SOIL AND SOCIETY

Carbon Management and Sequestration Center
Dr. Rattan Lal
The 68th UN General Assembly (A/RES/68/232) declared 2015 the “International Year of Soils”

The Objectives of IYS are:

• To create full awareness of civil society and decision makers about the fundamental roles of soils for human’s life

• To advance full recognition of the prominent contributions of soils to food security, climate change, adaptation and mitigation, essential ecosystem services, poverty alleviation and sustainable development.

• To promote effective policies and actions for the sustainable management and protection of soil resources.
The Anthropogenic Driver

\[ I = P \times A \times T \]

- **P** = Population
- **A** = Affluence
- **T** = Technology

Over the last 10,000 years, the number of humans has increased about a thousand-fold from 2-20 million to 7.3 billion.
The answer lies in soils.
Earth’s Historic Temperature and the Evolution of Agriculture
(Fagan, 2004)
Earth’s Climate During the Last 150,000 Years and an Interpretation of its Future

After Imbrie and Imbrie, 1986 as shown in Mackenzie and Mackenzie, 1995
## Net Land Use Change Emissions from 1700 to 2000

<table>
<thead>
<tr>
<th>Region</th>
<th>Emission (PgC)</th>
<th>1700-2000</th>
<th>1850-2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>44.2</td>
<td>39.1</td>
<td></td>
</tr>
<tr>
<td>South &amp; Central America</td>
<td>50.7</td>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>Eastern &amp; Western Europe</td>
<td>16.3</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>36.3</td>
<td>28.4</td>
<td></td>
</tr>
<tr>
<td>East Asia</td>
<td>26.1</td>
<td>19.9</td>
<td></td>
</tr>
<tr>
<td>South Asia</td>
<td>40.8</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>28.0</td>
<td>26.3</td>
<td></td>
</tr>
<tr>
<td>Australia &amp; Middle East</td>
<td>9.1</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Tropical Regions</td>
<td>145.6</td>
<td>122.5</td>
<td></td>
</tr>
<tr>
<td>Exo-Tropical Regions</td>
<td>105.8</td>
<td>87.9</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>251.4</strong></td>
<td><strong>210.4</strong></td>
<td></td>
</tr>
</tbody>
</table>

Smith and Rothwell (2013)
ANTHROPOGENIC EMISSIONS (Pg) BY CARBON CIVILIZATION

I. Land use
   (i) Prehistoric : 320
   (ii) 1750-2010 : 136
   (iii) 2010-2030 : 30

II. Fossil Fuel combustion
   (i) 1750-2010 : 200
   (ii) 2010-2030 : 190

These emissions have and will affect the ecosystems from which we derive food, feed, fiber, fuel and shelter.
THE SHORT-TERM GLOBAL CARBON CYCLE

- **Atmosphere**: 800 Pg, +4.0 Pg/yr
  - 10 Pg/yr fossil fuel combustion
  - 1.6 ± 0.8 Pg/yr deforestation
  - 120 ± 2.0 Pg/yr (photosynthesis)
  - Plant respiration: 60 ± 1.6 Pg/yr
  - MRT = 6Yr

- **Soils**: 2,500 Pg
  - (i) SOC: 1,550 Pg
  - (ii) SIC: 950 Pg
  - 60 Pg/yr (soil respiration)
  - 1.1 ± 0.2 Pg/yr (erosion)
  - Accelerated soil erosion: 60 Pg/yr
  - 0.6 ± 0.2 Pg/yr (deposition)
  - MRT = 25Yr

- **Biota**: 620 Pg
  - MRT = 5Yr

- **Fossil Fuels**: 4,130 Pg
  - (i) Coal: 3,510 Pg
  - (ii) Oil: 230 Pg
  - (iii) Gas: 140 Pg
  - (iv) Other: 250 Pg

- **Ocean**: 38,400 Gt + 2.3 Pg/yr
  - (i) Surface layer: 670 Pg
  - (ii) Deep layer: 36,730 Pg
  - (iii) Total organic: 1,000 Pg
  - MRT = 90 Gt/yr
  - MRT = 6Yr

- **Biofuel Offset?**

Mean Residence Time (MRT) = 400Yr
GLOBAL SOIL EROSION & DYNAMICS OF SOIL ORGANIC CARBON

- 1500 x 10^{13} gC in world soil
- 5.7 x 10^6 g yr C Displaced due to erosion
- 1.1 x 10^8 g yr decomposition and emission to the atmosphere
- 3.99 x 10^8 g yr Stored within the terrestrial ecosystem
- 0.57 x 10^6 g yr Transported to the ocean
EXTINCT AND ENDANGERED SOILS

• Soils which have lost most of their A, B and even C horizons by accelerated erosion, and have been irreversibly degraded.

• Mapping “Pedodiversity” can identify the endangered and extinct soils. The number of endangered soils in China is ~90

• Endangered soils, the victims of inappropriate agriculture and urban development, also exist in USA, Europe, Russia, etc.  
  
(Tennesen, 2014)
SOILS AND ECOSYSTEM FUNCTIONS

300,000 Soil Series

- Forest/Biodiversity
- Water Resources
- Animal Biodiversity
- Energy /Biofuels
- Aquaculture
- Climate Regulation
- Food Production
- Ecosystem Restoration
## Collapse of Historic Civilizations

<table>
<thead>
<tr>
<th>Civilization</th>
<th>Region</th>
<th>Era</th>
<th>Cause of Collapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sumerian</td>
<td>Mesopotamia</td>
<td>10,000 BCE</td>
<td>Salinization</td>
</tr>
<tr>
<td>Harappan</td>
<td>Indus Valley</td>
<td>2,000-2,000 BCE</td>
<td>Desiccation</td>
</tr>
<tr>
<td>Inca</td>
<td>Andean Region</td>
<td>750-900 CE</td>
<td>Soil Erosion</td>
</tr>
<tr>
<td>Maya</td>
<td>Central America</td>
<td>750-900 CE</td>
<td>Soil Erosion</td>
</tr>
<tr>
<td>Axum</td>
<td>Northern Ethiopia</td>
<td>100-600 CE</td>
<td>Ecological Degradation</td>
</tr>
<tr>
<td>Roman</td>
<td>Mediterranean</td>
<td>27BC – 395 AD</td>
<td>Exhaustion of soil</td>
</tr>
</tbody>
</table>
• Extractive Farming/Subsistence

• Depletion of SOC and Nutrients
• Decline in Soil Structure

• Loss of Soil Resilience

• Decline in Ecosystem Functions and Services

• Loss of Soil biodiversity
• Disruption of Key Processes

• Hunger
• Malnutrition
• Political Unrest
• Civil Strife
• War and insecurity

Severe Degradation
“Let us never forget that the world peace will not be built on empty stomachs or human misery”

Norman Borlaug, father of the Green Revolution

- Ortiz, 2011
BREAD AND PEACE

There are not many troubles in the world more alarming than those caused by the fire in the pit of an empty stomach.
HUNGER AND STEWARDSHIP

“Love and business and family and religion and art and patriotism are nothing but shadows of words when a man’s starving.”

… ‘O Henry

“Heart of the West” 1907
Securitization of Food and the Environment Through Soil Sustainability

Security → Political → Economic → Social → Environmental

Human (Gender) → Societal (Ethnic) → National → Regional → International → Global

Soil Quality

Food Security

Health/Nutritional Security

Water Security

Environmental Security

Energy Security

Climate Security

National Security

Political Security
**Cause of Insecurity**

Poverty and subsistence agriculture are root causes of national food insecurity in developing countries.

...Defra, *Food security and the U.K.* (2006)
GLOBAL FOOD INSECURITY (FAO, 2013)

- World's Hungry (10⁶)
  - South Asia 35.0
  - Sub-Saharan Africa 26.5
  - Eastern Asia 19.8
  - South-eastern Asia 7.7
  - Latin America & the Caribbean 5.6
  - Others 5.3

- Chronicles underfed ~ 1 billion
- Micronutrient deficiency ~ 2 billion

Year:
- 1992
- 2002
- 2007
- 2010
- 2013

World's Hungry (10⁶):
- 975
- 950
- 925
- 900
- 875
- 850
- 800
- 0
SOIL AND CIVILIZATION

• True democracy cannot survive in a country where a large part of the people are hungry.

• It was the superlative productivity and durability of the soils which made the first Egyptian civilization possible.

• The fall of the past civilizations was due in large part to bad management of the landscape.

Vernon Carter and Tom Dale (1973)
THE QUEST FOR VICTUALS

- Historically, major migrations and revolutions were driven by the never-ending quest for victuals, which have been a major justification for invasions and revolution. Then, agriculture was the foundation of power.

- In modern times (since 1980s), economic development and GDP have become the major source of power and global influence.

- Yet the need for food, a common thread in both eras, has led to proclivity, tensions, political instability, and social/ethnic conflicts.

Slogan about Gross National Happiness in Thimphu's School of Traditional Arts.
SOIL AND NATIONAL SECURITY

• Soil is not just an economic development or an environmental/health concern, it is also a peace and security issue.

• Densely populated regions (China, India, etc.) have low and shrinking per capita arable land area.

• Scarcity of good quality soil/land can increase the risk of instability, land-grabbing, state failure, and exacerbate regional and international tensions.

• Land grab, presently estimated at ~200 Mha between 2000 and 2010, can be a future threat to peace and stability.
"It is time to understand the ‘environment’ for what it is: the national security issue of the early 21st century – surging populations, spreading diseases, deforestation and soil erosion, water depletion air pollution, and possibly rising sea levels – will be the core foreign policy challenges from which most others will ultimately emanate”.

… Kaplan (1994)
Presently, China continues to consider agriculture as a matter of “national security”

http://resiliency-rising.blogspot.com/2013/10/nanjing-permaculture-to-pdc-or-not-to.html
HUNGER AND STEWARDSHIP

The national food security act (NFSA) legally binds the Federal Government of India to guarantee access to subsidized food to 70% of the 1.2 billion people (840 million), the combined population of USA and EU.

According to NFSA, food is now a basic right. During 2011-12, > 500 million Indians received 51.3 million tons of subsidized food or more than 10 times the direct food aid delivered by the World Food Program in 2011.

... NFSA (2013)
U.K. Government Policy

Food matters: towards a strategy for the 21st century

...PMSU (2008)
Food and National Security

- The Public Law 480 (10th July 1954, Eisenhower) renamed “Food for Peace” (1961, Kennedy), and Global Food Security Act (Sen. Lugar, 2009) recognized the food-peace nexus.

- On 24th Sept. 2009, Secretary of State Hillary Clinton made “food security” a key component of the U.S. foreign policy and recognized that hunger threatens the stability of governments, societies and borders.

- VP Biden stated on 28 Oct. 2011 that “Investments made to ward off food insecurity and prevent its recurrence can prevent the vicious cycles of rising extremism, armed conflict and state failure...”
UNDERSTANDING SOIL-HUMAN INTERACTION

• How can we double food production between 2005 and 2050 while restoring soil, mitigating climate change, improving the environment and maintaining peace and stability?

• This is a much larger challenge than was faced by Norman Borlaug, M.S. Swaminathan, and other Green Revolutionaries of the 1960s and 1970s.

• Soil scientists have a crucial role to play in meeting this challenge through close cooperation with other disciplines, including natural sciences and humanities.
ACTION FROM MULTIPLE FRONTS TO FEED 11 BILLION

1. Increase production from existing land & restoring soils: Sustainable Intensification (SI)
2. Reduce post-harvest losses: 10-40% (Developing countries)
3. Minimize food waste (farm → fork → landfill): 20-40% (Developed countries)
4. Reduce diversion of food to biofuels: ~1/3 of corn in U.S.
5. Prefer plant-based diet: 6-8 kg grain/kg of meat on grain-fed livestock
6. Per capita grain consumption: India = 170 kg/yr, USA = 635 kg/yr
**SOIL C SEQUESTRATION**

- **Subsistence farming, none or low off-farm input soil degradation**
- **New equilibrium**
- **Adoption of RMPs**
- **Maximum Potential**
- **Attainable Potential**
- **C Sink Capacity**
- **Δt Accelerated erosion**

- **MRT = Pool / Flux**

- **Lal, 2004**

- **Time (Yrs)**

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- **Innovative Technology II**
- **Innovative Technology I**
- •NT
- •INM & NUE
- •Cover Crops
- •Biochar
- •Agroforestry
- •Desert. Control
- •Afforestation
- •Pasture Mgmt
- •H₂O harv., DSI
**Nutrients Required to Convert Biomass into Humus**

**Crop Residues**

<table>
<thead>
<tr>
<th>Elemental Ratio</th>
<th>Cereal Residues</th>
<th>Humus</th>
</tr>
</thead>
<tbody>
<tr>
<td>C:N</td>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>C:P</td>
<td>200</td>
<td>50</td>
</tr>
<tr>
<td>C:S</td>
<td>500</td>
<td>70</td>
</tr>
</tbody>
</table>

**Biochemical Transformations**

+ (N, P, S etc.)

**Humus**


TRADING NUTRIENTS FOR CARBON

Sequestration of 10,000 kg of biomass C as humus requires additional nutrients:

- 833 kg N
- 200 kg P
- 143 kg S

These ingredients will produce + 17,241 kg of humus

28,000 kg of C in residues
62,000 kg of residues (oven dry)

Recalculated from Himes, 1998.
SOIL MICROAGGREGATE FORMATION (<250 µm) AND SOM STABILIZATION

Strongly sorbed polymer

Cation bridges

(Redrawn from Tisdall and Oades, 1982. Soil Sci 33:141-163)
Towards C-Neutral Agriculture

Chatting with plants through molecular-based signals

INM

No-till Farming

Soil biota and ecosystems services

Delivering nutrients and water directly to plant’s roots
NO PANACEA NOR A SILVER BULLET

Sustainable Intensification

- CA: Agroforestry
- TR: Micro-Irrigation
- RA: INM Disease/Suppressive Soils
- AD: Precision Farming
- DE: Farming System Analysis
- FO: GMOs
- FS: The Nexus Approach
- OS: Nutrition-Sensitive Agriculture

Climate-Resilient Agriculture & the Nexus Approach
TECHNOLOGICAL INNOVATIONS

- Hand Tools
- Animal Power
- Rotations

GREEN REVOLUTION
- Machine power
- Fertilizers
- Germplasm
- Improved cultivars
- Biotechnology
- No-till farming
- INM
- IPM
- Carbon sequestration

CONSERVATION AGRICULTURE
- Precision farming
- Perennial culture
- Complex rotations
- GMOs
- Sustainable intensification (SI)
- Rhizospheric processes
- Disease-suppressive soils
- Soil-less agriculture
- Sky farming
- Urban agriculture
- Sky farming

REAL RELATIVE FOOD PRODUCTION (Mg/ha)

WORLD POPULATION (BILLIONS)

YEAR


0.8 1 3 4 6 7.6 8 9.6

0.8 1 3 4 6 8 9.6

THE OHIO STATE UNIVERSITY
Carbon Management and Sequestration Center
REDUCING EMISSIONS FROM AGRICULTURE BY IMPROVING AGRONOMIC YIELDS

• The net effect of higher crop yields avoided emissions of up to 161 PgC (591 Pg CO₂ e) between 1961 and 2010.

• Each dollar invested in agricultural yields has resulted in 68 fewer kgC (249 CO₂ e) emissions relative to 1961 technology ($14.74/MgC) or avoiding 3.6 PgC (13.1 Pg CO₂ e) per year.

Burney et al. (1998)
## Inconsistency in Scientists vs. Public Opinion (2014)

<table>
<thead>
<tr>
<th>Issue</th>
<th>Public (%)</th>
<th>Scientists (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eating GM Food is Safe</td>
<td>37</td>
<td>88</td>
</tr>
<tr>
<td>Climate Change is Real</td>
<td>25 (11 in 2005)</td>
<td>100</td>
</tr>
<tr>
<td>US Science is the Best</td>
<td>54</td>
<td>92</td>
</tr>
<tr>
<td>Safety of Vaccinations</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Evolution</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Leshner (2015)
# INCONSISTENCY IN SOIL SCIENTISTS VS. PUBLIC OPINION

<table>
<thead>
<tr>
<th>Role of Soils in</th>
<th>Public (%)</th>
<th>Scientists (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food/ Nutritional Security</td>
<td></td>
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<tr>
<td>Water Scarcity</td>
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<tr>
<td>Poverty Alleviation</td>
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<tr>
<td>Tropical Deforestation</td>
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<td>Political Stability</td>
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<tr>
<td>Civil Strife</td>
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<td>Terrorism</td>
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<tr>
<td>National Security</td>
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<tr>
<td>Human Wellbeing</td>
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<tr>
<td>Modern Civilization</td>
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</tbody>
</table>
Speaking Up for the Importance of Soil Science

Soil Scientists must:

- **Engage with the Public**: in popular topics (e.g., food security, climate change, water quality, biofuel, biodiversity)

- **Speak with Journalists**: regarding implications of their research

- **Meet with Members of Public**: to resolve inconsistencies, discuss issues which make each side and address public concerns

- **Communicate with Policy Makers**: to translate science into action

- **Discuss with Educators**: to change curricula and include soil science in K2 to 12
NURTURING A PUBLIC THAT IS SUPPORTIVE

• Creating environment for soil science to contribute to the solutions of societal problems

• Helping soil scientists to become better public communicators

• Identifying forums through which soil scientists can work with members of the public on identifying solutions

• Building a societal culture that champions soil science and thrives on the outcome of a strong pedology-public relationship.
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.

... Lal (Science, 2008)

This is the time for the soil scientists to act and address issues of global significance because you have the capacity, knowledge and motivation to do so.
There are 3-dimensions of scarcity:

a) **Supply-Induced:** When resources are reduced and degraded faster than they are renewed.

b) **Demand-Induced:** It is created by population growth or increased per capita consumption.

c) **Structural-scarcity:** Resources are inequitably distributed when they are concentrated in the hands of a few people while the remaining population suffers from resource shortage (Hauge and Ellingsen, 1998).
RESOURCE DEGRADATION AND CONFLICT

• Countries suffering from land degradation are more prone to civil conflict. However, economic factors are more important than are environmental factors.

• Environmental degradation has a stronger impact on the incidence of smaller than large armed conflicts

**BLOOD AND SOIL**

- A **high level of land degradation** is the only factor that significantly increases the risk of civil conflict.

- Scarcity of natural resources has limited explanatory powers in terms of civil violence, whereas poverty and dysfunctional institutions are robustly related to conflict.

  Theisen (2008)
SOIL STEWARDSHIP

Soil stewardship and care must be embedded in every fruit and vegetable eaten, in each grain ground into the bread consumed, in every cup of water used, in every breath of air inhaled, and in every scenic landscape cherished.
Soil: The Global Icon

Soil is Life and Life is Soil

Water
Carbon
Nitrogen
Phosphorous
Sulfur