Organic Residues Management and Tropical Soils Functioning

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Objectives

1. Soils of the tropics
2. Demography of the tropics
3. Food availability in the tropics
4. Residue Management in the tropics
5. Sustainable systems of soil management

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Tropics

The land between 23ºN and S of the equator:

- **40% of the earth's surface**
- **5 billion hectares (Bha)**
- **50% of the world's rainfall**
- **53% of 3 Bha of the world's potentially arable land area**

Principal Soils of the Tropics

Order	Area (Mha)	Order	Area (Mha)
Alfisols	641	Mollisols	23
Andisols	168	Oxisols	1151
Aridisols	912	Spodosols	4
Entisols	326	Ultisols	902
Histosols	29	Vertisols	219
Inceptisols	457	Misc.	136

Buringh (1979); Van Wambeke (1990); Eswaran et al. (1992)

Principal Soil-Related Constraints in the Tropics

Constraint	Area (Bha)
Low nutrient reserves	1.7
Aluminium toxicity	1.5
Acid soils	1.1
High P fixation	1.0
Low CEC	0.25
Calcareous reaction	0.24
Salinity	0.07
Alkalinity	0.05

Sanchez and Logan (1992)

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Carbon Pool in Soils of the Tropics

Type	Pool to 1-m depth (Pg)
SOC	308-506
SIC	149-218
Total	457-724

Batjes (1996); Eswaran et al. (2000); Kimble et al. (1990)

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Biomass Burning in the Tropics

	C released	
Region	Biomass burning	Deforestation
	------------------Tg C/yr---------------	
Tropical America	780	665
Africa	1450	373
Asia	980	621
Oceania	200	--
Total	3410	1659

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Loss of SOC from Tropical Ecosystems

Deforestation	
(i) Historic……………….	**2-13 Pg**
(ii) Current rate……….	**90-219 Tg C/yr**
Shifting Cultivation…….	**4-9 Tg C/yr**
Burning of grasslands….	**112-276 Tg C/yr**
Plowing…………………….	**38-92 Tg C/yr**

………… Lal and Logan (1992)

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The Population Bomb

World Population Growth

Year	Billions
7000 B.C.	0.005-0.01
1 A.D.	0.2-0.4
1850	1
1930	2
1960	3
1975	4
1987	5
1998	6
2010	7
2025	8
2050	9.4
2100	10-12

Almost all growth is in developing countries

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Future Growth in World Population

The world population of 6.5 billion in 2005 is expected to reach 7 billion b y 2012. Ninety-nine percent of the growth will be in developing countries.

Global Grain Production and Per Capita Consumption 1950 - 2000

Year	Production (10^6 Mg)	Per Capita Consumption (Kg)
1950	631	267
1955	759	273
1960	824	271
1965	905	270
1970	1079	291
1975	1237	303
1980	1430	321
1985	1647	339
1990	1769	335
1995	1713	301
2000	1840	303

Kondratyev et al. (2003)

Chronically Undernourished/Food Insecure People in the World

Year	Global Population Affected (10^6)
1970	960
1980	938
1990	831
2000	790
2005	730
2010	680

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Death From Hunger

- 24,000 per day (Chirspeels, 2002).
- This is equivalent to crashes of 80 flights of 747's every day and yet it is not a newsworthy item.

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Climate Change and Global Food Security

- Climate change is likely to increase the frequency of crop failure in Africa . . . (Royal Soc., U.K., 2005).
- Extra 50 million people will be at risk of hunger by 2050, majority in Africa. . . . (Science, 16 September 2005).

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Hidden Hunger

There are also 3.7 billion persons who are at risk of hidden hunger caused by deficiency of micronutrients and vitamins exacerbated by soil degradation.

Food Gap by Regions (Shapouri, 2005)

Region	Food Gap	
	2000	2010
	- - - - 10^6 Mg/yr - - - -	
Sub-Saharan Africa	10.7	17.50
Latin America	0.63	0.99
Asia	1.70	3.63
Others	0.17	0.18
Total of 67 countries	13.20	22.30

Estimates of Crop Residue Production in the U.S.

Species	1991	2001
	- - - - - - 10^6 Mg - - - - - -	
Cereals	325	367`
Legumes	58	82
Oil Crops	17	20
Sugar Crops	25	14
Tubers	5	5
Total	430	488

(Lal, 2005)

Estimates of Crop Residue Production in the World

Species	1991	2001
	- - - - - - 10^6 Mg - - - - - -	
Cereals	2563	2802
Legumes	238	305
Oil Crops	162	108
Sugar Crops	340	373
Tubers	145	170
Total	3448	3758

(Lal, 2005)

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Residue Production by Rice-Based Crops in the Tropics (Singh et al., 2005)

Crop	Asia	Africa	South America	World
	------------------------------ 10^6 Mg/yr ------------------------------			
Rice straw	772	26	24	845
Rick husk	154	5	5	169
Wheat	380	27	26	947
Barley	34	7	2	208
Sugarcane	54	9	42	125
Cotton	6	0.3	0.07	7
Oats	2	0.3	2	52
Corn	166	39	54	604
Total	1568	114	155	2957

Energy in Biomass

One Mg of Corn Stover =

- **280 L of Ethanol**
- **15 - 18 GJ of Energy**
- **16 x 10^6 BTU**
- **2 Barrels of Diesel**
- **3 x 10^6 KCal**

(Lal, 2005)

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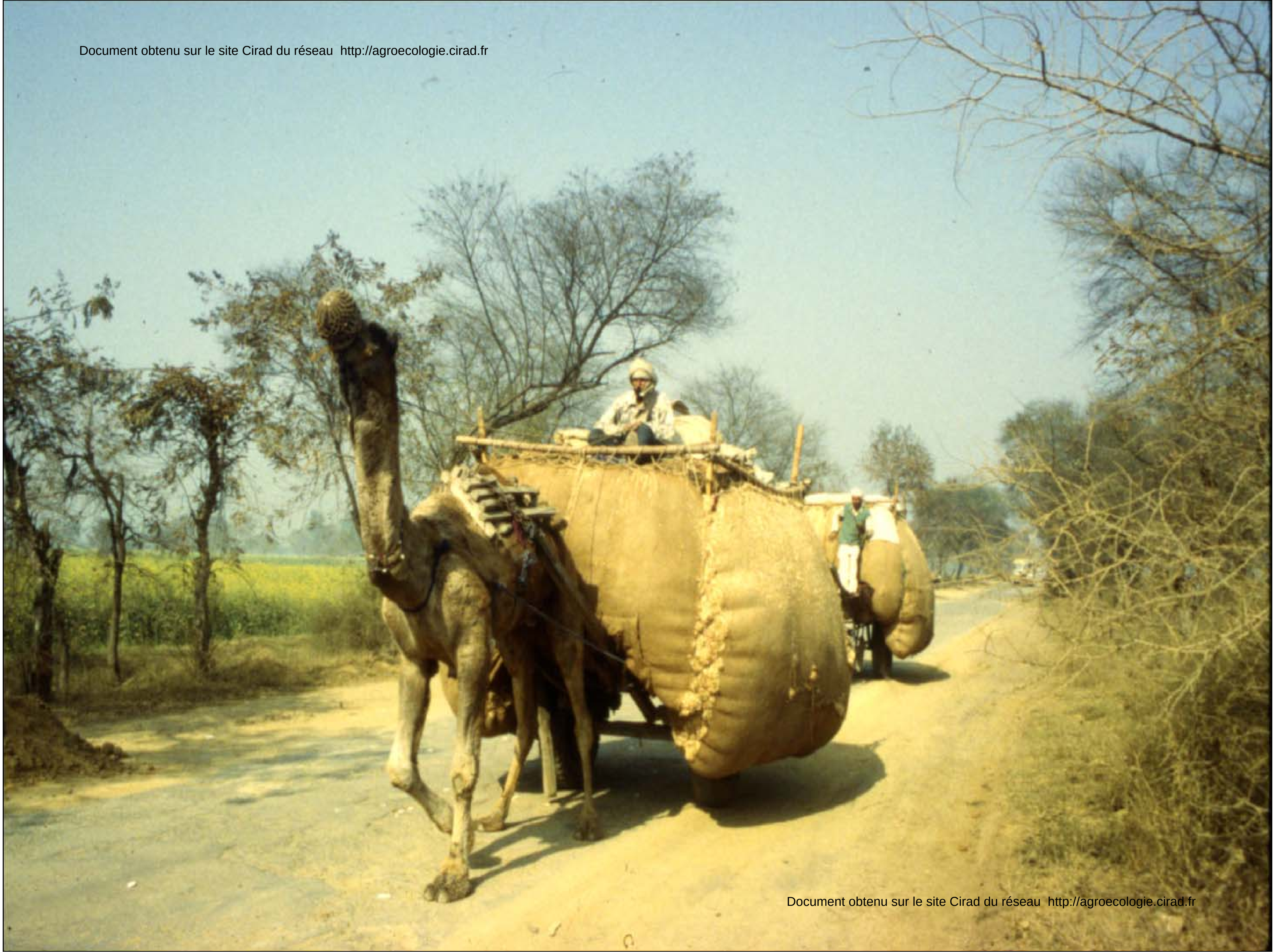

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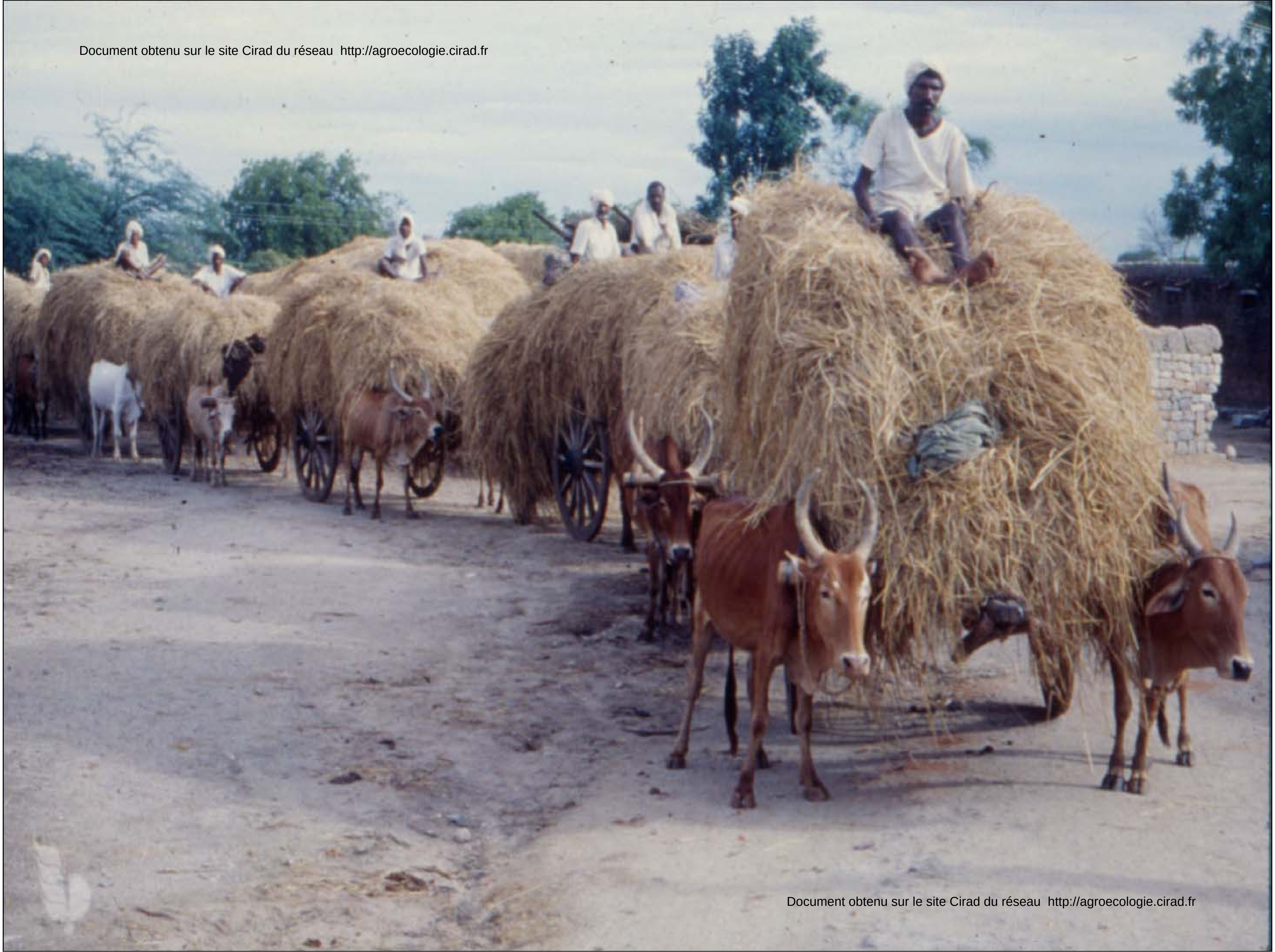

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Strategic Questions

- Should crop residues be used for carbon sequestration and soil quality improvement or producing energy?
- Should the answer to this question be determined by short-term economics or the long-term sustainability of natural resources?
- Should the need for fuel override the urgency to achieve global food security?

Soil Degradation in Developing Countries (Oldeman, 1994)

Degradative Process	Developing/ Tropical Countries	World
	- - - - - - - - 10^6 - - - - - - -	
Water erosion	837 (77%)	1094
Wind erosion	455 (83%)	548
Chemical degradation	213 (89%)	240
Physical degradation	44 (53%)	83

Collapse by Diamond, 2004

Soil Erosion in the Tropics

Region	Water erosion	Wind erosion	Physical degradation
	------------------------Mha	-----------------	
Africa	81	7	15
Asia	36	8	6
S. America	10	--	6
C. America	23	1	5
Oceania	?	?	1
Total	150	16	33

Oldeman (1994); Lal (2002)

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Competing Uses of Crop Residues

- Feed
- Fuel
- Fiber
- Construction material

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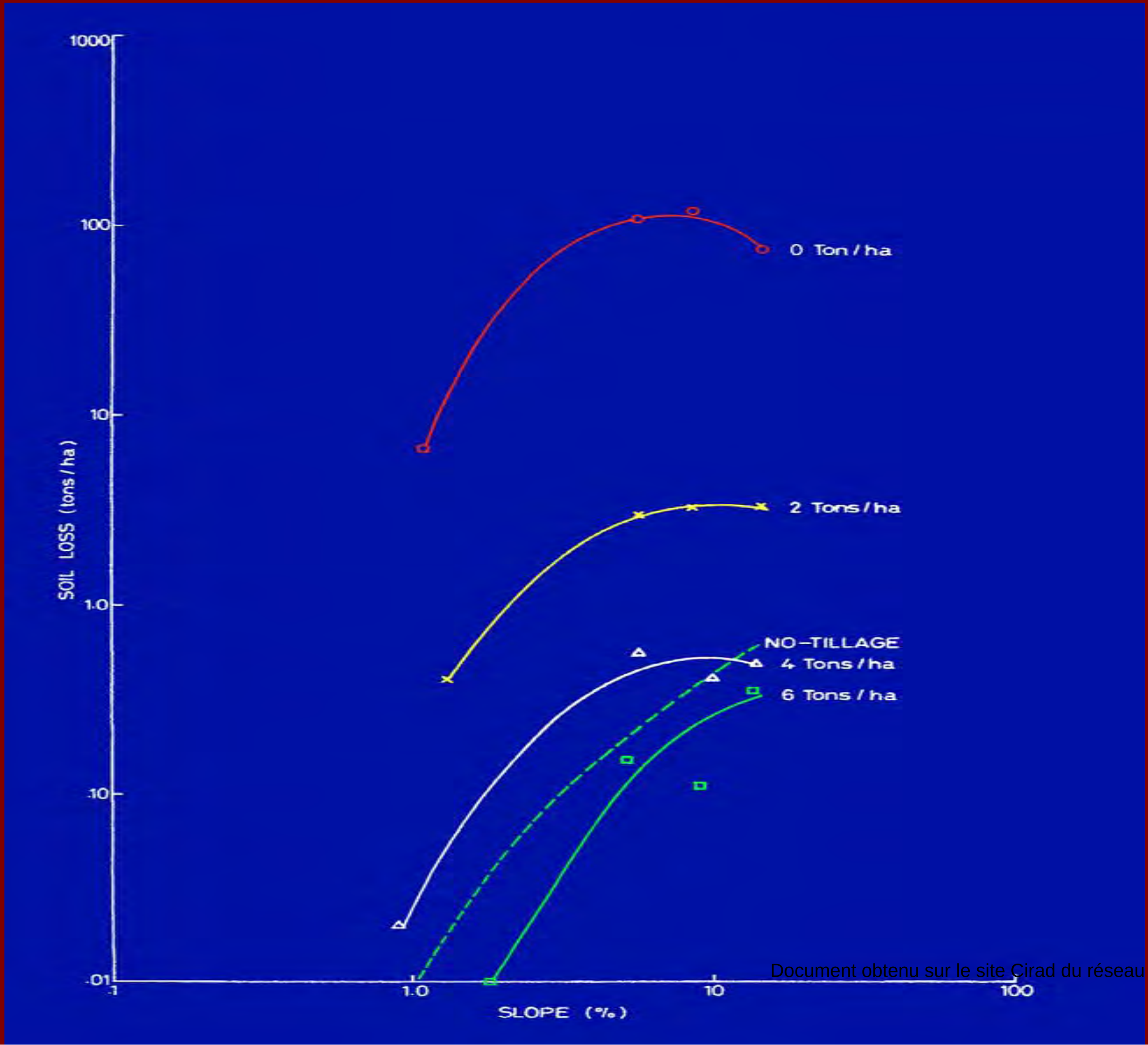
Estimates of Traditional Biofuel Use in India and Asia in 1995

Country/ Region	Fuel wood	Cattle Dung	Crop Residue	Total Range	Total Average
			$Tg\ C\ yr^{-1}$		
India	109 - 409	35 - 108	20 - 67	164 - 584	374
Asia	800 - 930	130 - 200	430 - 565	1360 - 1675	1018
World	1324 - 1615	150 - 410	442 - 707	1916 - 2732	2324

Mulch Rate and Soil Erosion in Nigeria (Lal, 1976)



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Slope-Soil Loss Relations for Different Mulch Rates (Lal, 1976)

Mulch Rate	r	Equation	Average (Mg/ha)	Relative Loss
0	0.81	$Y = 11.8\ S^{1.13}$	76.60	851
2	0.35	$Y = 0.5\ S^{0.87}$	2.40	27
4	0.57	$Y = 0.07\ S^{1.05}$	0.37	4
6	0.46	$Y = 0.01\ S^{1.0}$	0.09	1
No-till	0.36	$Y = 0.01\ S^{0.5}$	0.09	1

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Nutrients (NPK) Contained in Residues Produced by Different Crops Grown in Association with Rice (Singh et al., 2005)

Crop	Asia	Africa+S.A.	World
	-------------------10^6 Mg/yr----------------		
Rice	10.3	0.8	11.4
Wheat	4.5	0.7	14.2
Barley	0.5	0.1	4.1
Sugarcane	0.6	0.6	1.4
Cotton	0.1	0.01	0.2
Oats	0.1	0.05	1.3
Corn	2.2	2.0	13.2
Total	18.3	4.3	45.8

Economics of Residue Removal for Biofuel

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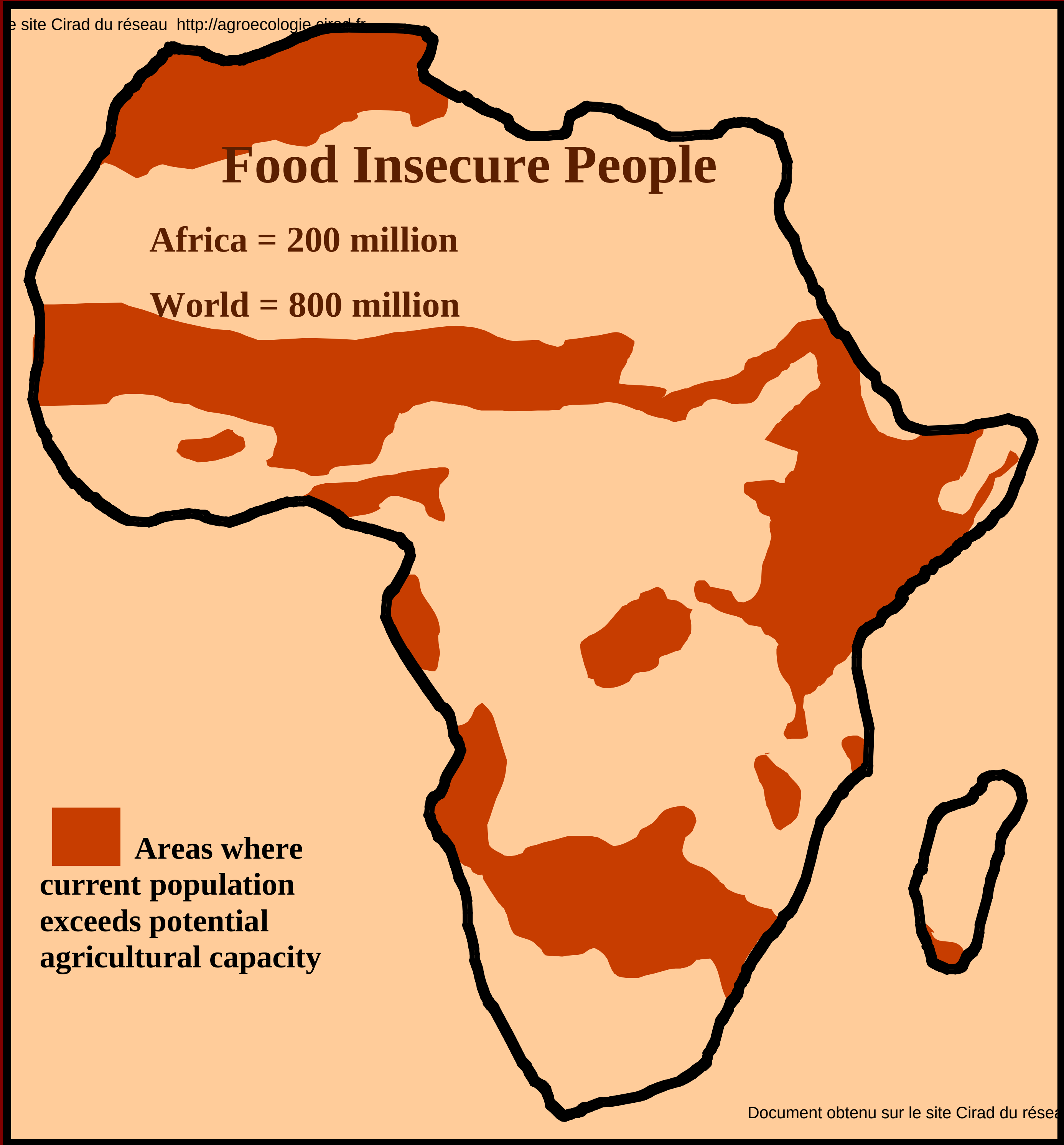
Food Insecure People
Africa = 200 million
World = 800 million
Areas where current population exceeds potential agricultural capacity

Food Gap by Region (Shapouri, 2005)

Region	Food Gap	
	2000	2010
	- - - 10^6Mg/yr - - -	
Sub-Saharan Africa	10.7	17.5
Latin America	0.6	1.0
Asia	1.7	3.6
Others	0.2	0.2
Total (67 Countries)	13.2	22.3

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Soil Degradation

It is a biophysical process fueled by socioeconomic and political forces.

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Symptoms of the Problem

- Recurring drought
- Accelerating desertification
- Perpetual food deficit
- Agrarian stagnation, and
- Political instability

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A Truism

When people are poverty-stricken and starving, they pass on their suffering to the soil.

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Degradation of Soil and Environments is Traced to

- **Human greed**
- **Short sightedness**
- **Poor planning, and**
- **Cutting corners for quick economic returns**

And impacts global food security.

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Global Cereals Production

1995-96: 1.9 billion Mg

2020 need: 3.0 billion Mg

Can we achieve that?

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Global Agricultural Intensification

Cereal yield increase to maintain status quo:

1992: 2790 Kg/ha

1995: 2960 Kg/ha

2020: 3950 Kg/ha

2025: 4210 Kg/ha

World Yield of Cereals (Mg/ha)

- **World average yield: 2.7**
- **Highest yield (Holland): 8.8**
- **Lowest yield (Botswana): 0.35**

………..FAO (1997)

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Expansion of Cropland Area

Agricultural land area could by 2050:

1. **Double in SSA and West Asia.**
2. **Increase by 25% in Asia-Pacific region.**
3. **20% of TRF may become cropland.**

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Future Challenges

How are the developing countries (e.g., India and SSA) going to feed themselves without inflicting further damage on an environment that is already under great stress?

The answer lies in selective agricultural intensification.

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Per Capita Land Area Needed

Farming system/input level	Ha/person
Shifting cultivation	2.65
Low traditional	1.20
Moderate traditional	0.60
Improved traditional	0.17
Moderate technological	0.11
High technological	0.08
Special technological	0.05

Adapted from Buringh (1989)

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Agricultural Intensification

Cultivating the best soils with the best management practices to produce the optimum sustainable yield and save marginal lands for nature conservancy.

Soil Management

- It is not possible to take more out of a soil than what is put in it without degrading its quality.
- In addition to the amount taken out, sustainable use also depends on the rate, timing, method and form of what is extracted.

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A Truism

An ecosystem utilized by human societies are only sustainable in the long term if the outputs of all components produced balance the inputs into the system.

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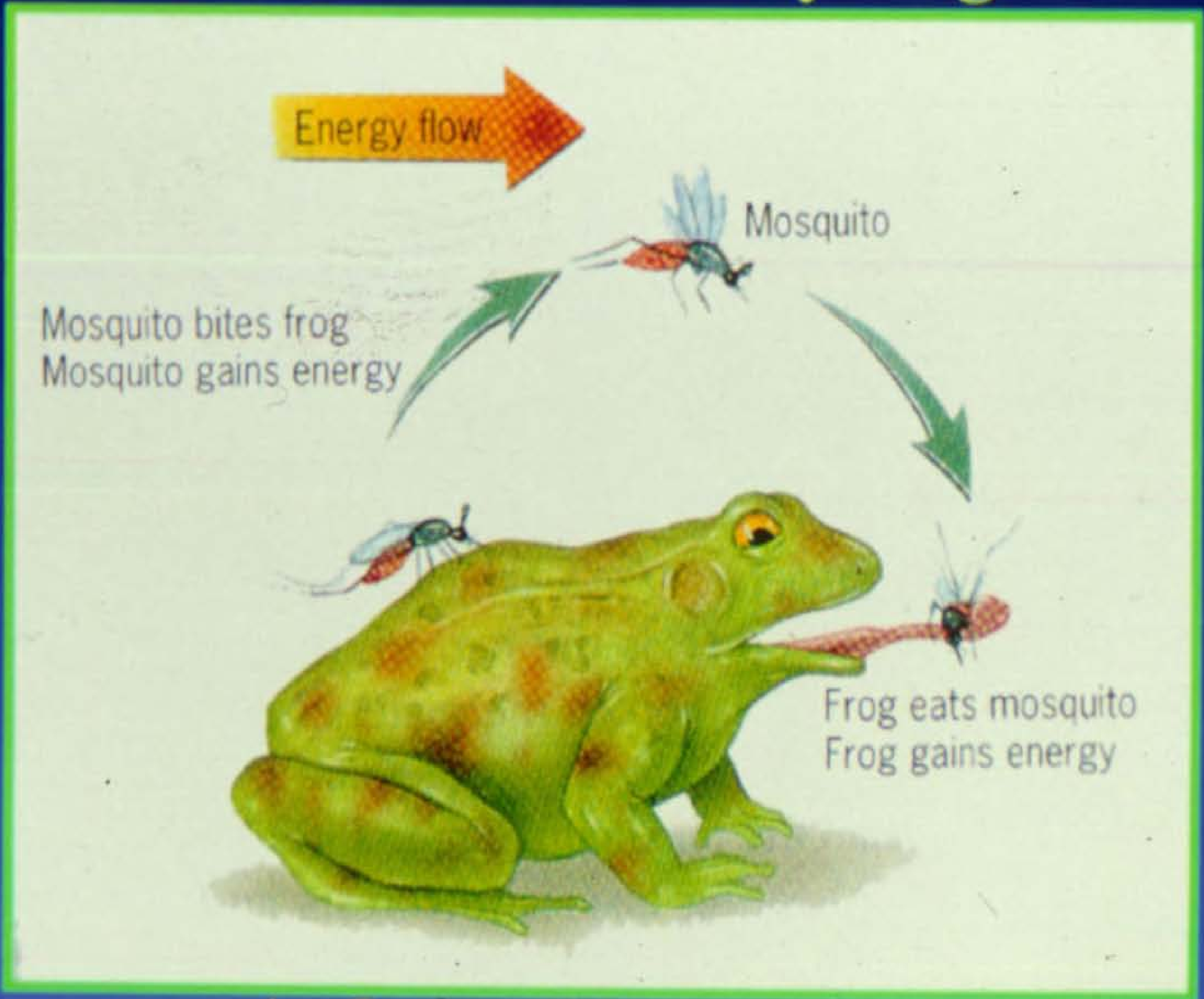
The Ultimate Recycling



An Impossible Ecosystem

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Organic vs. Inorganic Fertilizers

Plants cannot differentiate the nutrients supplied through the organic or inorganic sources. The question is of nutrient availability in sufficient quantity, form and at time needed for optimum growth and yield. Despite the bulk required, use of organic fertilizers can enhance soil quality.

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Soil Quality in the Context of 21st Century

It refers to soil's capacity to:

1. **Maximize long-term productivity per unit input of non-renewable resources.**
2. **Minimize risks of environmental (water, air) pollution.**
3. **Moderate fluctuations in components of the water and energy budget due to change in land use and land cover, and**
4. **Proxy interpretations of past, and predict future global climate changes.**

Issues of Soil Quality in Developed and Developing Countries

Developed countries	Developing countries
1. Optimizing crop yields per unit input 2. Minimizing input of chemicals and energy 3. Maximizing farm profit 4. Reducing risks of pollution/ eutrophication of surface and ground waters 5. Sustaining productivity on a long-term basis 6. Addressing issues of regional, national and global importance (e.g., global climate change)	1. Maximizing crop yields per unit area, time 2. Optimizing the use of off-farm input 3. Increasing household income 4. Ensuring adequate supply of water for human and animal consumption 5. Providing food for the family before the next harvest 6. Addressing concerns of the family

Global Issues of Soil Quality

1. Food security,
2. Availability of high quality water,
3. Waste disposal,
4. Urbanization and industrialization,
5. Air quality, and concentration of GHGs.

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Mining C

Mining C has the same effect on global warming whether it is through:

1. Burning coal
2. Using natural gas
3. Consuming petrol based products
4. Decomposing soil organic matter, or
5. Removing or burning biomass on land.

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Soil Carbon Sequestration to Mitigate Climate Change

World cropland soils……	0.4-0.8 Pg C/y
Desertification control…..	0.2-0.4 Pg C/y
Total	0.6-1.2 Pg C/y

It is a truly win-win situation

…..Lal (2003)

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Sustainability Indices

$$I_s = \left(\frac{C_o}{C_I} \right)_t$$

$$I_s = \left[\frac{C_o - C_I}{C_I} \right]_t$$

$$I_s = \left[\frac{C_o - C_I - C_{OR}}{C_I - C_{IR}} \right]_t$$

I_S=Index of sustainability
C_O=Sum of all output expressed in CE
C_I=Sum of all input expressed in CE
C_{OR}=Output in the reference treatment
C_{IR}=Input in the reference treatment
t=time

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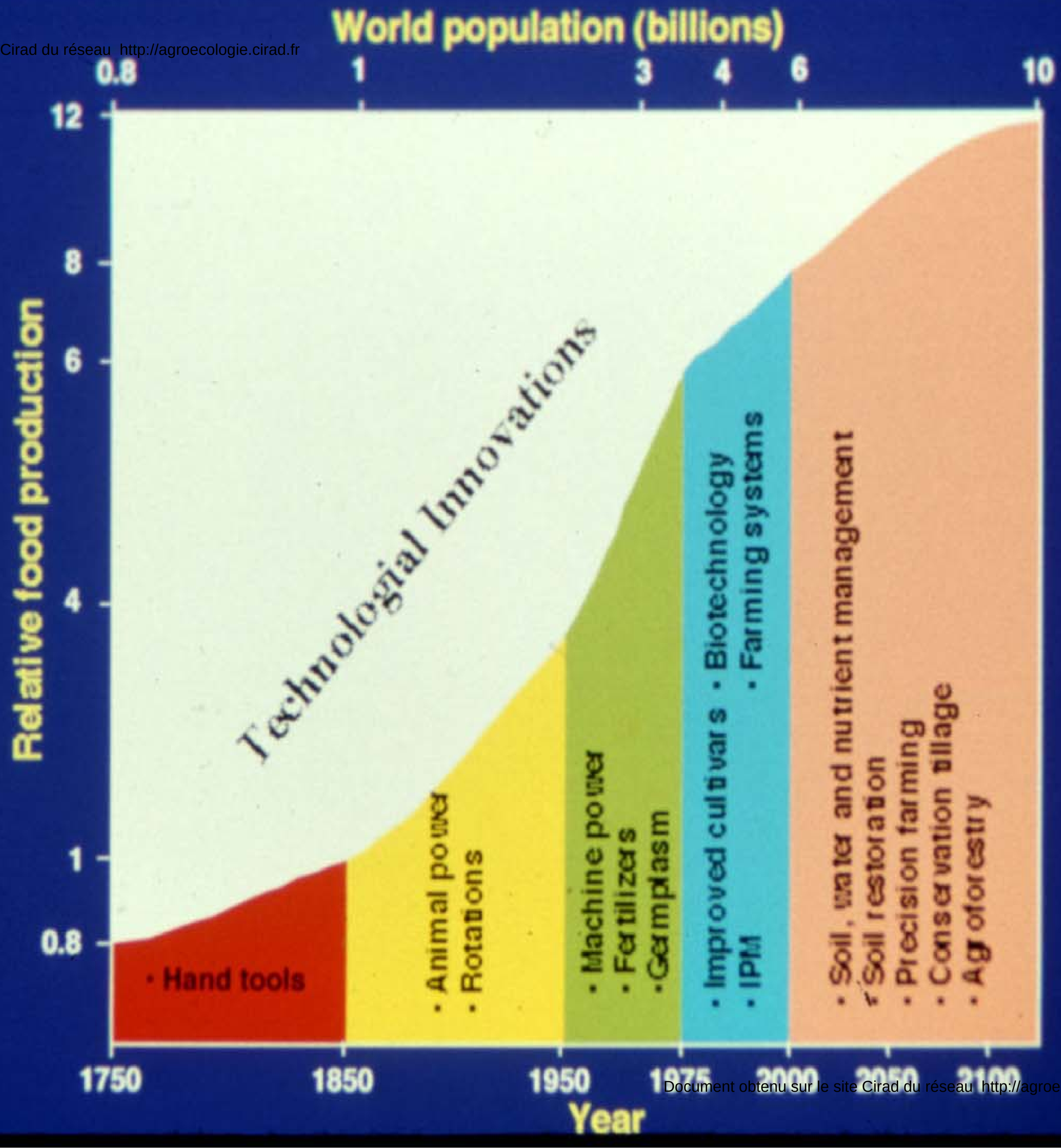

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Basic Human Right

Ending global hunger and malnutrition requires international acceptance of *food as a basic human right.*

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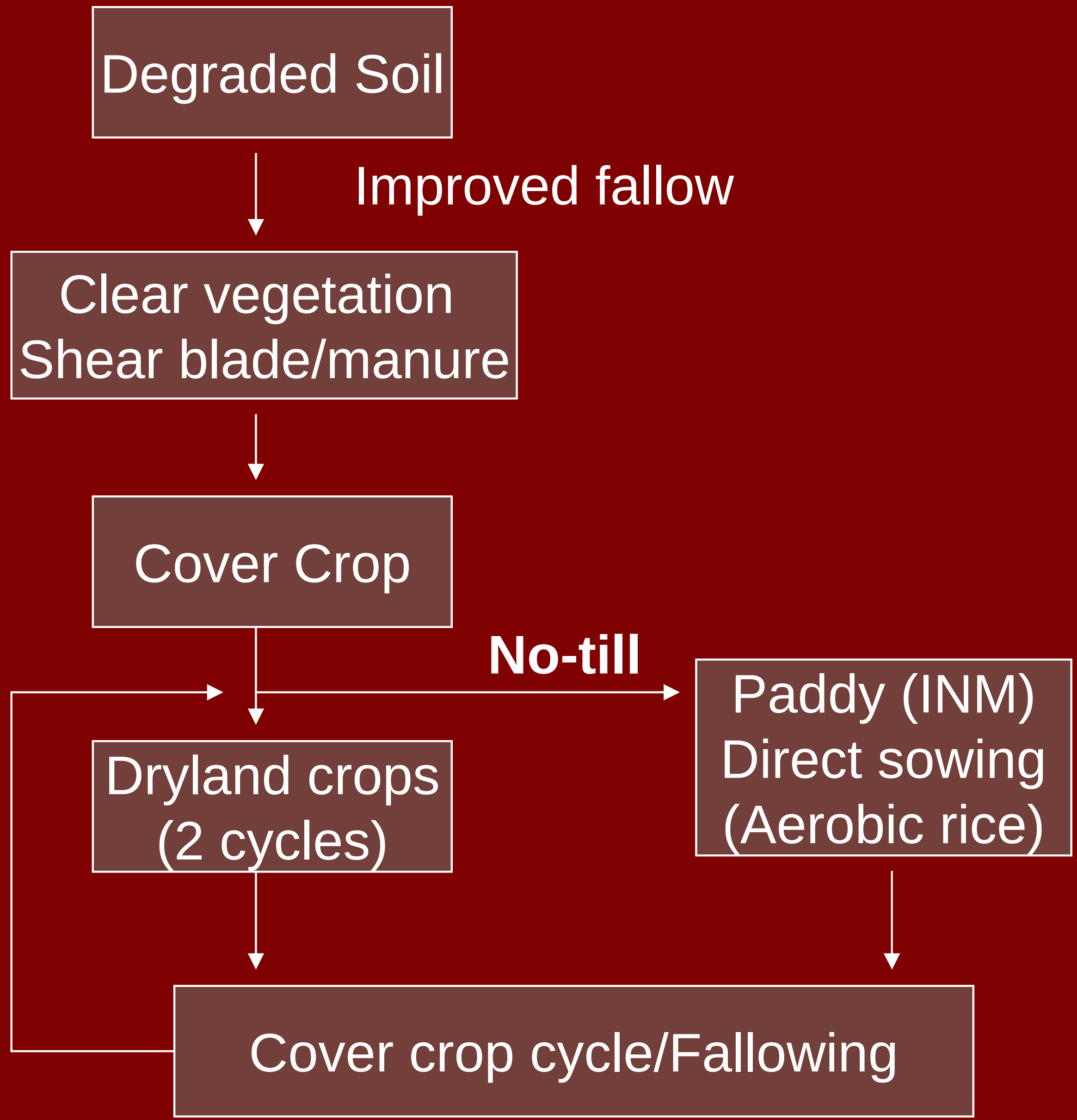
Estimates of Increase in Food Production in LDCs by Increasing SOC Pool by 1 Mg C ha^{-1} yr^{-1}

Crop	Area (Mha)	Production Increase (10^6 Mg yr^{-1})
Cereals	430	21.8 - 36.3
Legumes	68	2.0 - 3.2
Tubers	34	6.6 - 11.3
Total	532	30.4 - 50.8

Agricultural Intensification

Delivering nutrients and water directly to roots of improved plants

An Alternative to Slash and Burn



Modern Science and Tropical Agriculture

- Nanotechnology: Nanofertilizers, nanosensors
- Biotechnology: BT, roundup ready corn
- Digital Highway: Decision support system

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Biofuels

- Energy plantations (SRWP, WSG etc)
- Halophytes
- Algae
- Cyanobacteria

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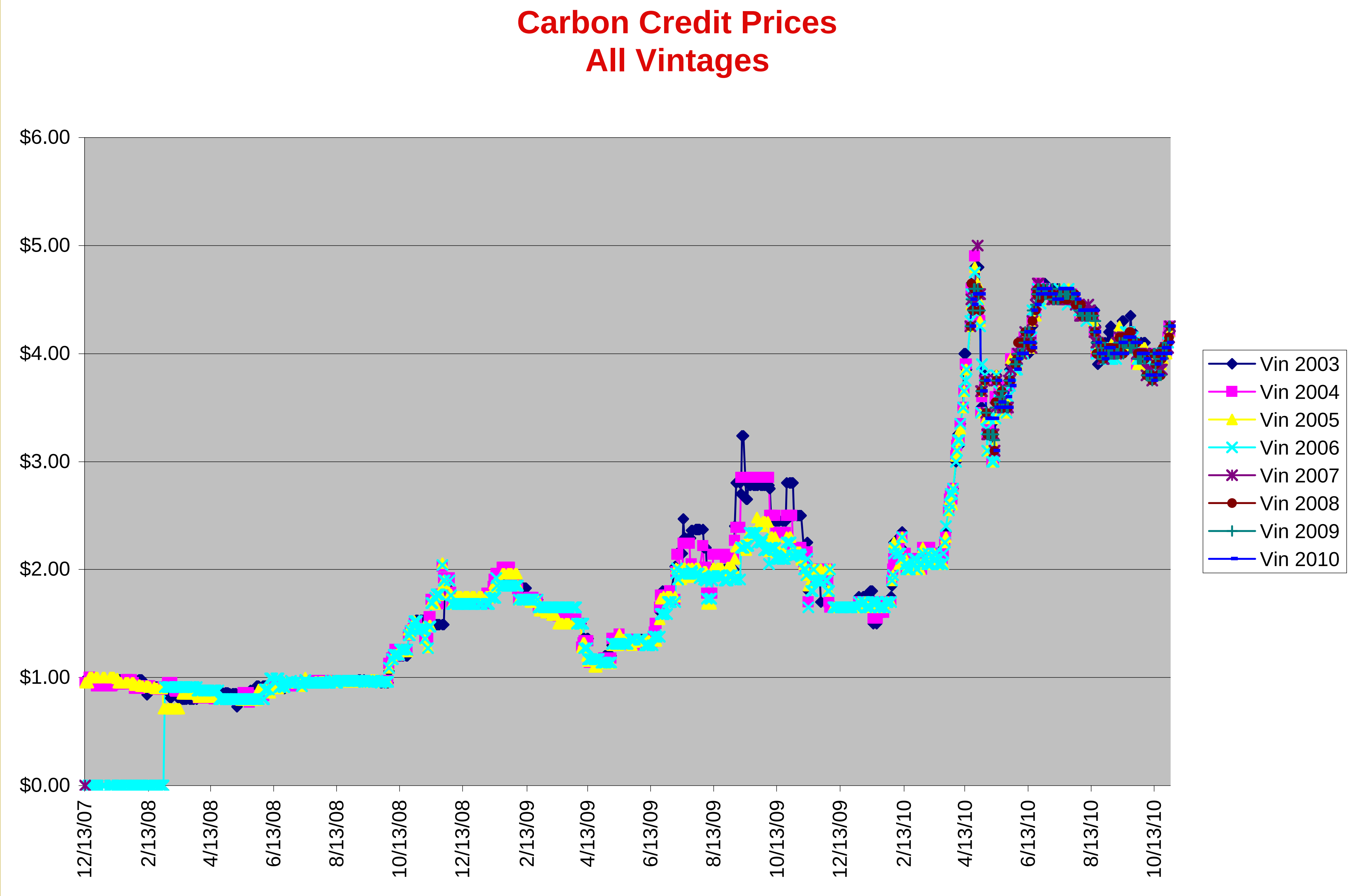

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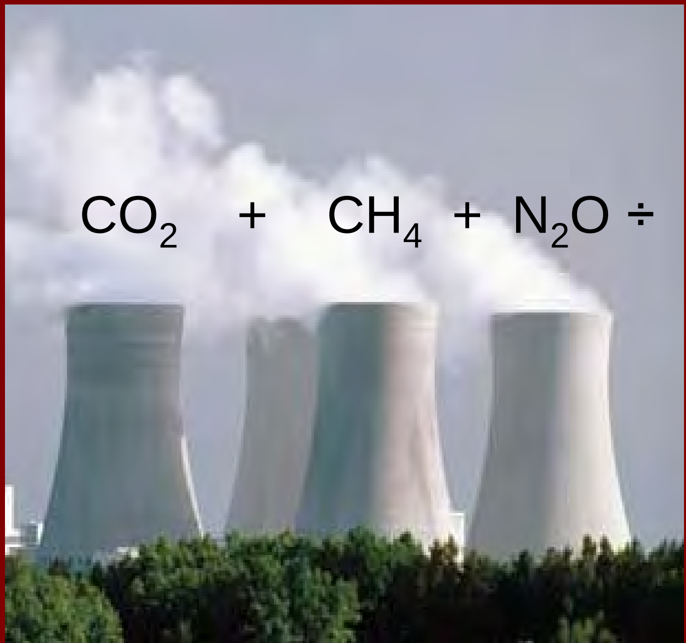
(CCX, Miller, 2006)

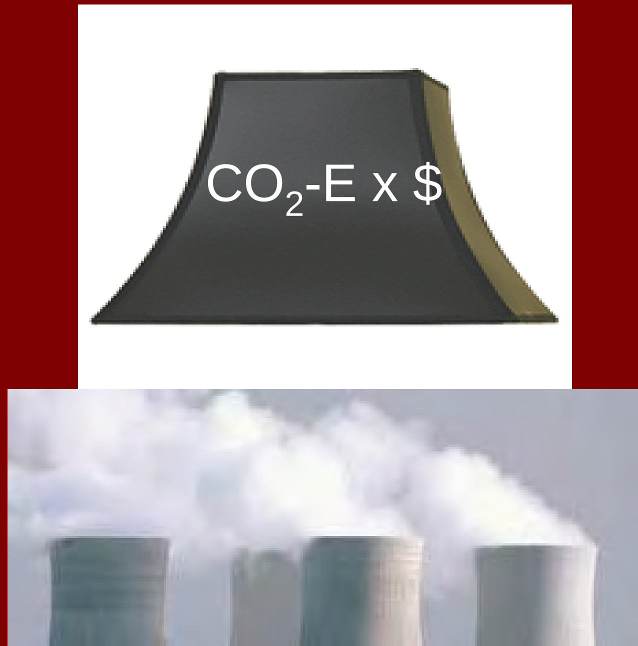
Carbon Ranching and Carbon Farming

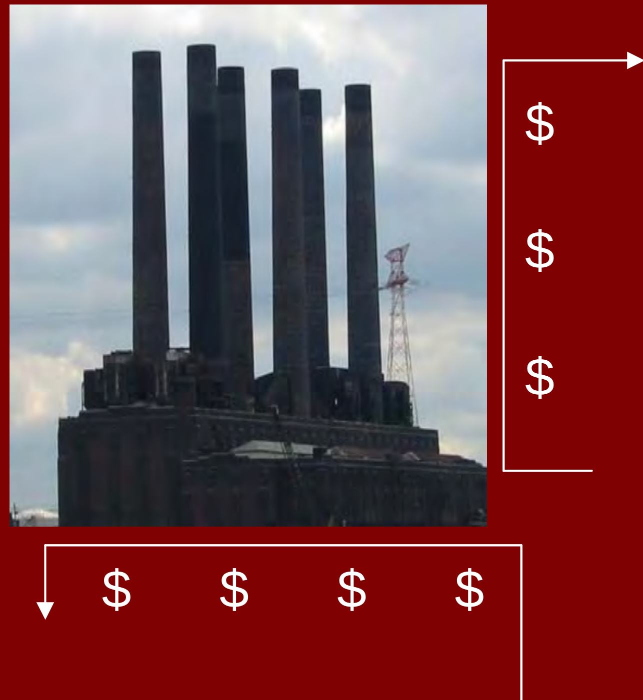
Carbon Ranching/Farming

- Industry offsets CO_2 emissions by paying developing countries (e.g., Madagascar) to preserve their forests.
- One ha of tropical forest converted to ranchland on crops is worth \$200-\$500. This is nothing compared to the value of preserving the rainforest as a sponge for CO_2.
- In European Exchange, 1 Mg of CO_2 = \$20. However, each ha of forest stores about 500 Mg of CO_2 worth \$10,000.
- Thus, deforestation for ranch/cropland means destroying \$10,000 worth of property to secure CO_2 and convert it into \$200 worth of ranch/cropland.

The Cost of Going Green







Step 1: Add total greenhouse-gas emission, compute CO_2 equivalent, then divide by annual revenue In millions of dollars. Result: total carbon intensity, or the amount of emissions per $1 million in revenue.

Step 2: Multiply total emissions by the current price of carbon offsets-$32 per metric ton on the European market. This yields the carbon footprint in terms of the total cost of offsetting emissions.

Step 3: Determine the price of reducing carbon as a percentage of the company's revenue. If the cost is too high, the business may face risks should carbon-cap legislation be passed.

…..Modified from (Walsh, 2007)

Sustainable Management of Soils

Use of crop residues as soil amendment is essential so that:

- soil quality is progressively restored rather than diminished,
- soil organic carbon pool is enriched rather than depleted,
- susceptibility to erosion and other degradation processes is reduced rather than exacerbated, and
- agronomic/biomass productivity per unit input and time is increased rather than reduced or plateaued.

Ten Options of Sustainable Management of Soils

1. Retain crop residue as mulch.
2. Adopt no-till farming.
3. Include leguminous cover crops in the rotation cycle.
4. Maintain a positive nutrient balance INM (e.g., manure, compost).
5. Use precision farming/site specific management.

Ten Options (continued)

6. Conserve water through sub/drip irrigation and water harvesting.
7. Restore marginal/degraded/desertified soils.
8. Grow improved/GM plants along with agroforestry measures.
9. Integrate principles of watershed management.
10. Restore wetlands.

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Ultimate Goal of Soil Management

The strategy is to:

- **Adopting RMPs where extractive farming practices are widely used.**
- **Enhancing SOC pool through use of residue mulch and manures where soil has been traditionally mined for millennia.**
- **Using INM (Manure, biosolids BNF, fertilizers) to achieve positive nutrient balances, where negative balances have occurred, and**
- **Making agriculture and soil a solution rather than cause of the environmental problem.**

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Restoration of SOC Pool

- Irrespective of the climate debate, the SOC pool must be enhanced.
- Feeding a population of 6.5 billion in 2006, 7 billion in 2020, 8 billion by 2025, and 20 billion by 2050 or beyond makes it essential that soil quality is restored/enhanced.
- With 850 million people in the world food insecure, U.N. Millennium goals in jeopardy, crop residues must be used to restore soil quality.

Four Laws of Ecology

1. Everything is connected to everything else.
2. Everything must go somewhere.
3. Nature knows best.
4. There is no such thing as a free lunch.

. . . Barry Commoner (1971)

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