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MITIGATION POTENTIAL AND OPPORTUNITIES

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ABSTRACT

Adapting to climate change implies choice of soil and crop management practices to make appropriate adjustments in farming operations with regards to increase in soil temperature, decrease in plant available water, change in the growing season duration, increase in soil erosion hazard, etc. (Lal, 2004; Lal, 2008a). In comparison, mitigation options involve choice of land use and soil/crop management practices which would either reduce emissions or sequester emissions. Emission reduction strategies include those which avoid deforestation, reduce soil erosion, minimize losses of fertilizers and pesticides, and make soil a net sink for atmospheric CO_2 and CH_4. Most agricultural soils have lost 30 to 50 t C/*h*a due to past land use and management based on extractive farming practices (Lal,2004). The soil C pool can be increased by restoration of degraded/desertified soils through afforestation and reforestation, improving degraded pastures, rehabilitating polluted/contaminated soils, and adopting recommended management practices (RMPs) on agricultural soils to create positive C and nutrient budgets and conserving soil and water. Among RMPs are no-till farming with crop residue mulch and cover cropping, integrated nutrient management (INM) along with judicious use of fertilizers including slow release formulations, conserving water in the root zone, and adopting complex cropping and farming systems (Lal, 2008b; 2009). The rate of C sequestration ranges from 500 to 1500 kg/*h*a/yr in soils of cool and humid climates, and 100 to 500 kg/*h*a/yr in those of warm and arid climates. In addition to organic C, soil C sequestration also occurs through formation of secondary carbonates (pedogenic carbonates) in arid and semi-arid climates and through leaching of bicarbonates in soils irrigated with good quality water. The rate of formation of secondary carbonates is 2 to 20kg/C/*h*a/yr, and is important at the geologic time scale. Removal of crop residues, for biofuel and/or grazing as well as biomass burning, creates a negative C budget and depletes soil C pool (Wilhelm et al., 2004). Soil degradation by erosion and other processes also depletes C Pool and exacerbates emissions (Lal, 2003). Contrary to the claim by sedimentologists (Van Oost et al., 2007; Stallard, 1998), soil erosion emits about 1 Gt C/yr (Lal, 2003). The potential of C sequestration is about 1 Gt C/yr in soil of each of the croplands, grazing/range land, degraded desertified soils and ecosystems. The global potential of these 3 terrestrial ecosystems(~3GtC/yr) is equivalent to withdrawing about 50 ppm of atmospheric CO_2 over 50 years. In addition to mitigating climate change, soil C sequestration is also essential to advancing food security (Lal, 2006). Adoption of RMPs is developing countries to sequester C in soils at the rate of 1tC/*h*a/yr can increase food production by 30 to 50 millions t/yr (Lal, 2006), enough to fulfill the food deficit especially in Sub-Saharan Africa. It is a truly win-win situation, and a bridge to the future until low-C or no-C fuel sources take effect.

KEY WORDS Global warming, soil restoration, soil C sequestration, no-till farming, food security

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Greenhouse Effect Vs. Abrupt Climate Change

- The Greenhouse effect is a natural process that has increased the temperature of the Earth from -18 C to +15 C and made Earth a habitable planet for diverse life as we know it.
- The abrupt climate change is a process by which Earth's temperature increases at the rate > 0.1 C/decade. With 1 C increase in temperature the biomes shift poleward by 200-300 kms because ecosystems cannot adjust to ACC.

Historic Developments in ACC

- 1850 : Joseph Fourier estimated the energy balance of the Earth.
- 1859 : John Tyndall suggested that water vapors, methane, and carbon dioxide are not transparent to long wave radiation.
- 1896 : Svaante Arhenius estimated that doubling carbon dioxide in the atmosphere may increase Earth's temperature by 4-6 C.

On-set of Anthropogenic Emissions

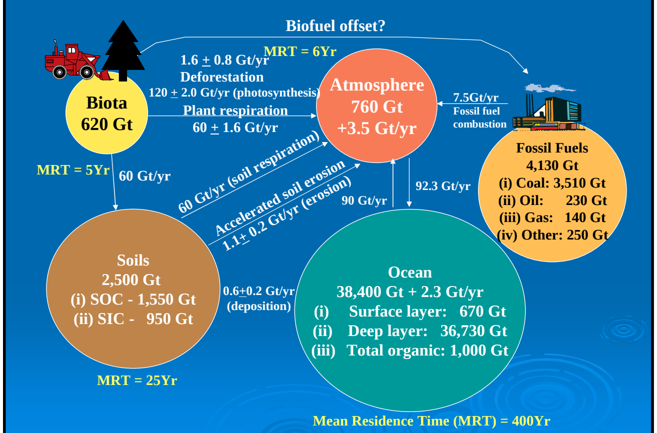
A trend of increase in atmospheric concentration of CO_2 began 8000 years ago, and that in CH^4 5000 years ago, corresponding with the dawn of settled agriculture with attendant deforestation, soil cultivation, spread of rice paddies and raising cattle.

…Ruddiman (2003)

Anthropogenic Emissions (1850-2000)

(a) Pre-Industrial era
   (i) 320 Pg (Ruddiman, 2003)

(b) Post-Industrial era
   (i) Fossil fuel: ~300 Pg
   (ii) Land use change: ~136 Pg
   Soil: ~78



Contemporary Carbon Budget

Source	1980s	1990s	2000s
	- - - - -Pg C/yr- - - - -		
Sources			
- Fossil fuel burning	5.4	6.3	7.5
- Land use change	1.7	1.6	1.6
Sinks			
- Atmosphere	3.3	3.2	3.3
- Ocean	1.9	1.7	2.2
- Land	0.2	1.4	1.4
Unknown terrestrial sink	1.9	2.4	2.2

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Coping With ACC

•**Adaptation**

Learning to live with the new environment (e.g., time of planting, changing varieties, new cropping systems)

•**Mitigation**

Offsetting the causative factors such as reducing the net emission of greenhouse gases

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Strategies for Agricultural Mitigation of Greenhouse Gases

Agricultural Mitigation Options

Reducing Emissions

Sequestering Emissions

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Options for Reducing Emissions

- Avoiding Deforestation
- Reducing incidence of wild fires
- Eliminating biomass burning
- Improving use efficiency of input (e.g., fertilizers, irrigation, tillage, pesticides, energy)
- Growing aerobic rice
- Minimizing soil erosion risks

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Water Erosion Affecting 1100 MHa

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Wind Erosion Affecting 550 MHa

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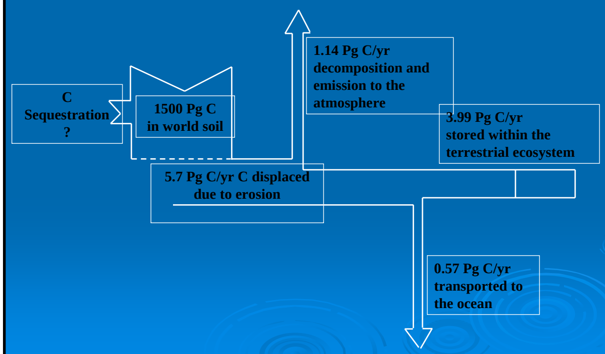
Global Soil Erosion and Dynamics of Soil Organic Carbon



Biomass Burning Emitting 3.7 PgC/year in the Tropics

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1 meter of Top Soil Developed over Millenia is used for Brick Making @ 0.7% per year of Cropland Area in Punjab & Haryana Leading to Emission of CO2 by burning Organic Matter in the Top Soil

Carbon Sequestration

Capture and secure storage of atmospheric C that would otherwise be emitted or remain in the atmosphere

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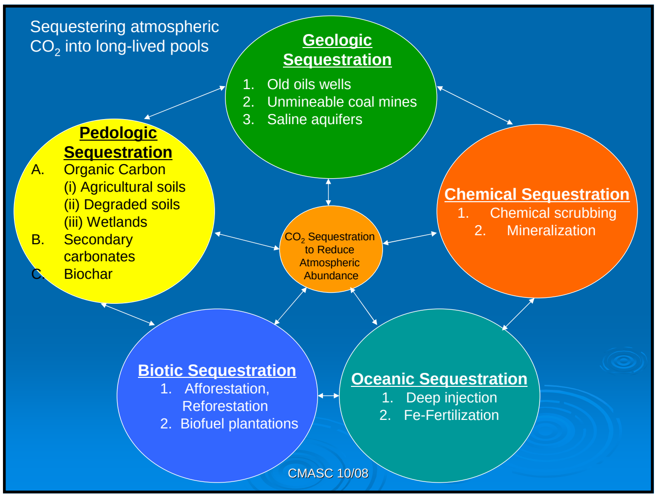
Sequestering atmospheric CO_2 into long-lived pools



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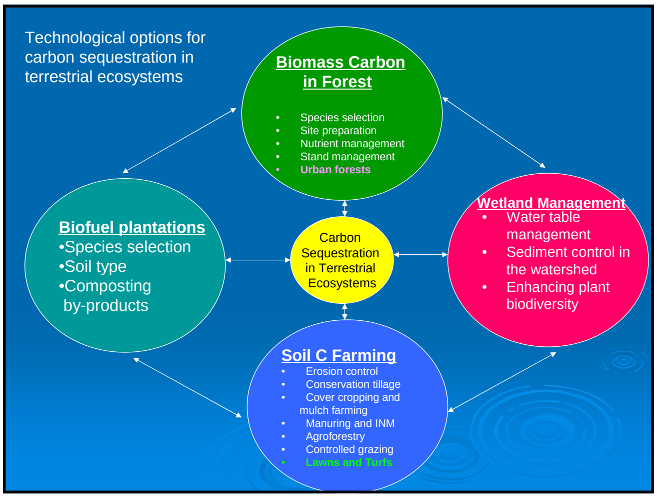
Technological options for carbon sequestration in terrestrial ecosystems



Terrestrial C Sink Capacity

- Historic Loss from Terrestrial Biosphere = 456 Pg with 4 Pg 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

- **The Average Sink Capacity = 50 ppm over 50 yr.**

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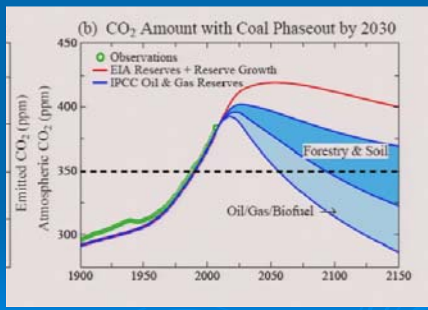
Potential of Mitigating Atmospheric CO_2



(Hansen, 2008)

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Estimates of Global and Regional Potential of Soil C Sequestration

Region	Potential Tg C/yr
1. World:	600 – 1200
2. USA:	144 – 432
3. India:	40 – 50
4. Iceland	1.2 – 1.6
5. Brazil:	40 – 60
6. W. Europe:	70 – 190
7. China:	126 – 364

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ECOSYSTEM CARBON BUDGET

ECB = ABGB+BGB+LDB+SC
ABGB = above ground biomass
BGB = below ground biomass
LDB = litter and detritus biomass
SC = soil carbon

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Soil Carbon Dynamics

$dC/dt = - KC + A$

K = decomposition constant
C = soil carbon pool
A = accretion of biomass

At equilibrium
$0 = -KC + A$
Sequestration: $- (KC + A) > 0$
Deletion: $- (KC + A) < 0$

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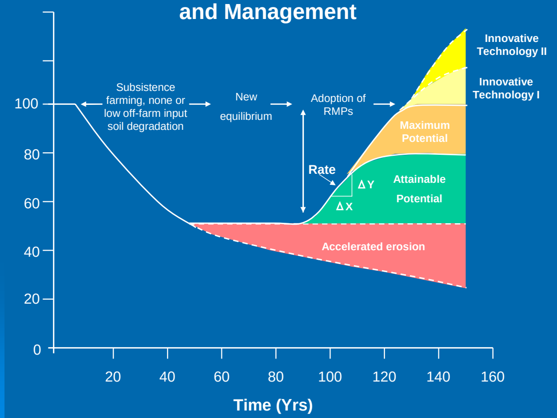
Soil Carbon Dynamics Under Changing Landuse and Management



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Recommended Management Practices and Soil Carbon

Recommended practices	C sequestration potential (Mg C/ha/yr)
Conservation tillage	0.10-0.40
Winter cover crop	0.05-0.20
Soil fertility management	0.05-0.10
Elimination of summer fallow	0.05-0.20
Forages based rotation	0.05-0.20
Use of improved varieties	0.05-0.10
Organic amendments	0.20-0.30
Water table management/irrigation	0.05-0.10
Lawn & Turf	0.5-1.0
Minesoil reclamation	0.5-1.0

Lal et al., 1998

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Potential of soil carbon sequestration in India (adopted from Lal, 2004a)

Strategy	Total potential (Tg C/yr)
(a) Restoration of degraded soil	
(i) Water erosion control	2.6 – 3.9
(ii) Wind erosion control	0.4 – 0.7
(iii) Soil fertility improvement	3.5 – 4.4
(iv) Improved drainage	0.1 – 0.2
(v) Reclaiming salt-affected soils	0.5 – 0.6
(b) Adoption of RMPs in drylands	
(i) Arid regions	0.7 – 1.3
(ii) Semi-arid regions	2.3 – 4.7
(iii) Sub-humid regions	5.6 – 8.0
(c) Secondary carbonates	17.3 – 18.7
Total	33.0 – 42.5

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Rationale for Soil Carbon Sequestration

- Mitigating climate change
- Advancing food security through improvement in soil quality

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Food Insecurity in Asia

Of the 850 million food insecure people in the world,

554 million live in Asia (66%)

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Food Gap by Regions (Shapouri, 2005)

Region	Food Gap 2000	Food Gap 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

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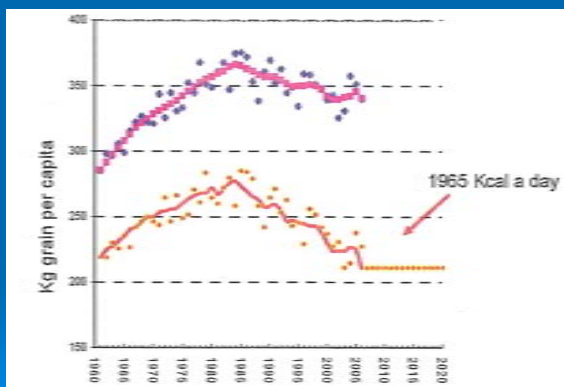
World Cereal Production Per Capita



(Flavell – National Academies, 2008)

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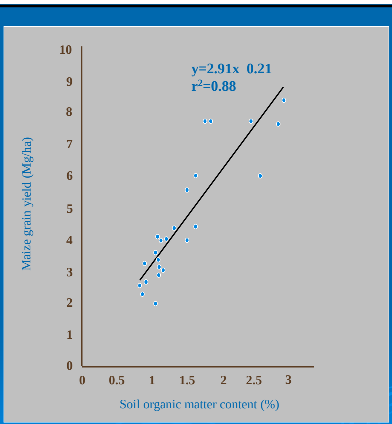
Future Challenges

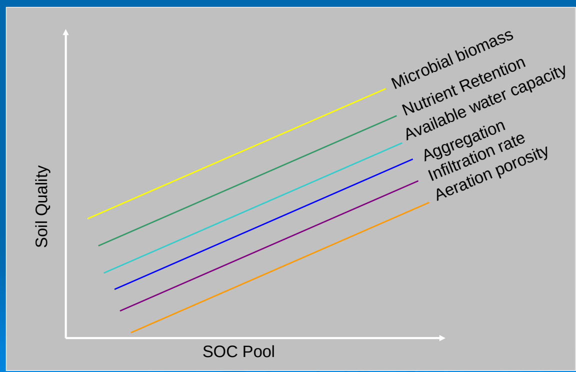
How are the developing countries (e.g., India) going to feed themselves without inflicting further damage on an environment that is already under great stress?

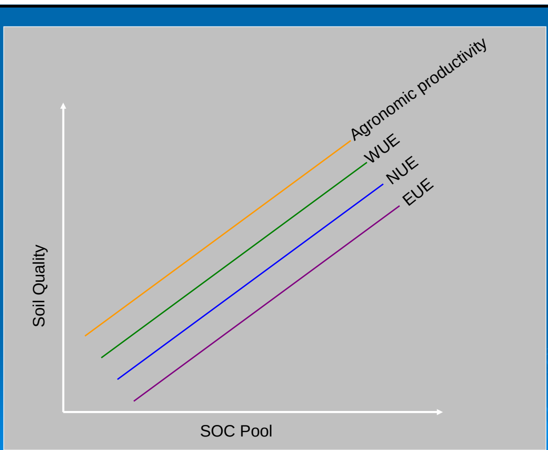
SOC Pool and Crop Yield

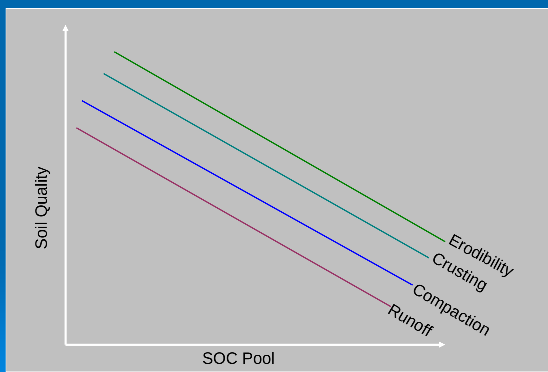
Crop	Yield Increase (kg/Mg SOC)
Wheat	40-60
Corn	200-400
Soybeans	40-60
Rice	30-50
Cowpeas	10-30



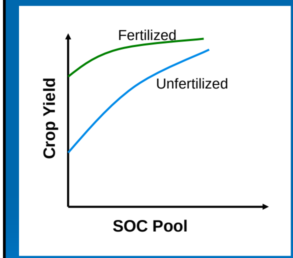
Relation between soil organic matter cor and maize grain yield in Thailand (redrawn Petchawee and Chaitep, 1995).

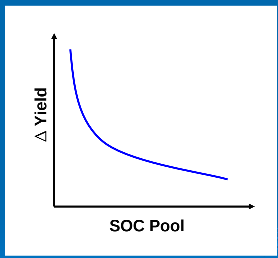






Crop yield and productivity effects of SOC pool





Estimate 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**

Creating Incentives to Adopt RMPs by Resource Poor Farmers in Asia

Giving hand outs Vs. payment for Ecosytem services including trading of carbon credits

Commodification of soil C

How can soil C be made a commodity that can be traded like any other farm product?

The value of soil carbon

- Value to farmer: for soil quality enhancement
- Value to society: for ecosystem services

Societal value of soil carbon

- Reduction in erosion and sedimentation of water bodies.
- Improvement in water quality.
- Biodegradation of pollutants.
- Mitigation of climate change.

On-farm value of soil carbon

- The quantity of NPK, Zn, Cu etc. and H_2O retention in humus.
- Improvements in soil structure and tilth.
- Decrease in losses due to runoff, leaching and erosion.

$\simeq$ \$200/ton

Need for determining a just value of soil carbon

- Under valuing a resource can lead to its abuse.
- It is important to identify criteria for determining the societal value of soil C, and using it for trading purposes.

Trading C Credits

The C market may reach $ trillion by 2020. We need to make this market accessible to land managers.

Ten Tenets of Soil and Water Management

Law #1 Causes of Soil Degradation

The biophysical process of soil degradation is driven by economic, social and political forces.

Soil Salinization & Chemical Degradation

Law #2
Soil Stewardship and Human Suffering

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

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The Resource-Poor Farmers of Asia

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Large Quantities of Essential Plant Nutrients are burnt as Cowdung & Crop Residue in Household Cooking

Storing Cowdung for Household Cooking Rather than Using it as a Soil Amendment

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.

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Balancing Input and Output for Sustainability

Numerous Competing uses of Crop Residues Make it Difficult to be Used as a Soil Amendment

Crop Residue Produced in India in 2000

Crop	Area (10^6 Ha)	Residue production (10^6 Mg)
Rice	26.7	112
Wheat	44.6	201
Sorghum	10.5	14
Millet	12.0	18
Maize	6.5	12
Chick pea	6.9	5
Soybeans	5.7	5
Ground nut	7.1	6
Cotton	9.0	9
Sugar cane	4.2	78
Total		460

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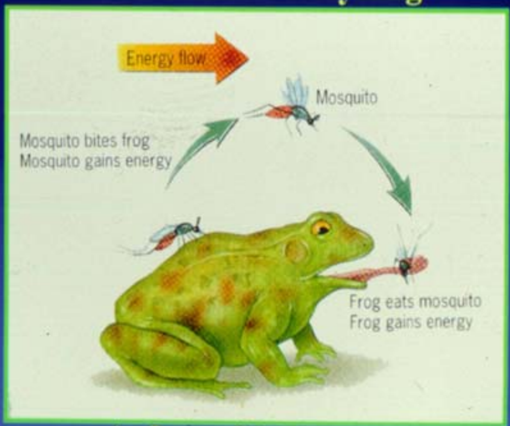
The Ultimate Recycling



An Impossible Ecosystem

Law #4
Marginality Principle

Marginal soils cultivated with marginal inputs produce marginal yields and support marginal living.

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Resource-Poor farmers of Asia

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Law #5
Organic Versus Inorganic Source of Nutrients

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

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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.

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Law #7
Soil Versus Germplasm

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

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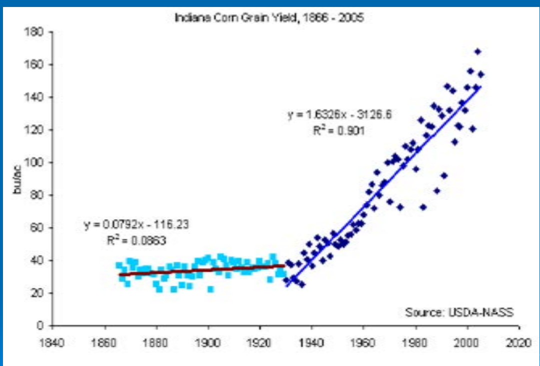
Technology-Agronomic and Genetic-Provides Success



Adoption of hybrid genetics has more than tripled US corn yield since 1940!

(Flavell – National Academies, 2008)

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Law #8
Soil As Sink For Atmospheric CO2

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

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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.

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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.

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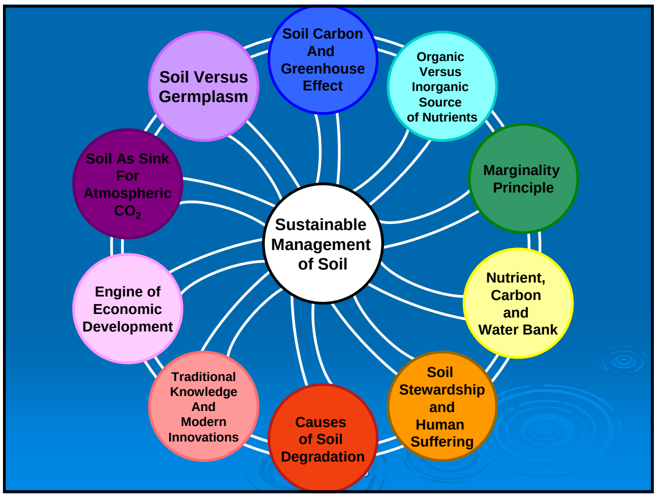

A Precious Resource

Irrespective of the climate debate, soil quality and its organic matter content must be restored, enhanced and improved.

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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)

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