ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE MANAGEMENT OF WATER, SOIL AND WASTE

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DRESDEN, GERMANY
THE NEXUS APPROACH TO MANAGING WATER, SOIL AND WASTE

Carbon Management and Sequestration Center
Dr. Rattan Lal
Population
Energy use
Water use
Deforestation
CO₂ Emissions
Land Degradation
Desertification

8000 BC

Time

Anthropocene

Human Impact

8000 BC
Earth Processes Transformed by Agroecosystems

Land Area: 38% of the Terrestrial Surface

GHG Emissions: 30-35% of the Global

Fresh Water Withdrawal: 71%

Increase Since 1960s:
  i) Irrigation: x2
  ii) Fertilizer: x5
  iii) Nitrogen: x8
Yet, **1 in 7** are food insecure.
Rather than a silver bullet or a panacea, we must look for multiple paths. We cannot afford to be myopic and locked into a specific strategy whether organic farming, no-till agriculture, biotechnology, and others.

We need some revolutionary approaches
ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE MANAGEMENT OF WATER, SOIL AND WASTE

NO PANACEA NOR A SILVER BULLET

Sustainable Intensification

- CA (Climate-Resilient Agriculture)
- GMOs
- Agroforestry
- Micro-Irrigation
- INM IPM
- Precision Farming
- Farming System Analysis
- LCA
- The Nexus Approach

Climate-Resilient Agriculture & the Nexus Approach
INTERCONNECTIVITY AMONG RESOURCES

Water

Energy

Soil

Biota/Vegetation

Climate Change and Variability

Energy Mass Transformation

The Hydrological Cycle

Plant Available Water Capacity

Growing for Food, Energy, and Natural Resources

Biogeochemical Cycling

Food Security under Changing and Variable Climate
INTER-CONNECTIVITY
OF HUMAN NEEDS

- Soil Security
- Water Security
- Climate Security
- Food Security
- Energy Security
- Economic Security
- Political Security
Soil

• Blue • Green • Grey

Energy

Waste

Biogeochemical Cycles

H₂O Cycle

Food Security

GHG Emissions

Climate

• Precipitation • Temperature

Water

• Blue • Green • Grey

Evaporation

Condensation

Recycling

Composting

Combustion

Biodigester Transformation

Evaporation

Potential, Kinetic Condensation
Shades of Water

BLUE

GREEN

GREY

ENERGY

ENERGY

HUMAN
## WATER FOOTPRINT OF BIOFUELS

<table>
<thead>
<tr>
<th>Crop</th>
<th>Brazil</th>
<th>The Netherlands</th>
<th>USA</th>
<th>Zimbabwe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>205</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>51</td>
<td>-</td>
<td>58</td>
<td>254</td>
</tr>
<tr>
<td>Maize</td>
<td>39</td>
<td>9</td>
<td>18</td>
<td>200</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>49</td>
<td>20</td>
<td>37</td>
<td>64</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>75</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poplar</td>
<td>55</td>
<td>22</td>
<td>42</td>
<td>72</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>25</td>
<td>-</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>214</td>
<td>67</td>
<td>113</td>
<td>-</td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td><strong>62</strong></td>
<td><strong>24</strong></td>
<td><strong>57</strong></td>
<td><strong>142</strong></td>
</tr>
</tbody>
</table>

... Adapted from Gerben-Leenes et al., 2009)
## Water Footprint of Food

<table>
<thead>
<tr>
<th>Food</th>
<th>Liters of water per kg</th>
<th>Relative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables</td>
<td>322</td>
<td>1</td>
</tr>
<tr>
<td>Starchy roots</td>
<td>387</td>
<td>1-20</td>
</tr>
<tr>
<td>Cereals</td>
<td>1644</td>
<td>5-11</td>
</tr>
<tr>
<td>Pulses</td>
<td>4055</td>
<td>12-56</td>
</tr>
<tr>
<td>Chicken meat</td>
<td>4325</td>
<td>13-43</td>
</tr>
<tr>
<td>Bovine meat</td>
<td><strong>15,415</strong></td>
<td><strong>47-87</strong></td>
</tr>
</tbody>
</table>

... Adapted from Mekonnen and Hoekstra, 2012
POVERTY ENVIRONMENT NEXUS

- “Love and business and family and religion and art and patriotism are nothing but shadows of words when a man is starving.”
  … O’Henry (1907)

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

- “When people are poverty stricken, desperate and hungry, they pass on their sufferings to the land.”
  … Lal (2008)
SOIL – WATER NEXUS

Food
(Availability, Access, Quality)

Soil
(Quality, Degradation)

Water
(Scarcity, Quality)

ENERGY
SOIL – WASTE NEXUS

- Composting
- Land Application
- Biosolids
- Energy (Biofuels)
- Affluent as Soil Amendment

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FOOD – NATURAL RESOURCES NEXUS

Climate
Change
Variability
Extreme Events

Soil
Nutrients
Water Transformations

Food
Calories
Protein
Micronutrients
**Importance of Urban Agriculture**

<table>
<thead>
<tr>
<th>City</th>
<th>Population (10^6)</th>
<th>Growth Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1950</td>
<td>2025</td>
</tr>
<tr>
<td>New Delhi</td>
<td>1.4</td>
<td>28.6</td>
</tr>
<tr>
<td>Calcutta</td>
<td>4.5</td>
<td>20.1</td>
</tr>
<tr>
<td>Bombay</td>
<td>2.9</td>
<td>25.8</td>
</tr>
<tr>
<td>Pune</td>
<td>0.6</td>
<td>6.6</td>
</tr>
<tr>
<td>Hyderabad</td>
<td>1.1</td>
<td>8.9</td>
</tr>
<tr>
<td>Bangalore</td>
<td>0.7</td>
<td>9.5</td>
</tr>
<tr>
<td>Madras</td>
<td>1.5</td>
<td>9.6</td>
</tr>
</tbody>
</table>

| % of population living in cities of > 1 million | 3.1 | 15.6 | 5.0 |

(Adapted from Kazmin, 2011)
SOIL-LESS CULTURE

- **Air**
  - Aeroponics (mist)
- **Solid**
  - Gravel-Bed Culture
  - Zeolites (Zeponics)
  - Vermiculite
  - Fabric
  - Floating Bed (Chinampas)
- **Liquid**
  - Liquid Flow Technique
  - Hydroponics
  - Aquaponics (Fish and Crops)
  - Plant Residues
  - Sand Culture
  - Wood
    - Chips
    - Saw dust
    - Bark
    - Shaving
  - Crop Residues
    - Bales
    - Rice husk
  - Bagasse
  - Peat Moss
BIOREGENERATING SOIL-BASED SPACE AGRICULTURE

Multiple life support functions of plants:

- Removing CO$_2$ through photosynthesis,
- Generating O$_2$,
- Producing food,
- Purifying waste water applied to roots through transpiration,
- Composting inedible biomass,
- Denaturing pollutants by soil and filtering H$_2$O,
- Increasing harvest index from 50% to 70% to reduce per capita food production area from 40 to 28m$^2$, with edible biomass productivity of 16 to 22g m$^{-1}$d$^{-1}$

...Wheeler, 2003; Silverstone et al., 2003)
GRAVITY EFFECTS ON SOIL PROCESSES

Physical: Soil buoyancy, hydrologic properties, advection, soil permeability, water infiltration rate, low water residence time,

Chemical: Nutrient dispersion & transport rate, low solute residence time,

Biological: Nutrient transformation,

Plant: Biomass dynamics

Coupled dynamics of soil hydrologic and biogeochemistry

Gravity: Earth 1g = 9.806 m s⁻²
Mars = 0.38g
Moon = 0.16g
Orbiting Space Station = 0g
TRILEMMA OF SOIL DEGRADATION
(Rates Per Minute)

Causes
• Population increase : 150 people (births 250, deaths 100)
• CO₂ carbon increase : 6150 ton
• Tropical deforestation : 25 ha
• Urban encroachment : 5.5 ha

Effects
• Soil degradation : 10 ha
• Deaths from hunger : 16 people (incl. 12 children)

Consequences
• Political instability
• Civil strife
THE FUTURE AGRICULTURE

• This is an exciting era, especially for agriculture and systems of food production
  – More change will happen between now and 2050 than during the past 10-12 millennia since the onset of agriculture

• With automation and full integration with the industrial sector, the global farmer population will decrease to < 1% of the 9.6 billion by 2050 or 11 billion by 2100

• The high tech 3-dimensional vertical farms can efficiently produce clean organic food within the urban centers
THE WAY FORWARD

- With projected population expected to be 9.6 billion by 2050, we have to be innovative and resourceful.
- The BAU approach will jeopardize the natural resources already under great stress.
- The losses must be minimized and efficiency enhanced by 3Rs:
  - Reduce,
  - Reuse, and
  - Recycle