Soil Restoration for Ecosystem Services

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ECOSYSTEM SERVICES

Multitude of resources and benefits that are supplied by natural ecosystems

• “A framework for structuring and synthesizing biophysical understanding of ecosystem processes in terms of human well being”.

…Mooney and Ehrlich (1997)
Natural capital vs. ecosystem services

SOC Pool
- Soil Conservation
- INM
- Farming Systems

Agronomic Productivity
- Food Security
- Climate Change Mitigation
- Water Quality
- Biodiversity
Soils are the basic substrate for natural ecosystems, but have not been adequately emphasized in sustainable development nor in sustainable management of natural resources.
INTERCONNECTIVITY OF ECOSYSTEM SERVICES AND FUNCTIONS

Ecosystem Functions
- Elemental Cycling
- NPP
- Soil Formation

Provisioning
- Food
- Feed
- Fiber
- Fuel
- Minerals

Regulating
- Climate
- Water
- Nutrients
- Biodiversity
- Gene pool

Cultural
- Aesthetic
- Cultural
- Recreational
- Scenic
- Spiritual
**Some Ecosystem Services Provided by Soils**

1. Climate Change Moderation
2. Carbon Sequestration
3. Water Storage and Purification
4. Biodiversity
5. Food Security
6. Poverty Alleviation
7. Soil quality
1. CLIMATE CHANGE MODERATION
It is the most dangerous and interactable problem:

Dangerous : Because it encompasses many issues,

Interactable : (i) 80% of the energy demand is met from the fossil fuel,

(ii) $20 trillion of infra-structure is built around fuel,

(iii) Deforestation and land use are intricately linked with food security, water quality, and biodiversity
STRATEGY

Reduce vulnerability

Increase adaptive capacity

Can humans solve this problem?
**BIOSEQUESTRATION OF ATMOSPHERIC CO$_2$**

Only 0.05% of the 3800 zettajoules ($10^{21}$ J) of solar energy is absorbed annually as GPP

- Gross Primary Productivity (GPP) = 123 Gt C/yr
- Net Primary Productivity (NPP) = 63 Gt C/yr
- Net Ecosystem Productivity (NEP) = 10 Gt C/yr
- Net Biome Productivity (NBP) = 3 Gt C/yr

“If we control what plants do with carbon, the fate of CO$_2$ in the atmosphere is in our hands”

-Freman Dyson (2008), BioScience (10/10)
1. **Carbon Sequestration**
SOIL CARBON SEQUESTRATION

Refers to the process of restoring depleted soil carbon through recommended land use and soil management.
### Carbon Pool in World Soils to 1-m Depth

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Magnitude (Pg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil organic C</td>
<td>1530</td>
</tr>
<tr>
<td>Soil Inorganic C</td>
<td></td>
</tr>
<tr>
<td>(i) Carbonates</td>
<td>940</td>
</tr>
<tr>
<td>(ii) Bicarbonates in groundwater</td>
<td>1404</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3874</strong></td>
</tr>
</tbody>
</table>

*Monger et al. (2015)*
C SEQUESTRATION AS SECONDARY CARBONATES

Rate ... 2-5 kgC/ha per yr

Total area of Arid/Semi-Arid Regions = 6150 Mha

Technical Potential of Secondary Carbonates = 0.01-0.03 PgC/yr

Monger et al. (2015)
## Total Potential of SIC Sequestration

<table>
<thead>
<tr>
<th>Process</th>
<th>Technical Potential (PgC/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Carbonates</td>
<td>0.01-0.03</td>
</tr>
<tr>
<td>Leaching of Bicarbonates</td>
<td>0.20-0.36</td>
</tr>
<tr>
<td>Total</td>
<td>0.21-0.39</td>
</tr>
</tbody>
</table>

Monger et al. (2015)
GLOBAL POTENTIAL OF SOC SEQUESTRATION (Pg C/YR)

Cropland: 0.4-1.2
Grazing land: 0.3-0.5
Salt-affected soils: 0.3-0.7
Desertified soils: 0.2-0.7

Total: 1.2-3.1

Lal (2010)
### Capacity of Land-Based Sinks Through Biosequestration of C

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Sink Capacity (Pg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent Forest</td>
<td>200-300</td>
</tr>
<tr>
<td>Soils</td>
<td>50-100</td>
</tr>
</tbody>
</table>
Coupled cycling of H$_2$O, C, N, P and the ecosystem services generated

Lal (2010)
4 FOR 1000 : A NEW PROGRAM FOR CARBON SEQUESTRATION IN AGRICULTURE

With soil C pool of 700 Pg to 30 cm depth, 4/1000 = 2.8 Pg C drawdown per year

= 1.4 ppm reduction of atmospheric carbon dioxide/yr
3. Water Storage and Purification
SOIL AND WATER

• Soil is one of the largest reservoirs of fresh water

• Water conservation in soils is crucial to sustainable management of natural resources
4. BIODIVERSITY
SOIL AND GENE POOL

Soil is a principal reservoir of gene pool.

Improvement of soil quality enhances biodiversity: both above and below ground.
SOIL IS FULL OF LIFE

As much as 25% of all biodiversity is in soil.

Soil functions can be sustained by improving biodiversity.
5. FOOD SECURITY
GLOBAL FOOD INSECURITY

(FAO, 2015)

World’s Hungry (10^6)

- Latin American & the Caribbean: 5.6
- South-eastern Asia: 7.7
- Eastern Asia: 19.8
- South Asia: 35.0
- Sub-Saharan Africa: 26.5
- Latin American & the Caribbean: 5.6
- Others: 5.3

Chronically underfed: ~0.8 billion
Micronutrient deficiency: ~2 billion

MDG of reducing undernourishment to 410 million by 2015 has not been met.
GLOBAL FOOD DEMAND IN 21ST CENTURY

Hunger-related death toll is 21,000/day (Chrispeds, 2002)

Global food demand would double over the period 1990-2030, and increase by 70% between 2010 and 2050

This would involve 3-4 times increase in the poorest countries

There have been severe droughts in Amazon in 2010, China in 2011, and West Africa in 2011

In Africa and Asia, plant-derived food requirements may increase by a factor of 2.5 to 7 in some countries
REQUIRED CEREAL YIELDS AND PRODUCTION TO MEET FUTURE DEMANDS

(WILD, 2003)

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield (Mg/ha)</th>
<th>Total Production (10^6 M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>3.27</td>
<td>2240</td>
</tr>
<tr>
<td>2025</td>
<td>3.60 (4.40)</td>
<td>2780 (3629)</td>
</tr>
<tr>
<td>2050</td>
<td>4.30 (6.00)</td>
<td>3255 (4553)</td>
</tr>
</tbody>
</table>

(with change to animal-based diet)
Land resources already allocated to agriculture production are adequate through sustainable intensification, soil restoration, and carbon sequestration.

Is there a peak soil?
Are there endangered soils?

- Competing Uses
- Nature conservancy

Lal (2015)
Nutrient Use Efficiency

- Recycle and reuse nutrients (e.g., grey water)
- Adopt strategies of INM
- Enhance use efficiency of nutrients in agro-ecosystems
- Establish threshold level of SOC for soil quality
CRITICAL LEVEL OF SOC FOR WHEAT YIELD

(Diaz-Zorita et al., 2002)
**FOOD PRODUCTION IN LDCS BY INCREASING SOC POOL BY 1 T/Ha per Yr**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (Mha)</th>
<th>Production Increase (10^6 Mg yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>430</td>
<td>21.8 - 36.3</td>
</tr>
<tr>
<td>Legumes</td>
<td>68</td>
<td>2.0 - 3.2</td>
</tr>
<tr>
<td>Tubers</td>
<td>34</td>
<td>6.6 - 11.3</td>
</tr>
<tr>
<td>Total</td>
<td>532</td>
<td>30.4 - 50.8</td>
</tr>
</tbody>
</table>
6. POVERTY ALLEVIATION
PES’s and Economic Development

• Payments for ecosystems services is an important strategy to promote adoption of BMPs by the resource-poor farmer

• Land managers must be rewarded for services e.g.:
  • C sequestration
  • Water quality
  • Biodiversity
  • Reducing NPSP
SOCIETAL & MARKET VALUE OF SOC

• Cost of Residue + Nutrients: $120/ Mg C
• Cost of Nutrients Only: $102/ Mg C

Lal(2014)
PAYMENTS FOR SOC SEQUESTRATION

With average C sequestration rate of 300 kg/ha per yr, payments are: $40/ha per yr

Lal(2014)
7. Soil Quality
DISEASE-SUPPRESSIVE SOILS

1. Organic Amendments: Animal and green manure, compost, peat (partially decomposed)

CHARACTERISTICS OF DISEASE-SUPPRESSIVE SOILS

Soils in which disease development is minimal even in the presence of a virulent pathogen and a susceptible host.

(i.) General Suppression : Related to total amount of microbial activity

(ii.) Specific Suppression : Through a specific micro-organism or group of micro-organisms
SOIL QUALITY IS THE ENGINE OF ECONOMIC DEVELOPMENT.

WATER RESOURCES
- Quality
- Quantity

CLIMATE CHANGE
- Mitigation
- Adaptation
- Stabilization

BIODIVERSITY
- Above ground
- Below ground

FOOD SECURITY
- Quantity
- Quality

Lal (2012)
INTERNATIONAL YEAR OF SOILS 2015

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.
SOIL: THE GLOBAL ICON

Soil is Life and Life is Soil

-Lal (2014)