Managing Soils to Address Global Challenges

Speaker: Dr. Rattan Lal
Opening Remarks: Mike Michener
Moderator: Robert Bertram
Opening Remarks

Mike Michener
Deputy Assistant Administrator
Bureau for Resilience and Food Security, USAID
Dr. Rattan Lal

Distinguished University Professor of Soil Science and Director of the CFAES Rattan Lal Center for Carbon Management and Sequestration

The Ohio State University
Soil Science and Global Challenges

Dr. Rattan Lal

CFAES Rattan Lal Center for Carbon Management and Sequestration,
The Ohio State University, Columbus, OH 43210 USA

BIFAD Webinar, 24th Feb. 2022
## Domestic Animals vs. Human Population

### Human

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (10⁹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2022</td>
<td>7.9</td>
</tr>
<tr>
<td>2050</td>
<td>9.8</td>
</tr>
<tr>
<td>2100</td>
<td>11.0</td>
</tr>
</tbody>
</table>

(UN 2020)

### Domestic Animals

<table>
<thead>
<tr>
<th>Species</th>
<th>Amount (10⁹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows</td>
<td>1.4</td>
</tr>
<tr>
<td>Pigs</td>
<td>1.0</td>
</tr>
<tr>
<td>Sheep and Goats</td>
<td>1.9</td>
</tr>
<tr>
<td>Chickens</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Science 344(2014), 1067
HUMAN USE OF EARTH’S RESOURCES

Humanity is using one-and-a-half planets.
**Humanity Water Footprint**

- **Green water**: 6700 km$^3$/yr
- **Blue water**: 1000-1700 km$^3$/yr
- **Grey water**: 1400 km$^3$/yr
**HUMANITY FOOTPRINT: ACTUAL VS SUSTAINABLE**

**Carbon**: 46-55 vs. 18-25 Gt CO₂ Eq/yr

**Ecological**: 18.2 Bha vs. 12 Bha

**Material**: 70 Gt/yr (10.5t/cap. Vs. 8t/cap)

Hoekstra and Wiedma (2014)
## Human Footprint Increase in the Period 1900 to 2000

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue water</td>
<td>5.6</td>
</tr>
<tr>
<td>Reactive N</td>
<td>9.0</td>
</tr>
<tr>
<td>C Emissions</td>
<td>16.0</td>
</tr>
</tbody>
</table>
**Historic Carbon Emission From Land Use and Fossil Fuel Emissions**  
*(Friedlingstein et al., 2021)*

<table>
<thead>
<tr>
<th>Emissions</th>
<th>1750 - 2020</th>
<th>1850 - 2021</th>
<th>1960 - 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use Change</td>
<td>235 ± 75</td>
<td>200 ± 65</td>
<td>80 ± 45</td>
</tr>
<tr>
<td>Fossil Fuel</td>
<td>460 ± 25</td>
<td>465 ± 65</td>
<td>375 ± 20</td>
</tr>
<tr>
<td>Total</td>
<td>690 ± 80</td>
<td>660 ± 65</td>
<td>455 ± 45</td>
</tr>
</tbody>
</table>
## Per Capita Food Waste CFP (FAO, 2014)

<table>
<thead>
<tr>
<th>Region</th>
<th>Per Capita Kg CO$_2$ eq/Person - yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America and Oceania</td>
<td>860</td>
</tr>
<tr>
<td>Industrialized Asia</td>
<td>810</td>
</tr>
<tr>
<td>Europe</td>
<td>680</td>
</tr>
<tr>
<td>Latin America</td>
<td>540</td>
</tr>
<tr>
<td>North Africa/West Africa</td>
<td>350</td>
</tr>
<tr>
<td>South/SE Asia</td>
<td>350</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>210</td>
</tr>
</tbody>
</table>
## Carbon Stock in the Atmosphere

<table>
<thead>
<tr>
<th>Era</th>
<th>Pg C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Agriculture</td>
<td>360</td>
</tr>
<tr>
<td>Pre-Industrial Revolution</td>
<td>560</td>
</tr>
<tr>
<td>Present</td>
<td>880</td>
</tr>
</tbody>
</table>

Total Emission From LUC & Agric. = 575 Gt  
Total Emission From Fossil Fuel = 445 Gt

GLOBAL SOIL DEGRADATION

Global Land Area Degraded
= One-third of Total Land Area

Comprising:
Forest = 47%
Cropland = 18%

2 B ha of degraded/degraded lands

FAO (2015)
Bai et al. (2008)
Suitable arable agricultural land 0.25 ha/capita

0.05 ha/capita? Land grab / civil unrest

Soil Refugees

Is there a peak soil? Are there endangered soils?
Natural Resources Used for Agriculture

- 40% of the Earth’s terrestrial surface is used for agriculture,
- 75% of agricultural land (3.73 Bha) is allocated to raising animals,
- 70% of the global freshwater withdrawals are used for irrigation,
- 30-35% of global greenhouse gas emissions are contributed by agriculture.

And yet 1 in 10 persons is food-insecure and 1 in 4 are malnourished.
GLOBAL FOOD INSECURITY
(FAO, IFAD, UNICEP 2020)

World's Hungry (10^6)

- Sub-Saharan Africa - 34.1
- South Asia - 37.4
- Latin America, 5.9
- South-eastern Asia, 9.4
- Other, 13.2

- Chronically underfed ~ 0.82 billion
- Micronutrient deficiency ~ 2 billion

Year
- 1992
- 2002
- 2007
- 2010
- 2013
- 2019
- 2020

MDG of reducing undernourishment were not met, will SDGs be met?
GLOBAL ISSUES OF THE 21ST CENTURY

1. Population of 7.9 billion and increasing at 1.1%/yr (7.25 million/month).
2. Per capita arable land area of 0.22 ha and decreasing to <0.07 ha for 30 countries by 2025.
3. Soil degradation of 2 billion ha and increasing at 5-10 Mha/yr.
4. Renewable fresh water supply of < 1000m³ for 30 countries and increasing to 58 countries (4 billion people) by 2050.
5. Atmospheric CO₂ concentration of 412.5 ppm (2/22/22) and increasing at 0.5%/yr, or ~2ppmv/yr.
6. Energy use of 575 Quads in 2015 and increasing by 8 quads/yr (10^{15} BTU/yr, and increasing at 2.2%/yr between 2001 and 2025, and expected to be 736 quads by 2040).
7. Per capita grain consumption of 300 Kg/yr and decreasing.
8. Food-insecure population of 820 million (11% of the population) and increasing.
9. Per capita CO₂ emission in the world is 4.48 Mg CO₂/yr and in the U.S. is 17.56 Mg CO₂/yr.
10. Humanities per capita water footprint at global level is 1385 m³/yr and increasing.

U. N. Sustainable Development Goals are a Challenge.

Solutions lie in managing natural resources
LIMITATIONS OF THE PRESENT FOOD SYSTEMS

• Failed to end hunger and malnutrition,

• Haven’t provided adequate nutritious food, health diet, and safe food, and

• Have degraded soils, polluted water, aggravated global warming, dwindled biodiversity, and denuded landscapes.
THE WAY FOOD IS PRODUCED AND CONSUMED

- Affects the health of soil, plants, animals, people, ecosystems and the planet itself
- Above all the SDGs of the Agenda 2030 are not on the track
NATURE-POSITIVE PRODUCTION

• Mitigating climate change,
• Reducing emissions and increasing carbon capture,
• Regenerating and protecting critical ecosystems,
• Reducing food waste and energy usage, and
• Returning half of the land back to nature.
MANAGING SOIL HEALTH

- Regenerative Agriculture (e.g., CA)
- Digital Agriculture: Precision Agriculture
- Artificial Intelligence: Robots, Drones
- Biofortification of crops to fight hidden hunger
- Soil-Water-Air-Energy Nexus
- Build New Soil
- Urban/Soilless Farming

Drawdown of CO₂ from the Atmosphere
"When we try to pick out anything by itself, we find it hitched to everything else in the Universe." (John Muir).

(Lal 2020)
https://www.researchgate.net/figure/Rendzina-or-humus-calcareous-soil-Bulgarian-classification-1976-Rendzic-Leptosol-WRB_fig2_312825283
Nutrients Required to Convert Biomass into Humus

Crop Residues

Biochemical Transformations

+ (N, P, S etc.)

Humus

<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>

Sequestering 12 Mg of C would need 1 Mg of N.
TRANSFORMATIVE STRATEGIES

5 Ds

Take Land From Nature

- Deplete
- Degrade
- Destroy
- Discard
- Dominate

5 Rs

Return Land to Nature

- Reduce
- Reuse
- Recycle
- Regenerate
- Restore

Transformational Change
REGENERATIVE AGRICULTURE

Inspired by eco-innovation, powered by non-carbon energy, driven by a circular economy and green infrastructure, and supported by the re-carbonization of the terrestrial biosphere as the bedrock of sustainable development.
MANAGING SOIL CARBON AND RESTORING SOIL HEALTH BY RA & EI

- Complex Rotations, Cover Crop
- Continuous Soil Cover
- Integrated Nutrient Management
- No Soil Disturbance
- Restoring SOC By Regen. Agric. & EI
- Producing More From Less
ZERO BUDGET NATURAL FARMING VS REGENERATIVE AGRICULTURE

RA is not to be confused with ZBNF. The latter is not an option to feed 8B people now and 11 B by 2100.

RA is based on the Law of Return by Sir Albert Howard “Anything taken from soil should be returned to it.”
THE LAW OF RETURN

“The law states that substance we take from nature must be returned to the place from which it was taken.”

— Sir Albert Howard
Creating Positive C Budget

Soil Carbon Sequestration
- Biochar
- Compost
- Cover Crops
- Root Biomass
- Crop Residues

Losses
- Erosion
- Leaching
- Decomposition

Gains
- Residue
- Compost
- Root Biomass

Soil Carbon Depletion
INNOVATIVE AGRICULTURAL PRACTICES

• Conservation agriculture
• Regenerative agriculture
• Agroecology
• Agroforestry
• Integration of crops with trees and livestock
• Practices with positive soil/ Eco.C budget
• (CNPK) through ISFM
• Balanced use of plant nutrients
• Drip Fertigation
• Digital Agriculture & Precision Farming
• Artificial Intelligence, Drones, & Robotics
TECHNICAL POTENTIAL OF C SEQUESTRATION

I. Soils ........................................... 1.45 – 3.44 Pg C/yr (2.45 Pg C/yr)  
   \textit{Lal (2018)}

II. Terrestrial Biosphere by 2100

   • Soils ........................................... 178 Pg
   • Vegetation ................................... 155 Pg

   \textbf{Total} 333 Pg (157 ppm CO}_2\textbf{)  

   \textit{Lal et al. (2018)}
SOCIETAL VALUE OF SOIL ORGANIC CARBON

• Inherent value: $130/ton C (Nickel per lb) = $35/ton CO$_2$

• For 0.5 ton C/ha = $65/ha = $26/acre

• For 0.33 ton C/ha = $43/ha = $17.5/acre
GLOBAL FOOD PRODUCED BY SMALL FARMS

• Total Crop Production: 28-31%
• Food Supply: 30-34%
• Gross Agricultural Area: 24%
• Total Number of Farms: 570 Million
• Farm Size: <2ha
• Total population of Small Farms: 2.3-3.5 B

Ricardi et al. (2018)
Lowder et al. (2016)
Demand for Food Production in Africa

SSA will need to produce three times more cereals by 2050 relative to 2005-2007 to maintain the present level of self-sufficiency (about 80%) due to population growth and dietary change.

Alexandreatos and Bruinsma (2012)
SOIL DEGRADATION IN AFRICA

- 65% of arable land, 30% of grazing land, and 20% of forest in Africa are already degraded
- Serious land degradation accounts for about a quarter of the land area of SSA
- About 180 million people who are living on the land that is in some way or another degraded
- Increase in erosion risks between 1980s and 2090 in Africa are +36% and the world are +14%
- Soil degradation is the cause of food insecurity

Montpellier Panel (2105)
Managing Nutrient Depletion in Africa

• Global fertilizer use = 135 kg/ha

• Fertilizer use in SSA = 17 kg/ha

• SSA has 20% of world’s arable land but it consumes only 2% of the world’s fertilizer
Irrigation in Africa

• Irrigation can alleviate drought and can double or more comparable rain fed crop yields

• Only 6-7% of cropland in Africa (13 Mha) is presently irrigated compared with 14% in Latin America and 37% in Asia
TEMPORAL CHANGES IN AVERAGE GRAIN YIELD OF CEREALS IN THE WORLD AND AFRICA

Rice Paddy

\[ y = 50.05x + 1871 \]
\[ R^2 = 0.99 \]

\[ y = 19.90x + 1564 \]
\[ R^2 = 0.95 \]

(Lal 2017)
TEMPORAL CHANGES IN AVERAGE GRAIN YIELD OF CEREALS IN THE WORLD AND AFRICA

Maize

\[ y = 68.07x + 1772 \quad \text{R}^2 = 0.99 \]

\[ y = 20.19x + 1017 \quad \text{R}^2 = 0.96 \]

(Lal 2017)
A ROAD MAP FOR FEEDING SSAFRICA

<table>
<thead>
<tr>
<th>Technological Options</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer Use (kg/ha)</td>
<td>17</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Irrigated Cropland (%)</td>
<td>6</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Conservation Agriculture (M ha)</td>
<td>1.5</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Agroforestry (% of tree cover on agric. land)</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

Cropland Area = 242 M ha

AF = Zomer et al. (2009)
CA = Kasam et al. (2019)
SELF-RELIANCE IN AFRICA
Goals for 21st Century

• Return Land to Nature: 10% per Decade

• Restore Degraded Land: 2 B Ha

• Protect all natural ecosystems

• Reconcile need to grow health food with the necessity of improving the environment

• No farmer left behind
THE ROLE OF PRIVATE SECTOR

Private sector can play a critical role in translating science into action by:

• Promoting nature positive agriculture,
• Increasing access to inputs,
• Improving investment in agric. research and development
COOPERATION WITH THE PRIVATE SECTOR

Private Sector

SDGs
#1, 2, 6, 13, 15

Land Managers

Policymakers

International Organizations

Academics
LiSAM for Making Soils and Agriculture a Carbon Sink: IICA/C-MASC

• Soils of managed ecosystems (crops, pastures, forests and urban) have a large C sink capacity, and it must be harnessed for adaptation and mitigation of ACC.

• Soil is a living entity, and its life-support processes must be enhanced

• Soils of these ecosystems can be sink for atmospheric CO\textsubscript{2} by judicious management and adopting the science-based options.
LONG-TERM OBJECTIVES OF CA4SH

- Enhancing cooperation among multiple stakeholders
- Promoting on-the-ground adoption of BMPs
- Developing tools for MMV of soil health & its indicators
- Advocating a system-based soil health agenda
- Implementing an action plan for restoring soil health
- Developing a protocol for payments of ESs
- Empowering farmers/land managers to adopt BMPs
- Strengthening human resource capital
- Enhancing respectability of soil health profession
- Alleviating drudgery of farming operations

Lal (2021)
EDUCATION OF THE NEXT GENERATION

• In addition to 3Rs, goal of the education is to prepare the next generations to address global issues:
  • Food and nutrition,
  • Environment: Soil, water, air, global warming
  • Personal responsibility: culprit and victim
  • Ethics
  • Integrity
  • Respect for nature
CONNECTING CHILDREN WITH NATURE
THE MANTRA

“Healthy Soil = Healthy Diet = Healthy People = Healthy Ecosystems = Healthy Planetary Processes”