THE OHIO STATE UNIVERSITY

Carbon Storage in Soil in Relation to Climate Change

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Impressive Agronomic Production Since 1960s

The rapid increase in agricultural production since the 1960s has been caused by massive inputs of fertilizers ,pesticides, energy use in plowing and other farm operations, irrigation of about 350 M ha of land, and expansion of agriculture to about 5 G ha of land area.

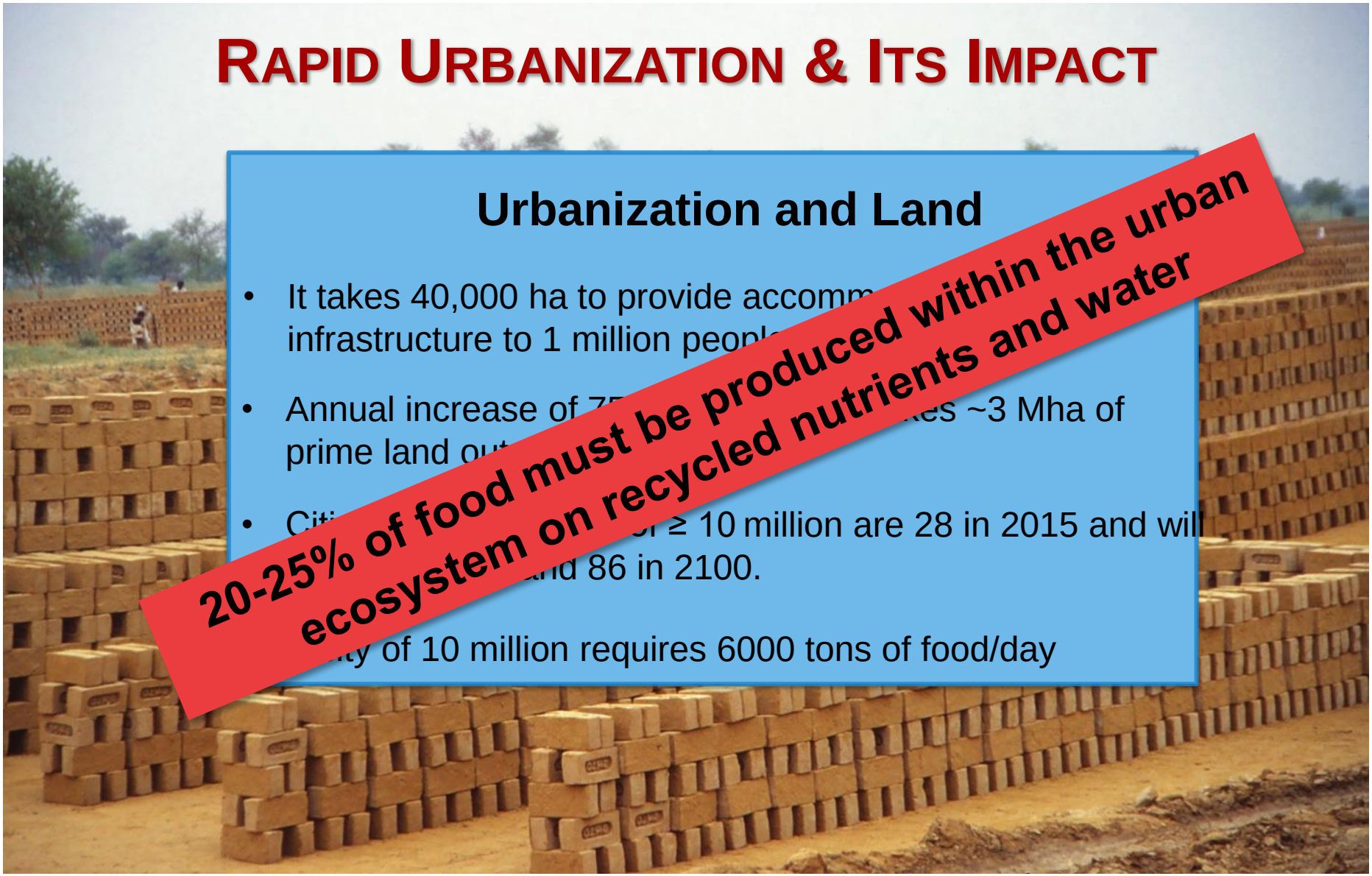
This has led to a strong interaction between human and nature as is evidenced by numerous indicators.

THE RESOURCES USED FOR AGRICULTURE

- 49% 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 9 persons is food-insecure, 2-3 in 7 are malnourished, global temperatures have increased by 1 C already and may increase by another 3-5 C by 2100.

RAPID URBANIZATION & ITS IMPACT



Urbanization and Land

- It takes 40,000 ha to provide accomm
  infrastructure to 1 million peopl
- Annual increase of 7
  prime land ou
  es ~3 Mha of
- Citi
  ≥ 10 million are 28 in 2015 and will
  nd 86 in 2100.
- ty of 10 million requires 6000 tons of food/day

20-25% of food must be produced within the urban ecosystem on recycled nutrients and water

GLOBAL AVERAGE SOIL EROSION

Global Sediment Load = 36.6 Gt/yr(Walling,2009)

A) Agricultural Land = 47.6 x $10^6 km^2$ = 4760 Mha
Average Sediment Rate = 7.7 Mg/ha

B) Accelerated erosion preferentially removes SOC and Clay.

C) Soil erosion by water emits 1.1 Gt C/Yr (Lal,2003)

D) Loss on productivity and use efficiency of input is a serious issue

E) Risks of soil erosion will increase with increase in climate change

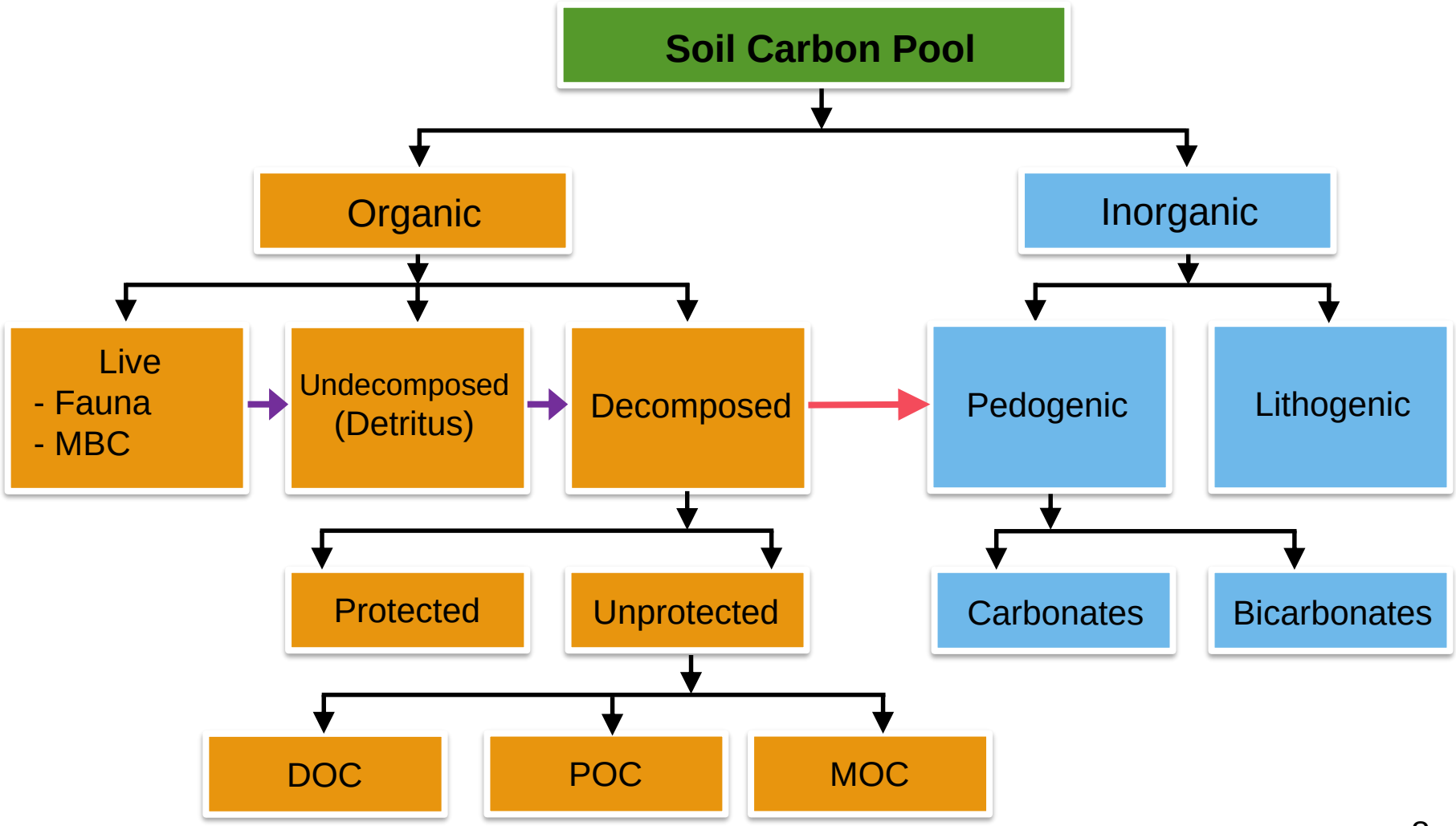
The Need for a Paradigm Shift

- There is a need for a paradigm shift in managing soils of agroecosystems so that human demands can be met while restoring the environment.
- Eco-intensification (EI), designed to restore soil organic carbon (SOC) and soil inorganic C (SIC) stocks of degraded soils, is an option to bring about the desired paradigm shift.
- Sustainable management of SOC, to maintain stocks above the threshold level of 1.5% to 2.0% in the root zone, is essential to sustaining productivity while restoring the environment.

Toward Making Soil of Agroecosystems A Carbon Sink

- Soils of agroecosystems, croplands and pasturelands combined, cover about 5 Gha of manageable land area for soil C sequestration.
- Soils of these ecosystems can be sink for atmospheric CO_2 by judicious management and adopting the science-based agriculture

SOIL C POOLS IN SHORT & LONG-TERM CYCLES



CARBON POOLS IN DIFFERENT RESERVOIRS FOR THE LONG-TERM CYCLE

Reservoir	C Pool (10^{18} g)
Carbonate in Rocks	60,000
Organic C in Rocks	15,000
Ocean (HCO_3^-, CO_3^{-2})	42
Soils	6
Atmosphere	0.8
Biosphere	0.6

There is extremely little CO_2 in the atmosphere compared to that in the rocks. Thus, if inputs and outputs are not closely balanced, the atmosphere would become overwhelmed with CO_2.

WEATHERING OF SILICATES

$$CO_2 + CaSiO_3 \longleftrightarrow CaCO_3 + SiO_2$$

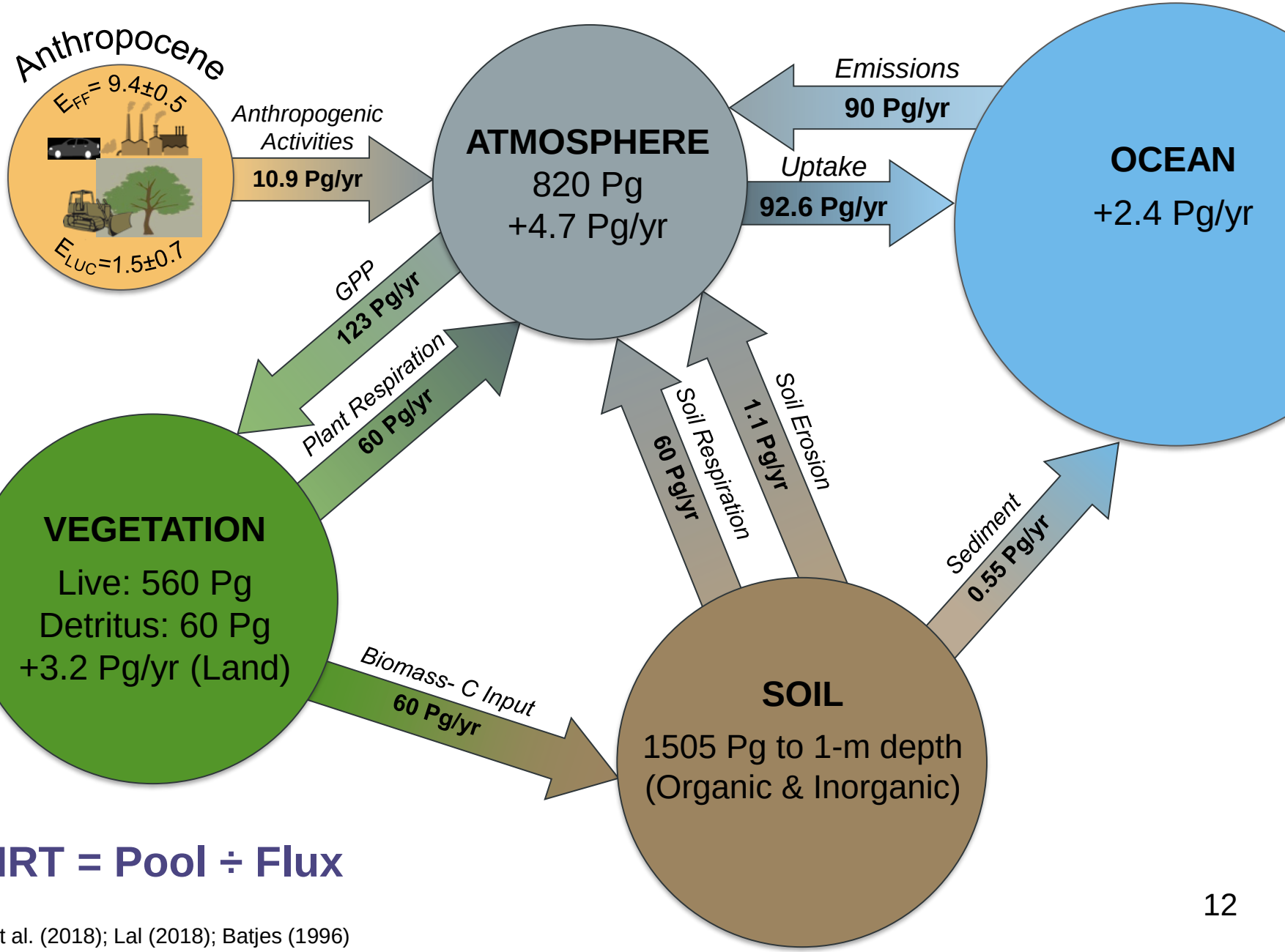
$$CO_2 + MgSiO_3 \longleftrightarrow MgCO_3 + SiO_2$$

Urey Reactions

CARBON POOLS IN DIFFERENT RESERVOIRS FOR THE SHORT-TERM CYCLE

Reservoir	Pool (10^{15} g)
Ocean	42,000
Fossil Fuel	5,000
Soils (3-m)	6,000
Atmosphere	780
Biota	620

THE SHORT-TERM GLOBAL CARBON CYCLE (2008-2017 DATA)



MRT = Pool ÷ Flux

Le Quere et al. (2018); Lal (2018); Batjes (1996)

SOIL CARBON SEQUESTRATION

It refers to the processes of transfer and long-term retention of atmospheric CO_2 in organic and inorganic carbon pools in soil through photosynthesis, humification of biomass C, formation of pedogenic carbonates and leaching of bicarbonates, synthesis and stabilization of organo-mineral complexes, and development of stable structural aggregates.

SOIL INORGANIC CARBON

The soil inorganic carbon (SIC) pool is comprised of the primary and secondary carbonates and bicarbonates, originating from the weathering of parent rock and pedogenic substances.

Global dryland area of 66.7 million Km^2 is an important sink of inorganic carbon with a large potential of sequestration of secondary carbonates and leaching of bicarbonates.

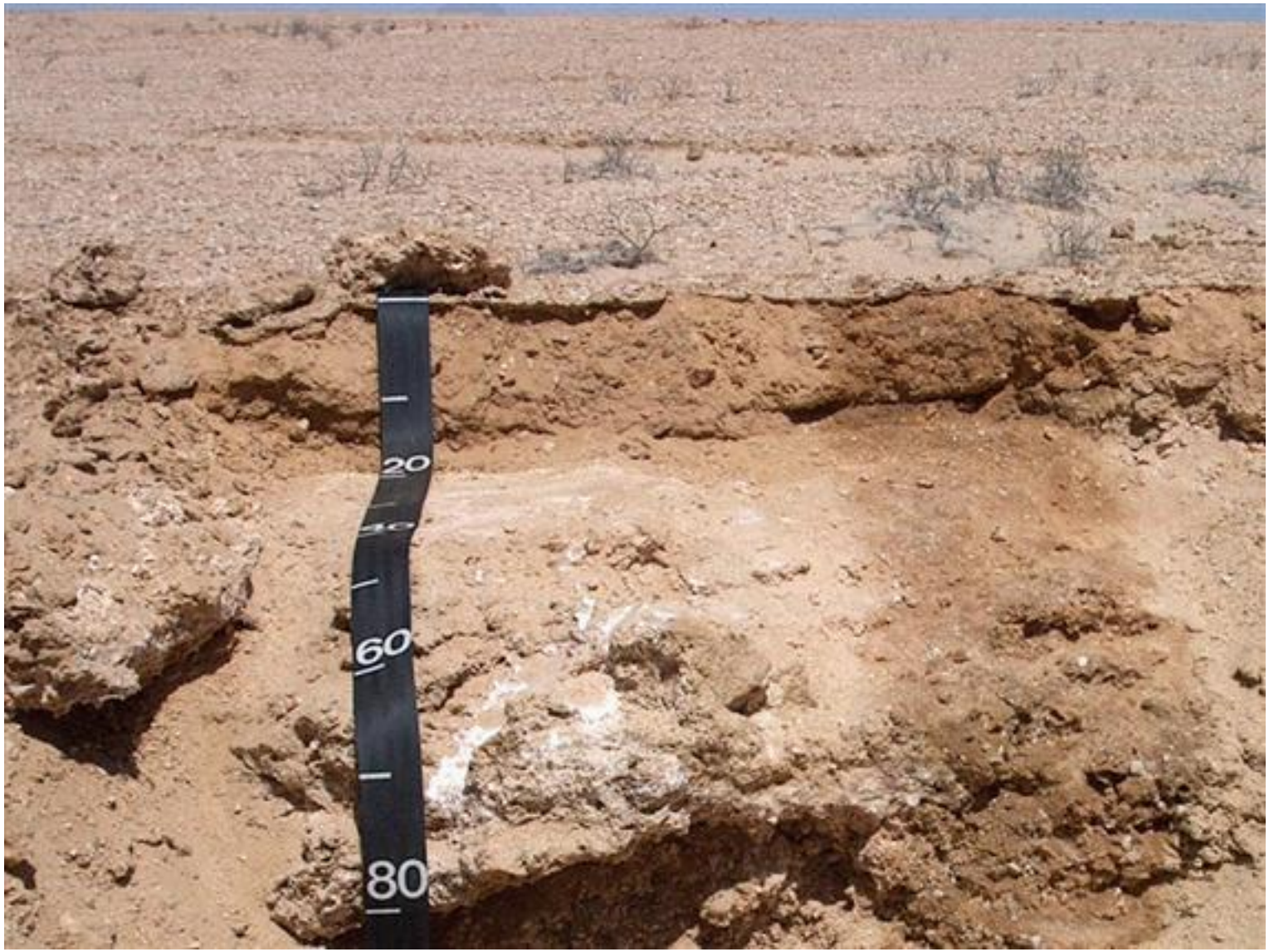
FORMATION OF SECONDARY CARBONATES
TOTAL LAND AREA OF DRYLANDS=66.7 MILLION KM^2

$$CO_2 + H_2O_1$$

g ↓↑

$$CaCO_3 + H_2CO_3 \leftrightarrows Ca^{2+} + 2HCO_3^-$$

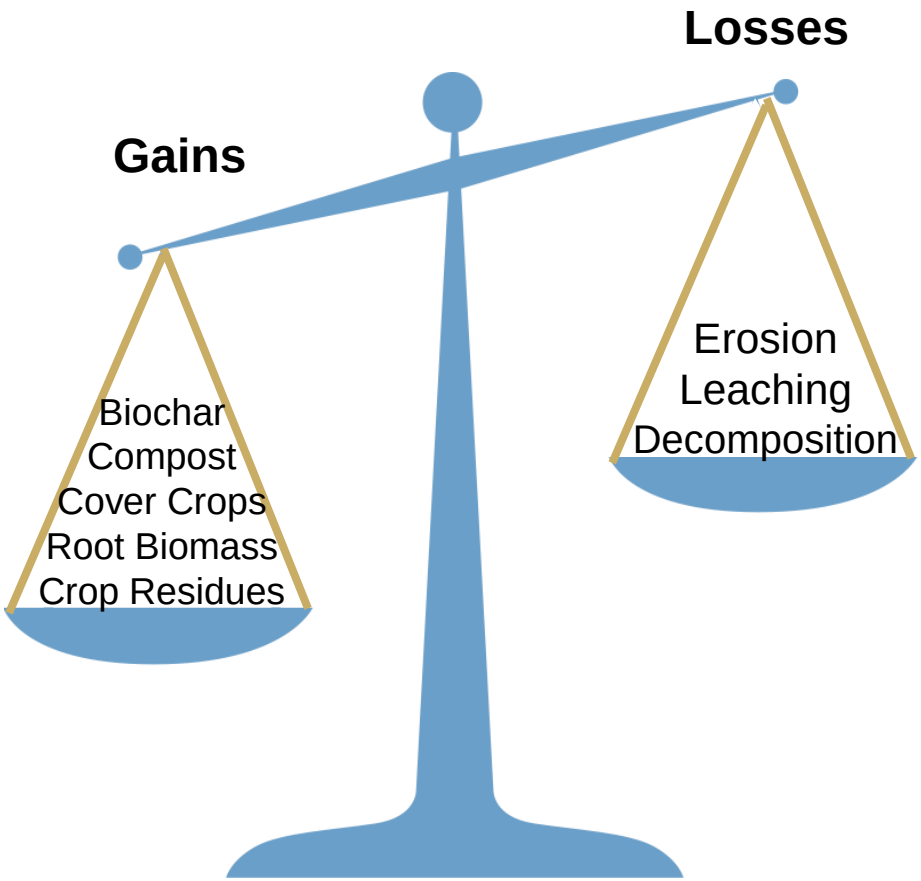
c aq aq Aq.



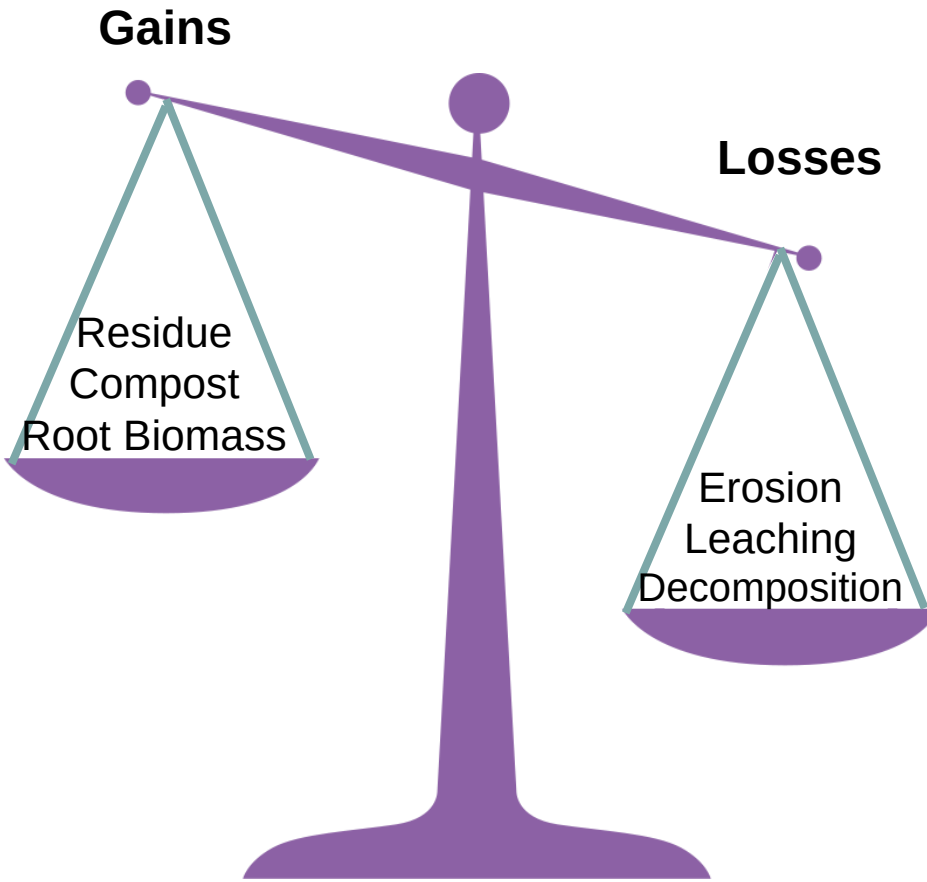
SOIL ORGANIC CARBON

The soil organic carbon (SOC) pool is comprised of the remains of plants, animals, microbes, and their by-products and pyro-genic substances at various stages of decomposition, forming integral components of organo-mineral complexes and structural aggregates.

CREATING POSITIVE C BUDGET



Soil Carbon Sequestration



Soil Carbon Depletion

TECHNICAL POTENTIAL OF C SEQUESTRATION

I. Soils ..... 1.45 – 3.44 Pg C/yr (2.45 Pg C/yr)

Lal (2018)

II. Terrestrial Biosphere by 2100

- Soils ..... 178 Pg
- Vegetation ..... 155 Pg

Total 333 Pg (157 ppm CO_2)

Lal et al. (2018)

Eco-Intensification(EI)

- EI is defined as intensification of biological processes supporting ecosystem services on medium-term (efficiency of management options) and long-term (sustainability of management options) basis

21ST CENTURY'S GREEN REVOLUTION

Rather than input-based (variety, fertilizers, irrigation), the GR of the 21st century must be:

(i) Soil-based	:	Soil resilience
(ii) Ecosystem-based	:	Eco-Efficiency
(iii) Knowledge-based	:	Science & Mgm-driven

Comparison of Organic Farming, Sustainable Intensification, and Eco-Intensification(Lal,2019)

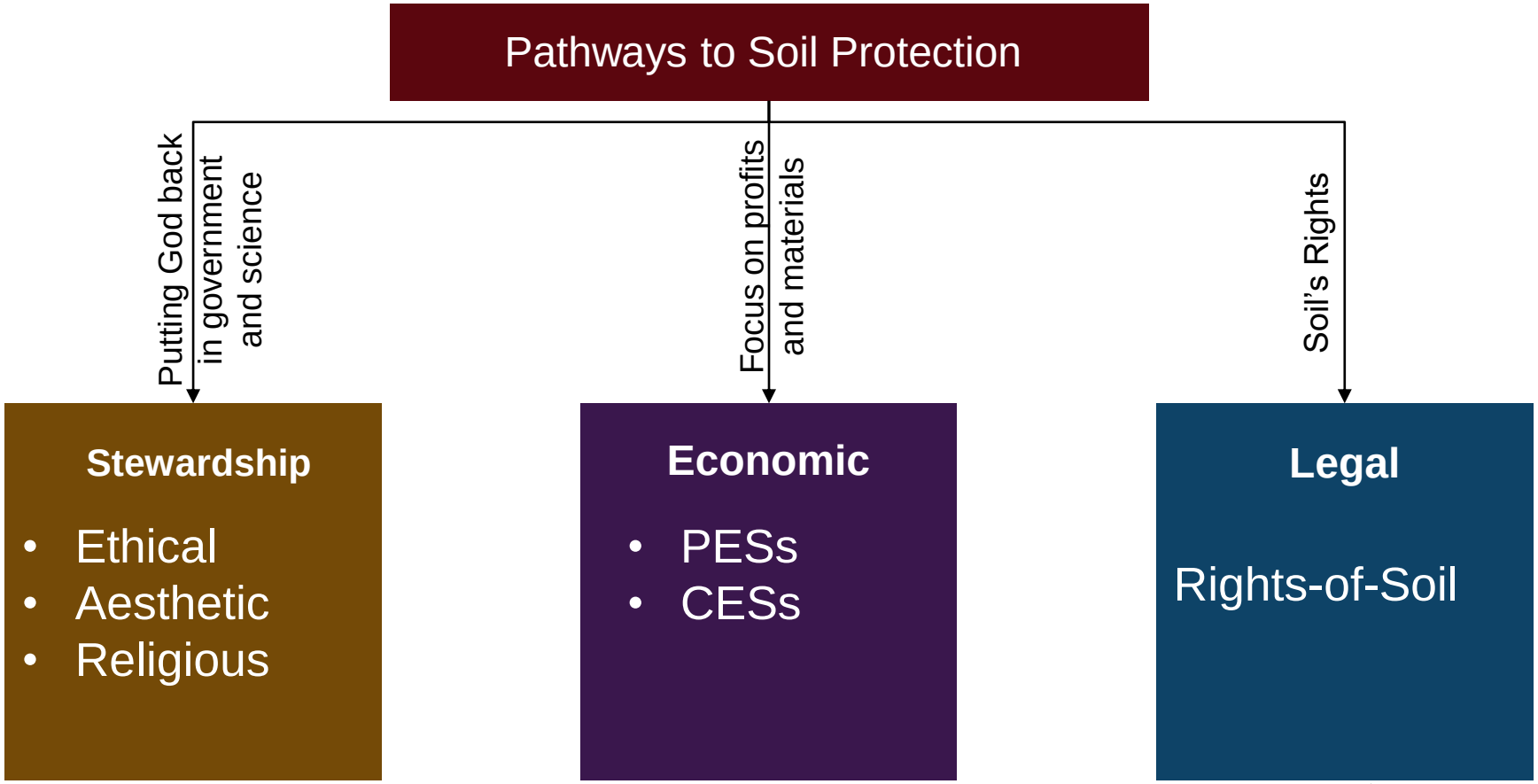
Parameter	Organic Farming	Sustainable Intensification	Eco-Intensification
Fertility management	Managing soil organic matter, enhancing soil biological activity, biological nitrogen fixation (BNF)	Using chemical fertilizers	Using INM based on a judicious combination of organic and inorganic sources, biomass recycling, and BNF
Disease and pest management	Crop rotations, natural predators, resistant varieties, diverse cropping systems	Chemical pest control: herbicides, fungicides, insecticides	IPM, creating disease suppressive soils, judicious chemical intervention, and enhancing biodiversity
Seedbed preparation	Mechanical tillage for weed control, residues incorporation, and manure management	No-till based on chemical weed control	CA based on a system approach
Water management	Soil-water conservation	Supplemental irrigation, drip-fertigation	Soil water conservation, minimal supplemental irrigation, resilience against drought-flood syndrome

REDUCING LAND AREA UNDER CEREALS IN THE 21ST CENTURY SAVING LAND FOR NATURE CONSERVANCY

Parameter	Year 2005–07	2050	2080	2100
Population (10^9)	6.4	9.7	10.6	11.2
Per capita food consumption (kcal)	2772	3070	3200	3300
Cereal production (10^6 Mg)	2012	3012	3350	3540
Land area needed for intensive agriculture (Mha)	682	600	560	500
Total fertilizer demand (10^6 Mg)	200	160	120	100
The desired global average cereal yield (kg ha^{-1})	3280	5000	6000	7000

"Use the best, save the rest"

Lal (2016)



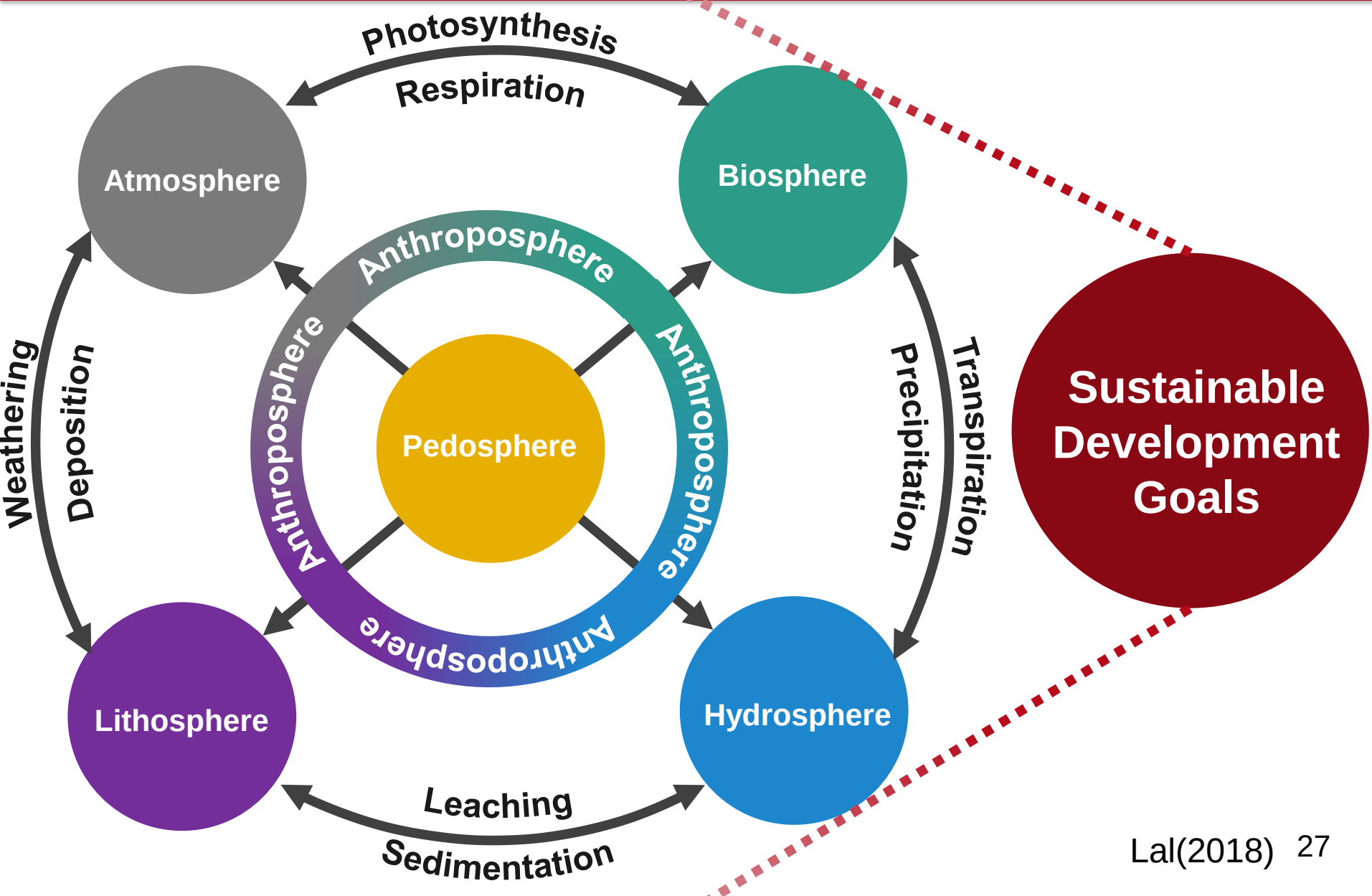
Paradigm Shift from Revolution to Evolution

Lal 2019)

RIGHTS-OF-SOIL

Just as Universal Rights of Human, Rights of animals , there must also be Rights-of- Soil , and Rights-of-Nature. Being the essence of all life, soils must also have rights to be protected, restored, thrive and managed judiciously.

The violator of basic soil rights ought to have legal and binding implications.


Photosynthesis
Respiration
Atmosphere
Biosphere
Anthroposphere
Anthroposphere
Anthroposphere
Pedosphere
Weathering
Deposition
Precipitation
Transpiration
Sustainable Development Goals
Lithosphere
Hydrosphere
Leaching
Sedimentation

Lal(2018)

CLIMATE CHANGE, AGRICULTURE AND THE WORLD PEACE


Illustration by Lincoln Agnew, NYT 4/21/2013

- Humans have not had to deal with such a drastic climate change since 10-12 millennia ago
- Now the humans, with population of 7.7 billion in 2019 and projected to be 11.2 billion by 2100, have to deal with it and increasingly so in the future
- **COP-25 in Santiago in December 2019 is a historic landmark for making soil and agriculture a solution. Now is the time for a concrete action.**

ACTIONS NEEDED BETWEEN 2020 AND 2030 TO LIMIT GLOBAL WARMING TO 1.5^{O}C

- Limiting GHG emissions to a budget of 420 Gt of CO_2 The current rate of emissions is 42 Gt CO_2/yr (Hoegh-Guldberg et al.2019),
- Phasing out fossil fuels, along with reduction of CH_4, N_2O and black C,
- Reducing land use emissions (~1Gt C/Yr) which are critical to achieving zero net emissions by 2050,
- Removing CO_2 from the atmosphere such as sequestering emissions in terrestrial ecosystems
- Including soil restoration as an integral component of the U.N. Decade of Restoration
- Ensuring global peace through soil restoration

Soil Degradation

The Regime Shift by Extractive Farming

- 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
- 68.5 Million Refugees in 2018

Severe Degradation

SECURITIZATION OF FOOD AND THE ENVIRONMENT THROUGH SOIL SUSTAINABILITY

Security → Political → Economic → Social → Environmental

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

SOLUTIONS UNDER FOOT: THE POWER OF SOIL AND WORLD PEACE

Depleting Soil Organic Matter and Declining soil fertility, Degrading Soils and Denuding Landscapes, Recurring Drought and Intensifying Heat Waves, Low Crop Yields and Perpetual hunger, Marginal living and Desperateness are as Real Threats to Global Peace and Security as are ICBMs and Nuclear Weapons. The fire that burns in the pit of an empty stomach is so intense and ferocious that it can only be extinguished by the divine powers in a loaf of bread made from grains grown on a healthy soil. This is the time to make agriculture a solution to issues of food, climate, poverty, desertification and for achieving SDGs.

Rattan Lal
2019 Japan Prize
8th April Tokyo ,Japan