SOIL CARBON SEQUESTRATION FOR ADVANCING FOOD SECURITY AND OFF-SETTING CO_2 EMISSIONS

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WORLD POPULATION GROWTH

Year	Population (Billions)	Growth Rate (%/y)
1650	0.550	-
1750	0.725	0.276
1850	1.175	0.483
1900	1.60	0.617
1930	2.00	0.744
1950	2.56	1.23
195	4.00	1.78
1980	4.48	2.27
1986	5.00	1.83
1990	5.33	1.60
1995	5.68	1.27
2000	6.13	1.52
2025	8.18	1.15

(Bartlett, 2004)

WORLD IRRIGATED LAND AREA

Year	Area Irrigated	% of Cropland
1950	97	8.6
1960	135	11.3
1972	176	13.1
1990	244	16.1
2000	275	17.9
2003	277	18.0
2020	300	-
2050	359	-

THE HABER-BOSCH PROCESS

$$3\,CH_4 + 6H_2O \rightarrow 3\,CO_2\uparrow + 12\,H_2$$

$$12\,H_2 + 4\,N_2 \rightarrow 8\,NH_3$$

GLOBAL FERTILIZER USE

(IFDC, 2004; Tilman et al., 2001)

Year	Area (10^6 Mg/yr)			
	N	P	K	Total
1950	<10	-	-	<10
1960	11.6	10.9	8.7	31.2
1970	31.8	21.1	16.4	73.3
1980	60.8	31.7	24.2	116.7
1990	77.2	36.3	4.5	138.0
2000	80.9	32.5	21.8	135.2
2020	135.0	47.6	-	
2050	236.0	83.7	-	

TRENDS IN GLOBAL MEAN YIELDS OF CROPS

(Clay, 2004; FAO, 2008)

Crops	Mean Yield (mg/ha)						% Increase (1961-2007)	
	1961	1970	1980	1990	2000	2007	Total	Per Year
Corn	1.9	2.4	3.2	3.7	4.3	4.9	158	3.4
Rice	1.9	2.4	2.8	3.5	3.9	4.2	121	2.6
Sorghum	0.9	1.1	1.2	1.4	1.4	1.5	67	1.5
Soybean	1.1	1.5	1.6	1.9	2.2	2.3	109	2.3
Sugarcane	50	55	55	62	64	71	42	0.9
Wheat	1.1	1.5	1.9	2.6	2.7	2.8	155	3.4

WORLD CEREAL PRODUCTION IN 1998 (WILD, 2003)

Parameter	World	Developing Countries
Production (10^6 Mg)	2081	1223
Area (10^6 Ha)	693	465
Yield (Mg ha^{-1})	3.01	2.64

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AREA OF CEREAL CULTIVATION REQUIRED IN DEVELOPING COUNTRIES BY 2025 AND 2050

Year	Required area	New area
	-----------------10^6 ha-------------	
2025	757	290
2050	1032	565

The area in 2000 in developing countries was 457 Mha (Wild, 2003).

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AVERAGE YIELD OF CEREALS REQUIRED IN DEVELOPING COUNTRIES BY 2025 AND 2050

Year	Required yield (Mg/ha)
2025	4.4
2050	6.0

Grain yield in 2000 in developing countries was 2.64 Mg/ha (Wild, 2003).

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IMPROVING PRODUCTIVITY OF RAINFED AGRICULTURE

Average grain yield in 2000 = 2.7 t/ha

Required grain yield in 2050 = 4.5 t/ha
(+ 1 %/yr)

(i)Increase in cropland area of 7% with improvement in rainfed agriculture

(ii)Increase in cropland are of 53% with no improvement in rainfed agriculture

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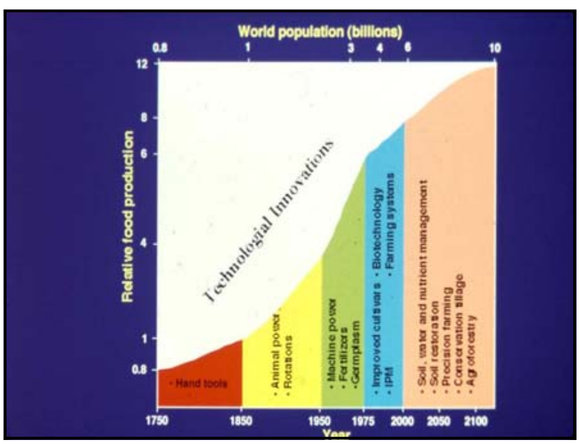

Agricultural Intensification

Delivering nutrients of improved and water directly to roots plants

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INCREASE IN CROP YIELDS

Parameter	% Increase 1960-2000	% Increase 2000-2030
1. Yield Improvement (genetic/agronomic)	78	70
2. Expansion in Cropland Area	15	20
3. Increase in Cropping Intensity	7	10

Vergé et al. (2007)

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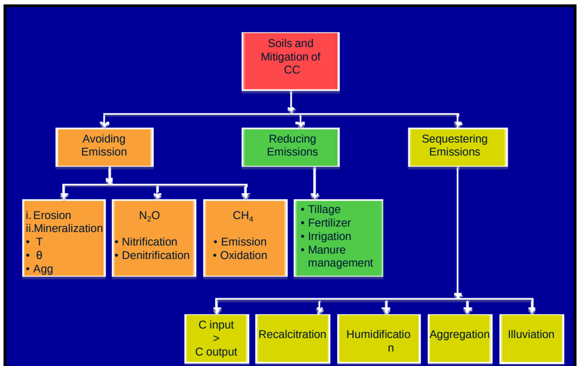
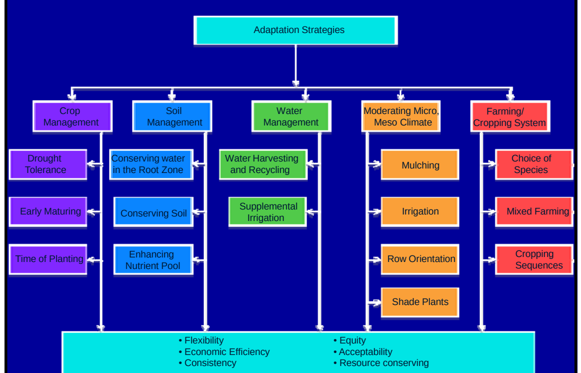
THE CONTEMPORARY GLOBAL CARBON BUDGET

(IPCC, 2007a; Houghton, 2001; Falkowski et al., 2000; Canadell et al., 2007)

	Parameter	Flux (Gt C/y) 1980s	1990s	2000s
I.	Sources			
	1. Fossil fuel combustion	5.4	6.4	7.5
	2. Land use conversion	1.4	1.6	1.6
	Total	6.8	7.8	9.1
II.	Sinks			
	1. Atmosphere	3.3	3.2	4.0
	2. Ocean	1.8	2.2	2.3
	3. Land	0.3	1.0	0.9
	Total	5.4	6.4	7.2
III.	Unknown land sink	1.4	1.4	1.9
	Natural Sink (% of total source	51.4	58.9	56.0



AGRICULTURAL STRATEGIES FOR ADAPTATION TO ABRUPT CLIMATE CHANGE



CAPACITY OF TERRESTRIAL CARBON SINK

- Historic Loss from Terrestrial Biosphere = 456 Gt with 4 Gt of C emission = 1 ppm of CO_2
- The Potential Sink of Terrestrial Biospheres = 114 ppm
- Assuming that up to 50% can be resequestered = 45 – 55 ppm
- Cropland Soils: 1 Gt/yr
- Rangeland Soils: 1 Gt/yr
- Restoration of Degraded/Desertified: 1 Gt/yr
- Drawdown: 50 ppm of CO_2 over 50 years

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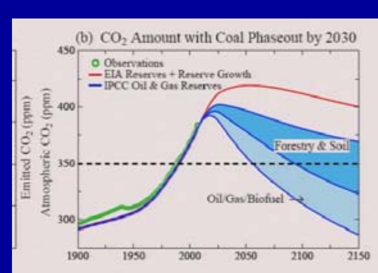
POTENTIAL OF MITIGATING ATMOSPHERIC CO_2



(Hansen, 2008)

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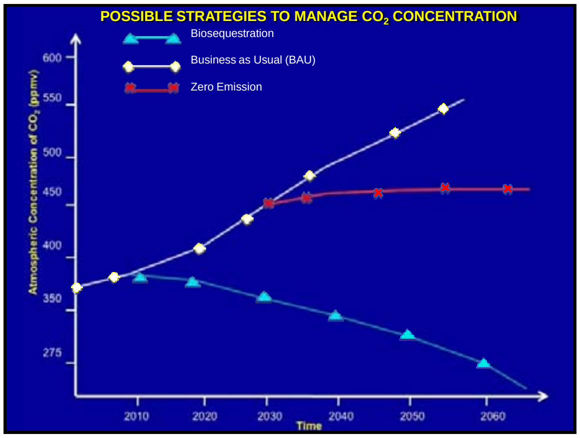

Newsweek 2009

SOIL C AS AN INDICATOR OF CLIMATE CHANGE

There are numerous advantages:

1. It is a familiar property,
2. It involves direct measurement,
3. It can be measured in 4 dimensions (length, width, depth, time),
4. It lends itself to repeated measurements over the same site,

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SOIL C AS AN INDICATOR OF CLIMATE CHANGE (CONTD.)

5. It is linked to ecosystem performance and services,
6. It is a key driver of soil formation,
7. It is important to soil fertility,
8. It has memory,
9. It has well defined properties,

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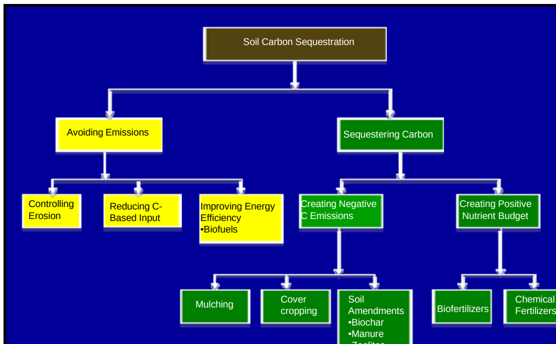
SOIL C AS AN INDICATOR OF CLIMATE CHANGE (Contd.)

10. It can be used in synergism with other indicators,
11. Its uncertainty can be quantified,
12. Its pathways across the landscape can be followed,
13. It is an important archive of paleo-environmental conditions.



STRATEGIES OF SOIL CARBON SEQUESTRATION

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CARBON SEQUESTRATION IN SOILS AND TERRESTRIAL ECOSYSTEMS

C Sequestration	=	$C_{input} > C_{output}$
C Depletion	=	$C_{input} < C_{output}$
C_{output}	=	Erosion, Decomposition, leaching, Harvest
C_{input}	=	Residues, Mulch, Compost, Amendment, Deposition

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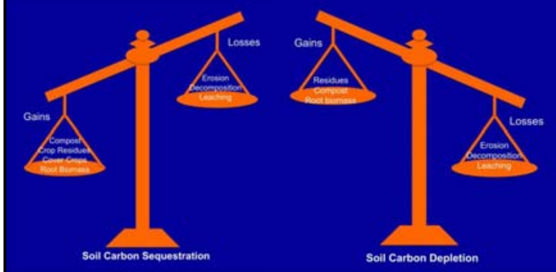
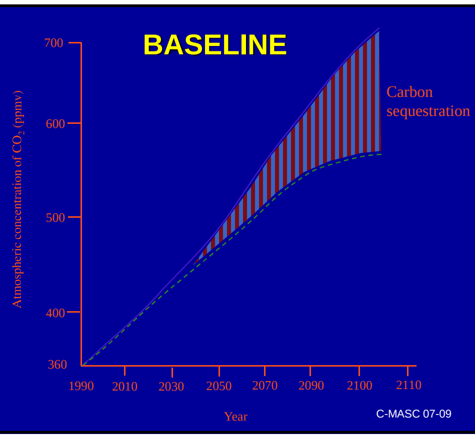
CREATING POSITIVE C BUDGET





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Workers in India's fertile Punjab pull an overstuffed load of rice stalks to a farm where they will be used as animal feed. High-yielding varieties, along with subsidized fertilizer and irrigation, have helped India stave off famine for decades. (National Geographic, June 2009)

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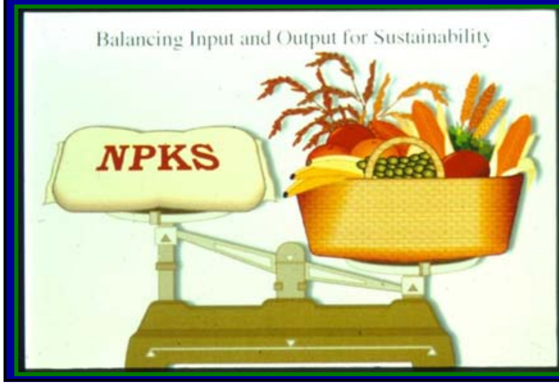
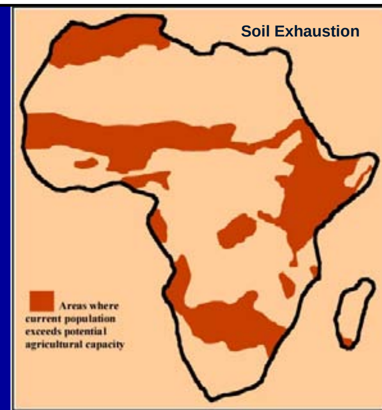
Asian brown cloud caused by traditional biofuels.

Source: NYT 4-16-09

CREATING POSITIVE NUTRIENT BUDGET





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STRATEGIES OF CARBONIZATION OF THE TERRESTRIAL BIOSPHERE

1. **Restore forest and savannahs**
2. **Control soil erosion**
3. **Reclaim degraded soils**
4. **Inundate/restore peat soils**
5. **Adopt RMPs on agricultural soils**

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NO-TILL EFFECTS ON SOIL C

NT Management:

(i) Increase C-rich macro-aggregates

(ii) Reduce rate of macro-aggregate turnover

(iii) Enhances formation of highly stable micro-aggregates within macro-aggregate

Therefore, NT stabilizes and sequesters C over long time.

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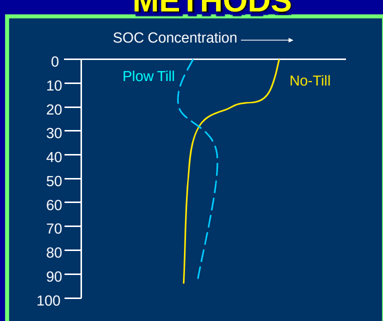
SOIL C PROFILE AND TILLAGE METHODS



CARBON FOOT PRINT OF CONVENTIONAL TILL AND NO-TILL CORN

Parameter	Kg CE/ha Conventional Till	Kg CE/ha No Till
1. Input	803	786
2. Output	6431	6688
3. Soil erosion	-60	0
4. C Sequestration	-500	500
5. Net C output	5871	7188
6. C Output : Input	7·3	9·1

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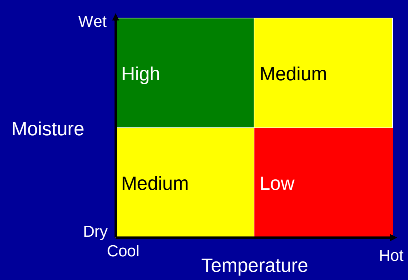
CARBON SEQUESTRATION IN RELATION TO CLIMATE



TECHNOLOGICAL NITCHES

Technology	Temperate			Tropics			Highlands		
	Humid	Sub-Humid	Arid	Humid	Sub-Humid	Arid	Humid	Sub-Humid	Arid
No-Till									
Cover Cropping									
Manuring									
Biochar									
Agroforestry									
Irrigation									
INM									
Improved Pasture									

SOIL GUIDE FOR C SEQUESTRATION

Technology	Clay		Silt		Sandy Loam	
	Poorly Drained	Well Drained	Erodible	Non-Erodible	Erodible	Droughty
No-Till						
Cover Cropping						
Manuring						
Biochar						
Agroforestry						
Irrigation						
INM						
Improved Pasture						

RATE OF SOC SEQUESTRATION

Depends on many factors:

1. **Baseline or reference point.**
2. **Clay content and type.**
3. **Antecedent SOC pool.**
4. **Residue management.**
5. **Internal drainage.**
6. **Soil wetness.**

ECONOMIC SERVICES

These are public goods which provide benefits to a large group of people.

- **Local Benefits: Water quantity and quality**
- **Global Benefits: C Sequestration**

SR 401 (JUNE 2008)

Soil science is important to the sustainable management of nation's natural resources.

HOUSE RESOLUTION 2998 (JUNE 2009)

(7) Biological Sequestration:

The "biological sequestration" and "biologically sequestered" mean the removal of greenhouse gases from the atmosphere by terrestrial biological means, such as growing plants, and the storage of these greenhouse gases in plants or soils".

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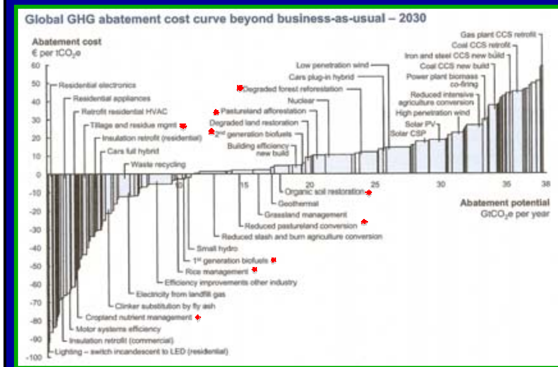
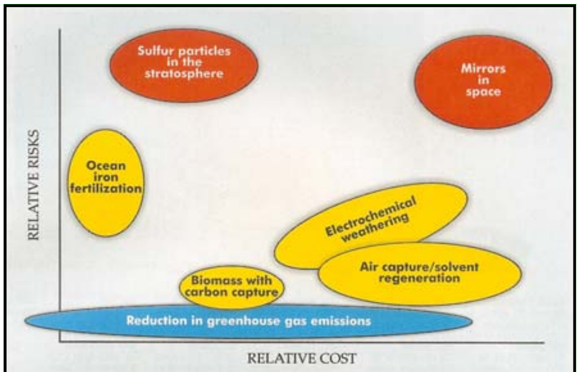
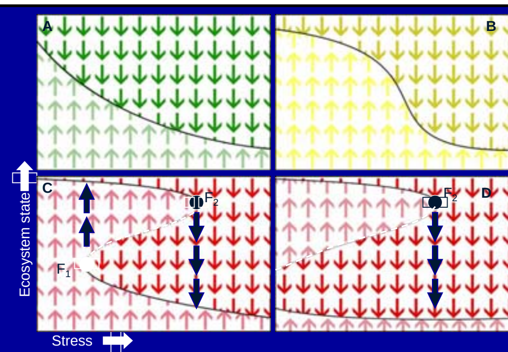


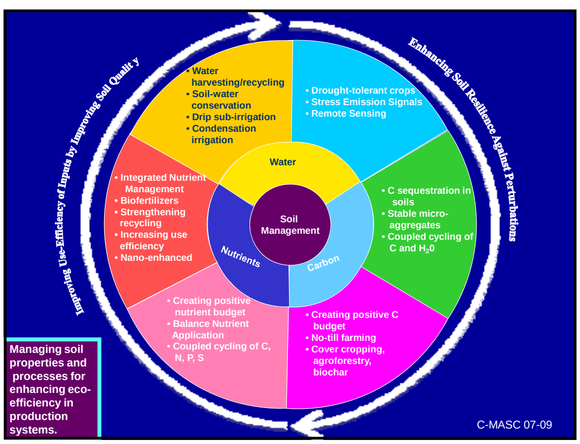
(McKinsey & Co., 2009)

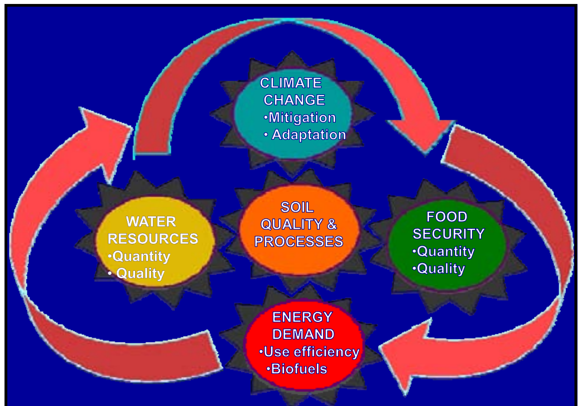


Relative costs and risks of various geoengineering schemes. (Figure courtesy of Kurt House, Harvard University.)



Schematic representation of four possible responses of ecosystems to stress imposed by human use. The lines represent equilibrium states. The arrows indicate the direction of change when the system is out of equilibrium.





PRODUCTIVITY INCREASE BETWEEN 1900 AND 2000 (PONTING, 2007)

Parameter	Increase Factor Between 1900-2000
Population	3.8
Urban Population	12.8
Industrial output	35
Energy Use	12.5
Oil Production	300
Water Use	9
Irrigated Area	6.8
Fertilizer Use	342
Fish Catch	65
Organic Chemicals	1000
Car Ownership	7750

PLUNDERING MOTHER NATURE

There are in nature no rewards, or punishments.

Just consequences.

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LAW #1 CAUSES OF SOIL DEGRADATION

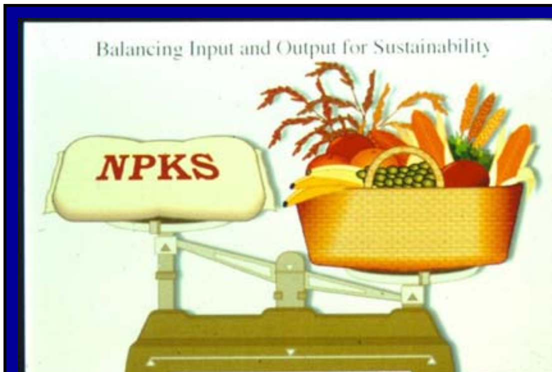
- The biophysical process of soil degradation is driven by economic, social and political forces.
- Vulnerability to degradation depends on "how" rather than "what" is grown.

LAW #2 SOIL STEWARDSHIP AND HUMAN SUFFERING

- When people are poverty stricken, desperate and starving, they pass on their sufferings to the land.

Law #3 NUTRIENT, CARBON AND WATER BANK

- It is not possible to take more out of a soil than what is put in it without degrading its quality.
- Only by replacing what is taken can a soil be kept fertile, productive, and responsive to inputs.



LAW #4

MARGINALITY PRINCIPLE

- Marginal soils cultivated with marginal inputs produce marginal yields and support marginal living.
- Recycling is a good strategy especially when there is something to recycle.

THE ULTIMATE RECYCLING

AN IMPOSSIBLE ECOSYSTEM

LAW #5

ORGANIC VERSUS INORGANIC SOURCE OF NUTRIENTS

- Plants cannot differentiate the nutrients supplied through inorganic fertilizers or organic amendments.

LAW #6

SOIL CARBON AND GREENHOUSE EFFECT

- Mining C has the same effect on global warming whether it is through mineralization of soil organic matter and extractive farming or burning fossil fuels or draining peat soils.
- Soil can be a source or sink of GHGs depending on land use and management.

LAW #7

SOIL VERSUS GERMPLASM

- Even the elite varieties cannot extract water and nutrients from any soil where they do not exist.

Law #8

Soil As Sink For Atmospheric CO_2

- Soil are integral to any strategy of mitigating global warming and improving the environment.

LAW #9
ENGINE OF ECONOMIC DEVELOPMENT

• Sustainable management of soils is the engine of economic development, political stability and transformation of rural communities in developing countries.

Law #10
TRADITIONAL KNOWLEDGE AND MODERN INNOVATIONS

- Sustainable management of soil implies the use of modern innovations built upon the traditional knowledge.
- Those who refuse to use modern science to address urgent global issues must be prepared to endure more suffering.

NOT TAKING SOILS FOR GRANTED

If soils are not restored, crops will fail even if rains do not; hunger will perpetuate even with emphasis on biotechnology and genetically modified crops; civil strife and political instability will plague the developing world even with sermons on human rights and democratic ideals; and humanity will suffer even with great scientific strides. Political stability and global peace are threatened because of soil degradation, food insecurity, and desperateness. The time to act is now.

Lal (Science, 2008)