **Agregation**
Structure **$\delta\ ^{13}C$**
Functional diversity

Main culture	Succession
Soybean	Fallow
Rice	Millet
Cotton	Sorgum
Maize	Pasture/crop

Management

Conventional
Conservative

Social and economic consequences

Population
Income distribution
Eduaction
Health
Sanitation

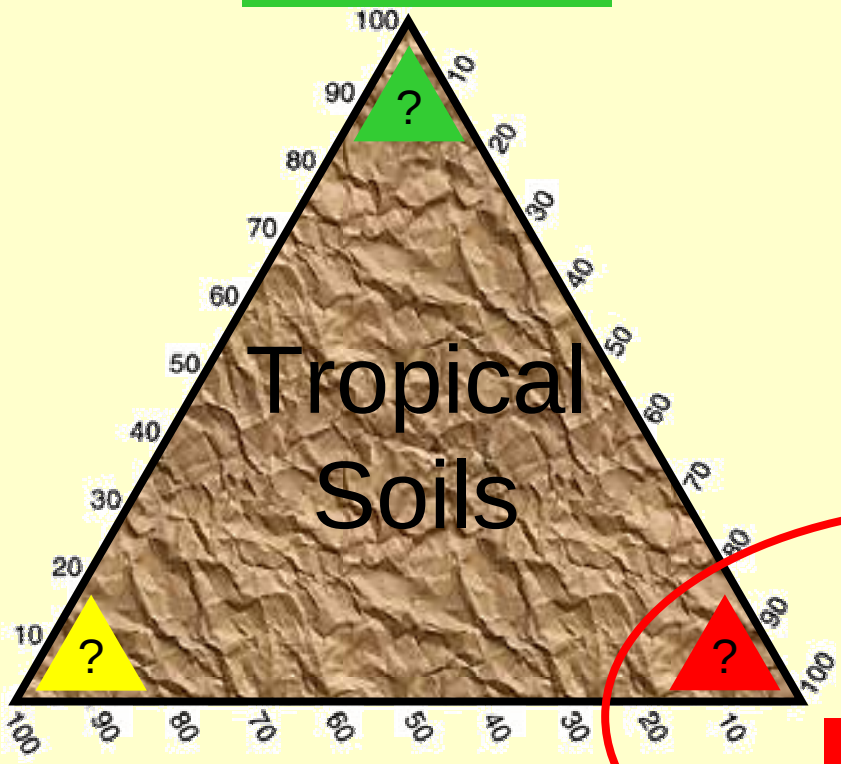
Modelling

Geographic Information System

Remote sensing

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

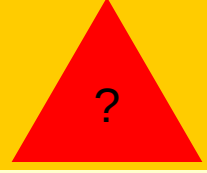
Known Knowns



Known Unknowns

Unknown Unknowns

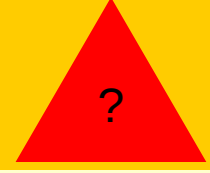
Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions



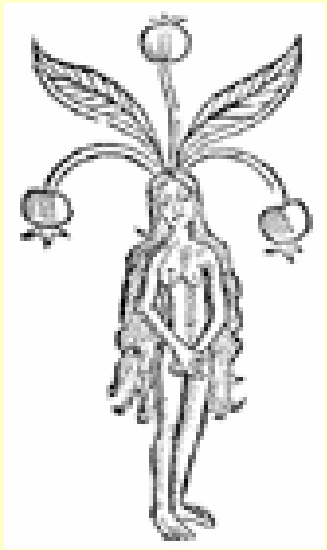
Unknown Unknowns

The most difficult part!!

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions



Unknown Unknowns



Biotechnological improvement

Is it possible to enhance C sequestration by changing soil microorganisms, plant biochemistry and/or belowground allocation by plant?

Do we know all about those??

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Do we know all about plant??

Unknown Unknowns

Vol 439|12 January 2006|doi:10.1038/nature04420 nature

LETTERS

Methane emissions from terrestrial plants under aerobic conditions

Frank Keppler[1], John T. G. Hamilton[2], Marc Braß[1,3] & Thomas Röckmann[1,3]

Here we demonstrate using stable carbon isotopes that methane is readily formed *in situ* in terrestrial plants under oxic conditions by a hitherto unrecognized process. Significant methane emissions

We suggest that this newly identified source may have important implications for the global methane budget and may call for a reconsideration of the role of natural methane sources in past climate change.

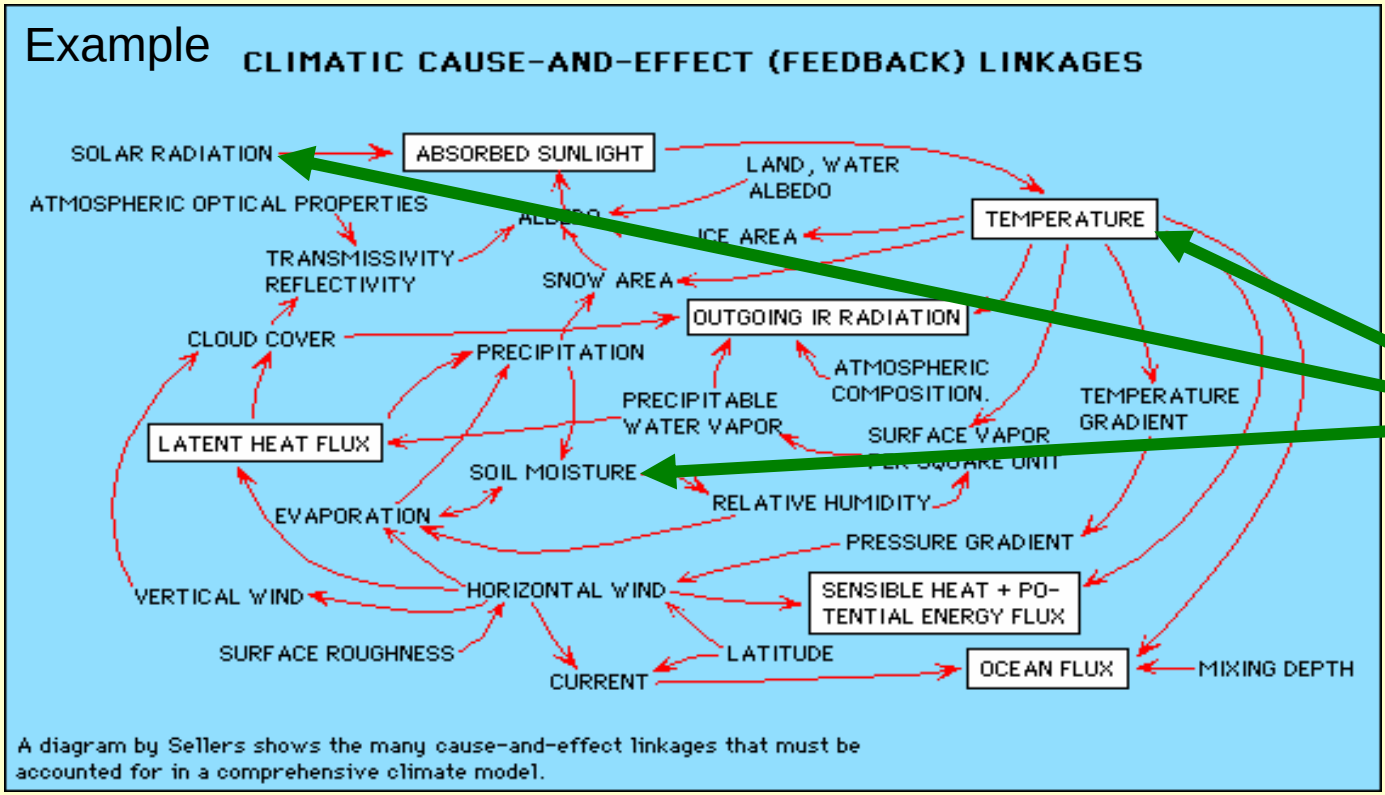
Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Unknown Unknowns

Feedbacks

Example



Plant and Soil

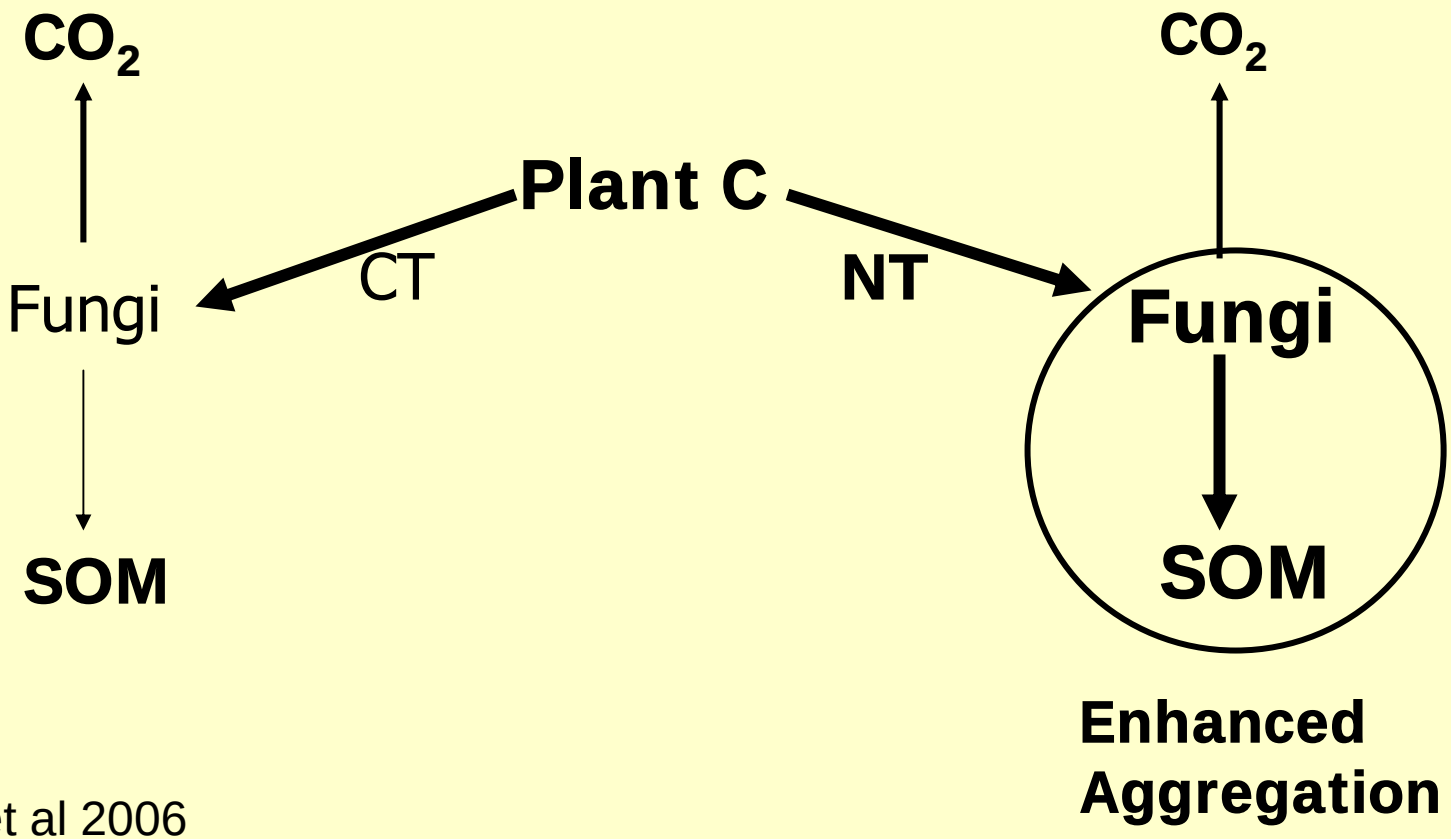
How will global warming, through its effects on carbon inputs (quantity and quality) and soil C mineralization, affect soil C stocks ?

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Unknown Unknowns

Adding residue and N stimulated fungi which seemed to have Inhibited C mineralization……Why?



Rice et al 2006

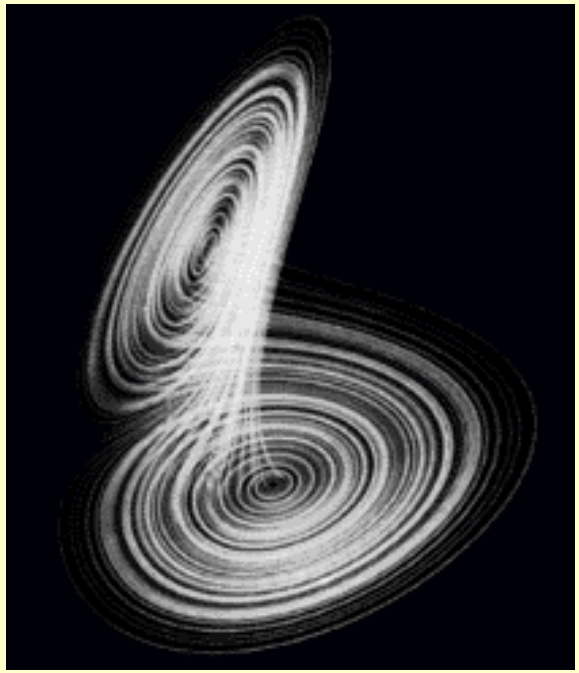
Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

?

Unknown Unknowns

Food Security

How will future “soil C sequestration/greenhouse gas emissions” impact on food security and livelihoods?



Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas (GHG) Emissions

TOPICS

General Considerations

- Importance of soil organic carbon
- Carbon balance and sequestration
- The tropics
- Carbon sequestration and international effort

Soil Organic Carbon / GHGs in the tropics

- Known knows
- Known unknowns
- Unknown unknowns

Final Considerations

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

Knowledge of SOC stocks and changes is needed to devise plans for:

- The sustainable management of ecosystems
- The mitigation of GHG emissions
- The likely impacts of climate change on soils/ecosystems in the future

Soil Organic Carbon Stocks/Sequestration and Greenhouse Gas Emissions

Our grandchildren still have problems to study…