CGIAR

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

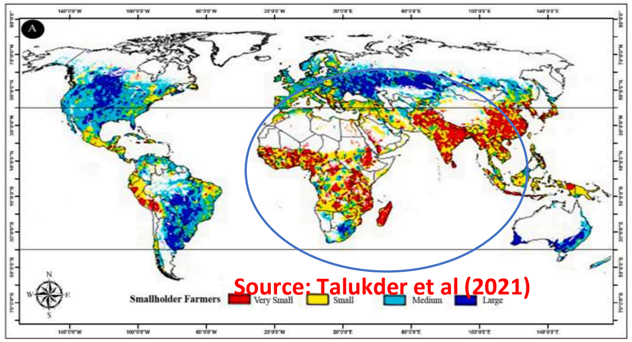
Regenerating Soil Health in Smallholder Systems of South Asia: Challenges and Strategies

Presentation at Soil Health 2024 Japan Workshop, January 30, 2024

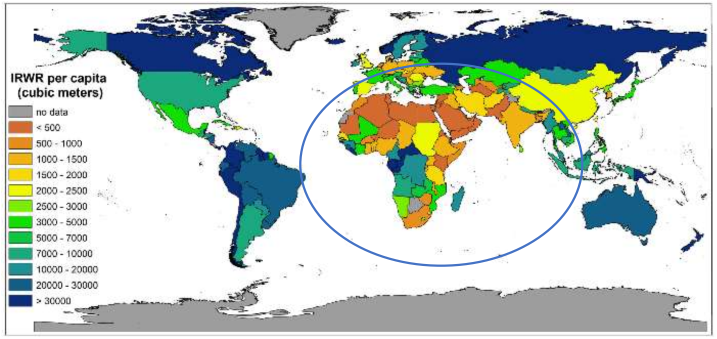
ML Jat | Director, Global Research Program on RFFS, ICRISAT |
mangilal.jat@icrisat.org | www.icrisat.org

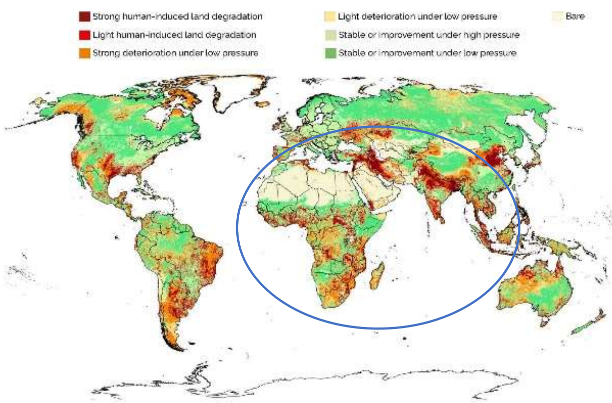
Smallholder Systems in South Asia has Unparallel Challenges

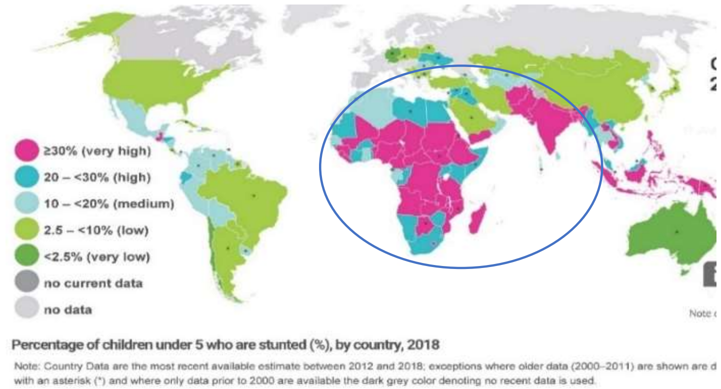
- A global ‘hotspots’ for contemporary and future climate vulnerability
- Natural resources (land, water, biodiversity) are highly stressed
- Emerging biotic stresses
- Smallholder’s dominance: smallholder farmers feed the majority of population
- Relationship of dominance of smallholders, drylands, land degradation and malnutrition



Source: Talukder et al (2021)



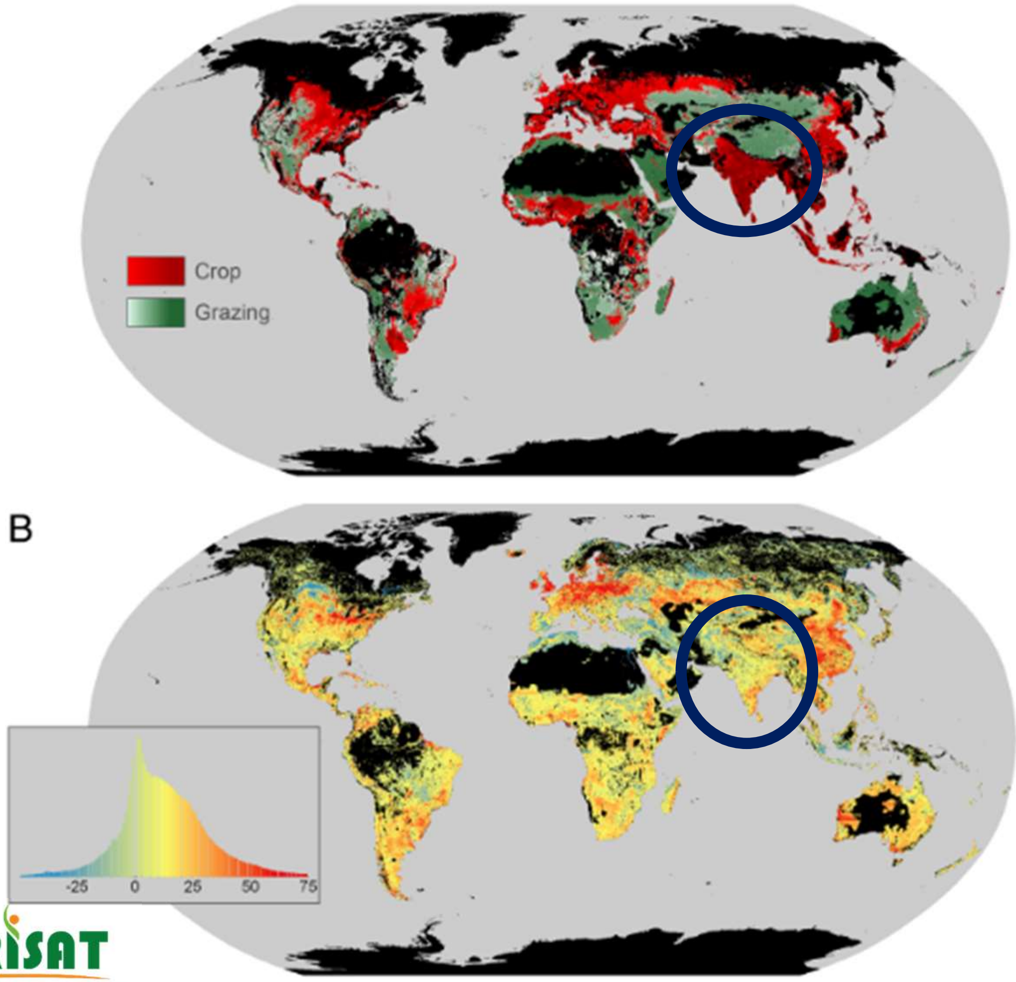




Source: EAT-Lancet Commission Report, (2019), UNICEF, 2019

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Global distribution of cropping and grazing and SOC change in the top 2 m



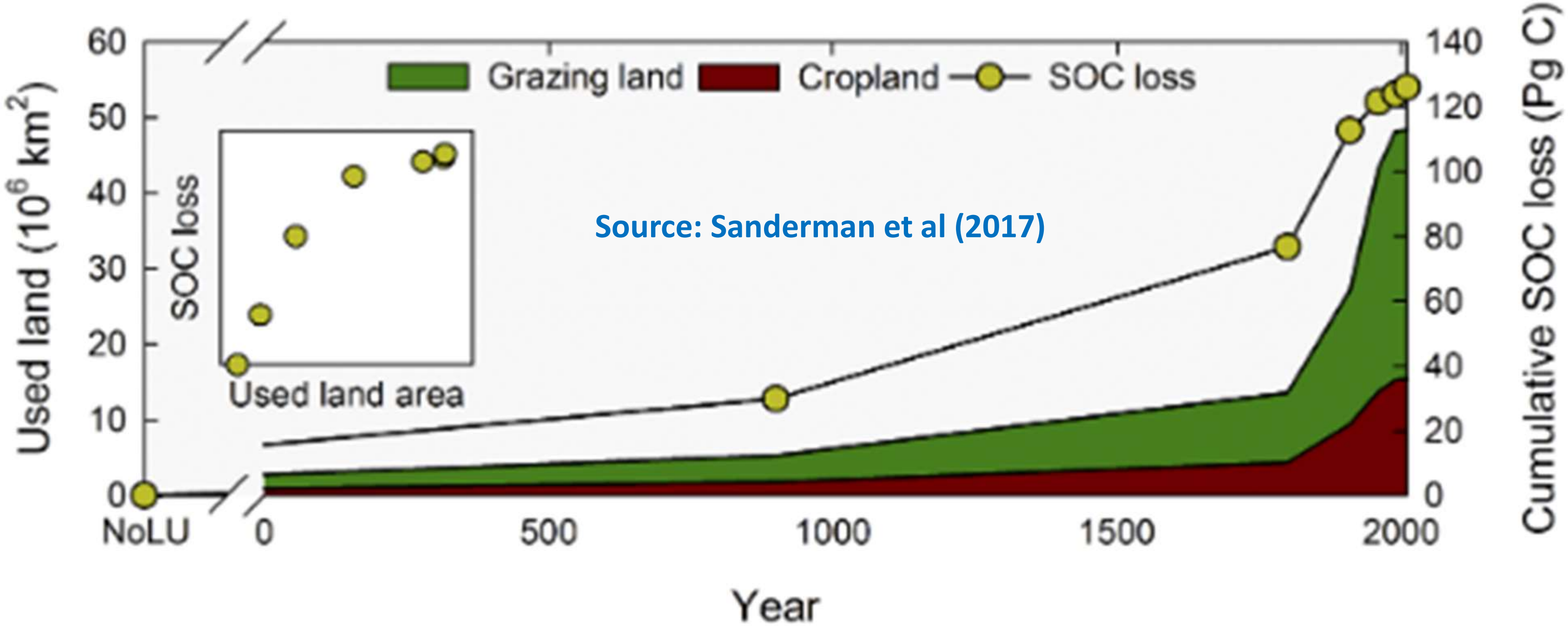
Land Use: Distribution of crop and grazing land

SOC: Gain (-) and Loss (+): Mg C ha^{-1}

Source: Sanderman et al (2017)

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Historic Trend in Cropland, Grazing Land & SOC Loss

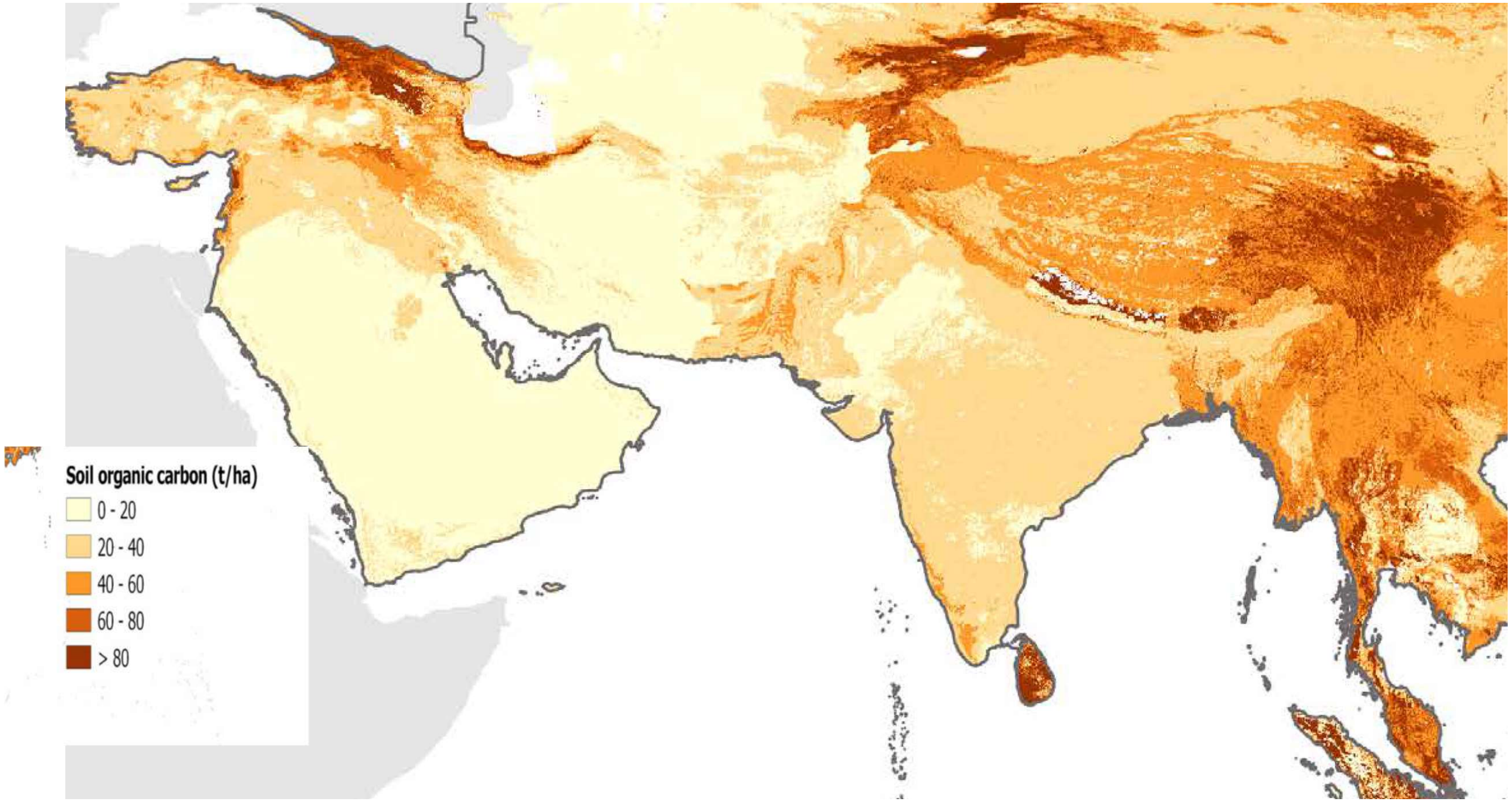


Source: Sanderman et al (2017)

- 133-Gt soil carbon deficit that has accrued over time
- beginning about 20 y ago, proposals for repaying this carbon debt, through regenerative farming practices, began to emerge as a climate mitigation strategy (*Ronald Amundson, 2022, PNAS*)

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Soil Organic Carbon - Asia

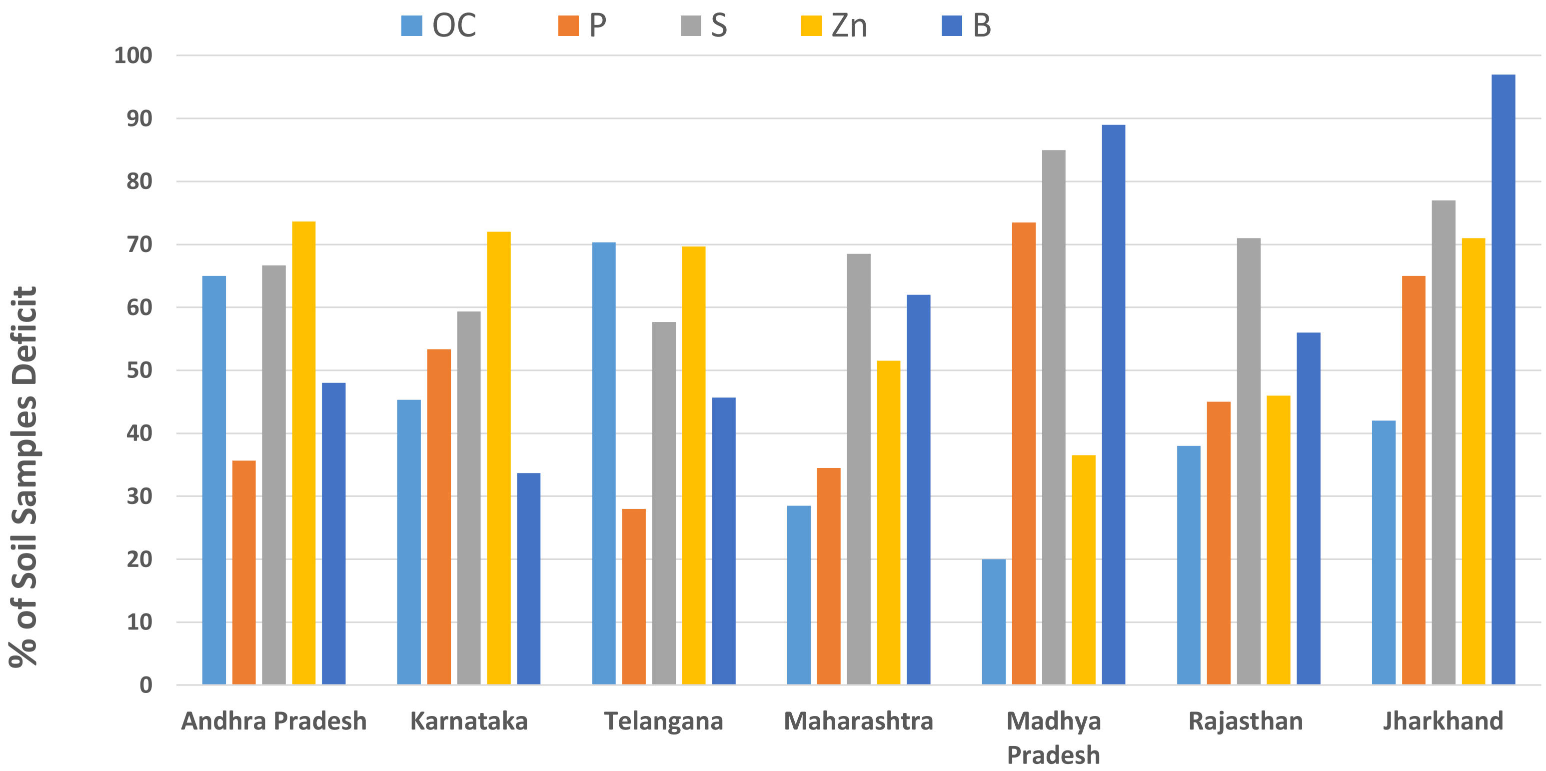


- **Top-soil (0-30 cm) store 248 petagrams of carbon**
- **Potential to sequester additional 180 metric T of C/yr (thru high C-input sustainable soil management practices)**

Source: Soil Carbon Map (FAO, 2022)

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Soil Health Monitoring: ICRISAT's Work in India

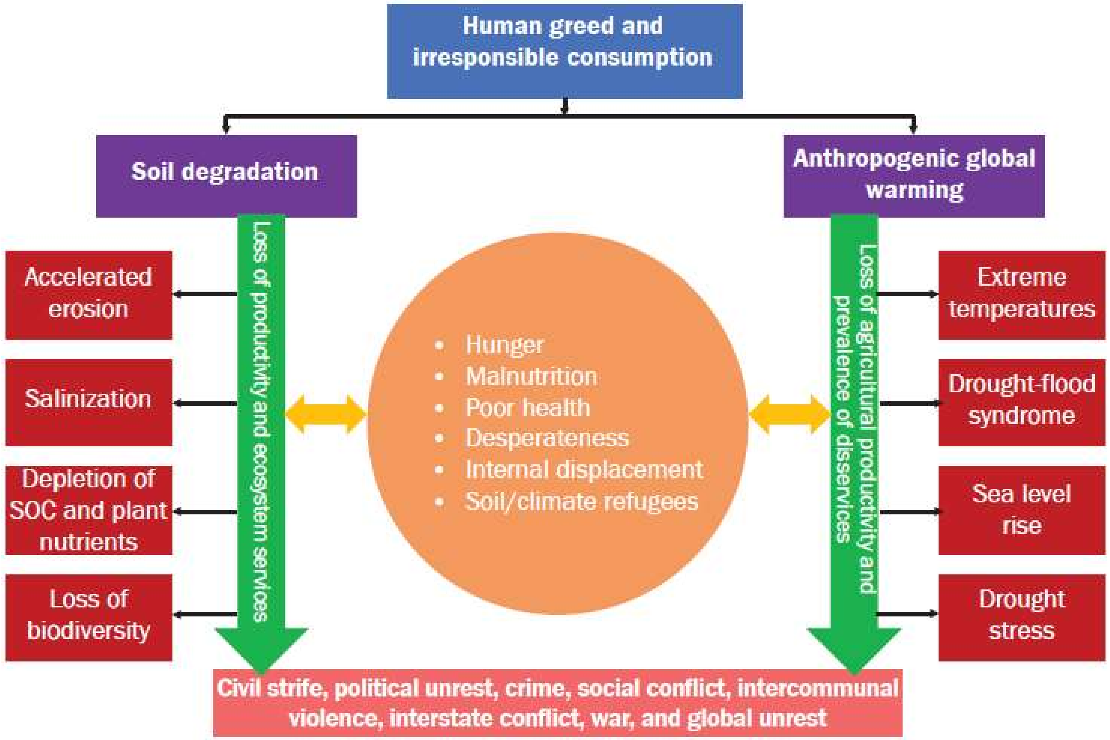


ICRISAT generated soil data (*n* =106845) displaying % of soil samples (India) showing different deficiencies of SOC, P, S, Zn, B

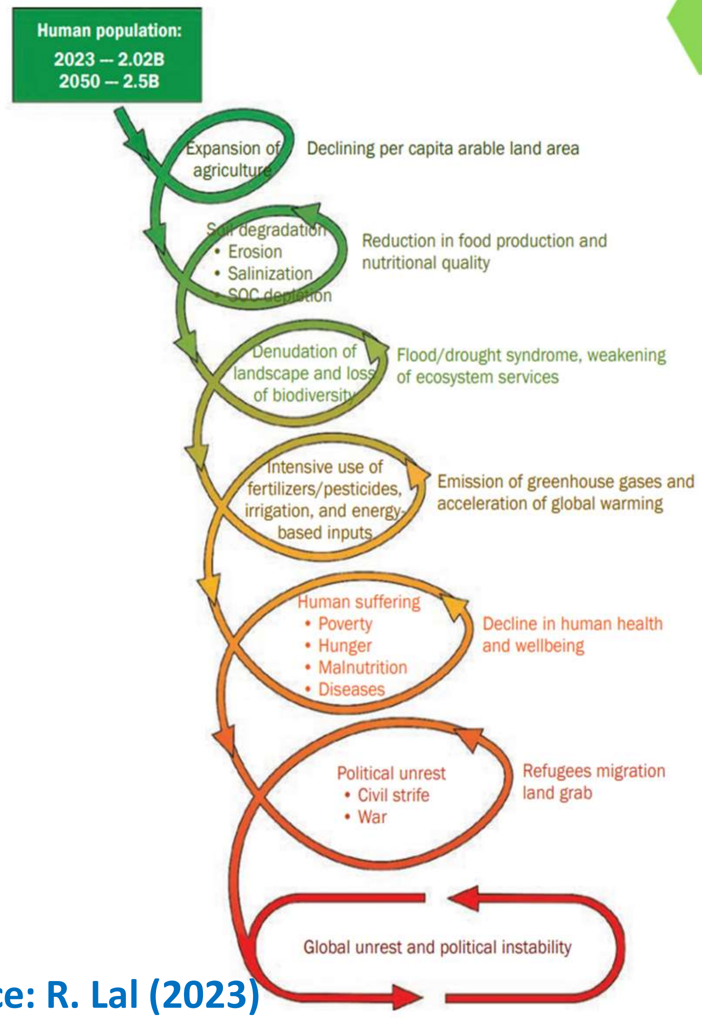
Source: Derived from soil health management projects, ICRISAT 2004-2021

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Stressors to Peace Caused by Soil Degradation and Global Warming



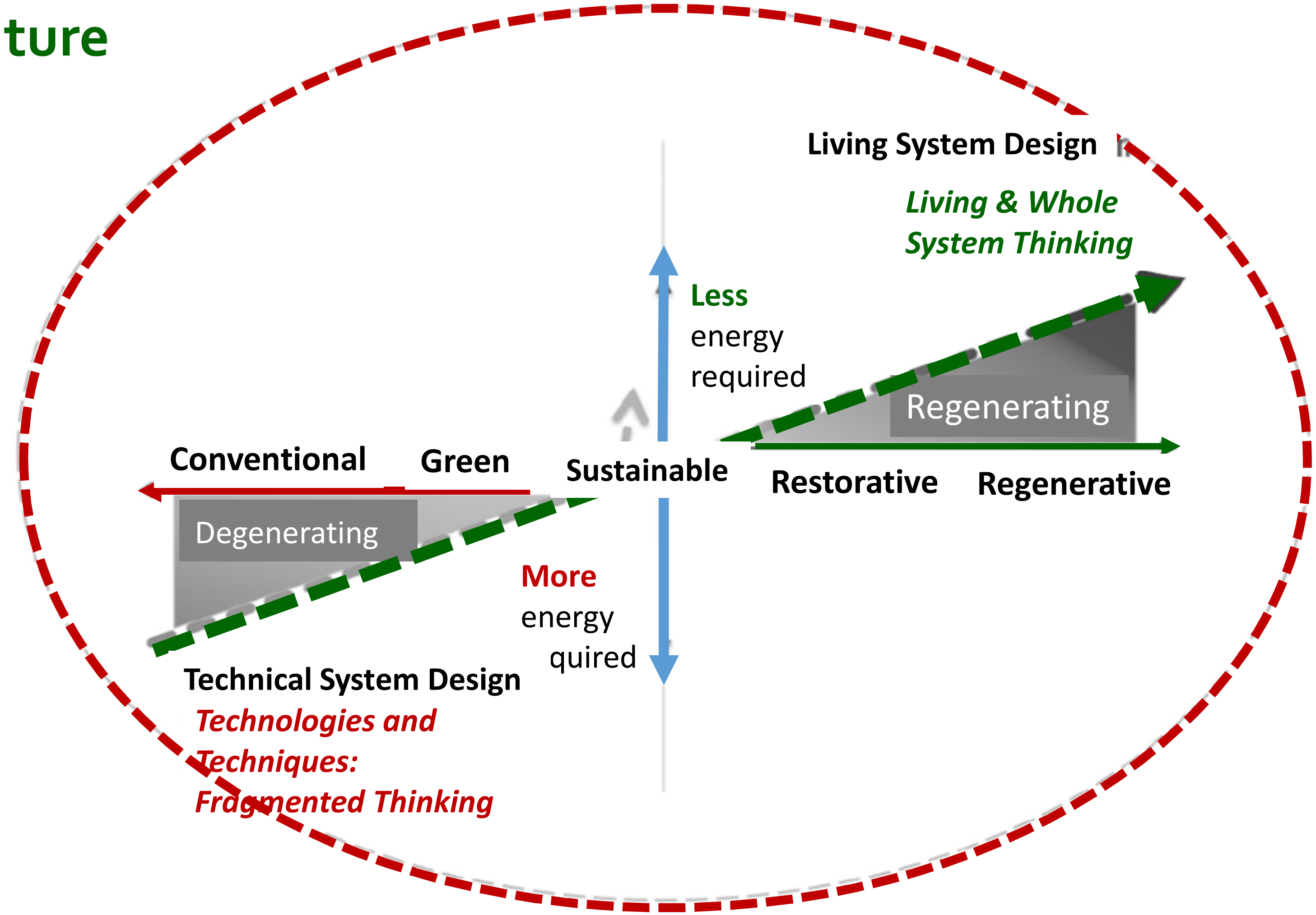
Source: R. Lal (2022)



Source: R. Lal (2023)

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Trajectory for Transitioning from Degenerative to Regenerative Agriculture



ICRISAT
INTERNATIONAL CROPS RESEARCH
INSTITUTE FOR THE SEMI-ARID TROPICS

Ways to Regenerate: RA

Regenerative agriculture (RA) is a prominent alternative seeking to transform food production and repair ecosystems. The farming practices and approaches that-

- Uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting ecosystem services
- Enhance not only the environmental, but also the social and economic dimensions of sustainable food production

Principles	Practices
Minimum tillage	conservation agriculture, Zero-till, reduced tillage,
Maintain soil cover	Mulch, cover crops, permaculture
Build soil C	Biochar, compost, green manures, animal manures
Sequester carbon	Agroforestry, silvopasture, tree crops, no-till+Residues
Relying more on biological nutrient cycles	Animal manures, compost, compost tea, green manures and cover crops, maintain living roots in soil, inoculation of soils and composts, reduce reliance on mineral fertilizers, organic agriculture, permaculture
Foster plant diversity	Diverse crop rotations, multi-species cover crops, agroforestry
Integrate livestock	Rotational grazing, holistic grazing, pasture cropping, silvopasture
Avoid pesticides	Diverse crop rotations, multi-species cover crops, agroforestry
Encouraging water percolation	Biochar, compost, green manures, animal manures, holistic grazing, No-till+ residues

Tangible Benefits of Conservation/Regenerative Agriculture

5-12% System Yield
(increased)

46-62% Energy (saving)

10-30 % in WUE
(increased)

20-27% Profitability
(increased)

26-44% Labor (saving)

12-33% reduction in
GWP

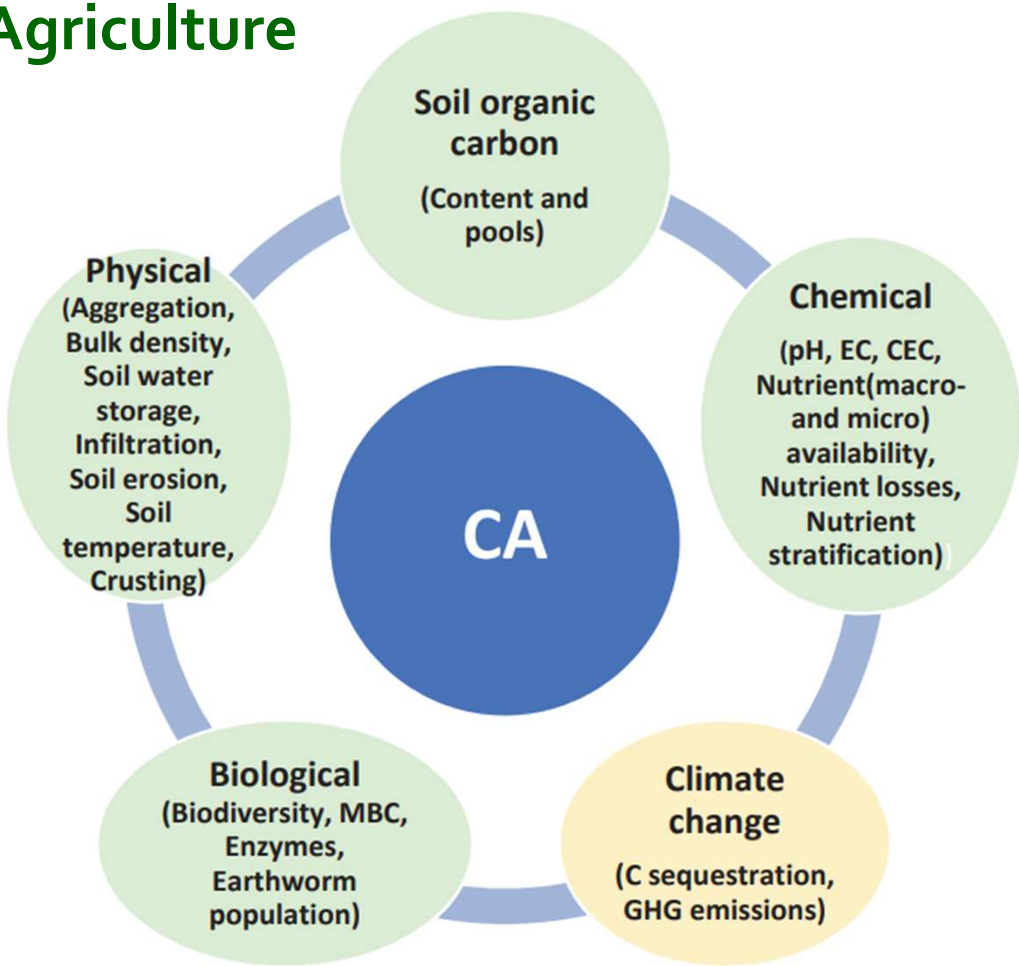
CA systems can dramatically improve biodiversity, increase the soil organic matter, and bring a lot of positive environmental externalities, minimize abiotic stresses etc

------REGENRATIVE AGRICULTURE

Source: Jat et al (2020), Nature Sustainability, Jat et al (2023)

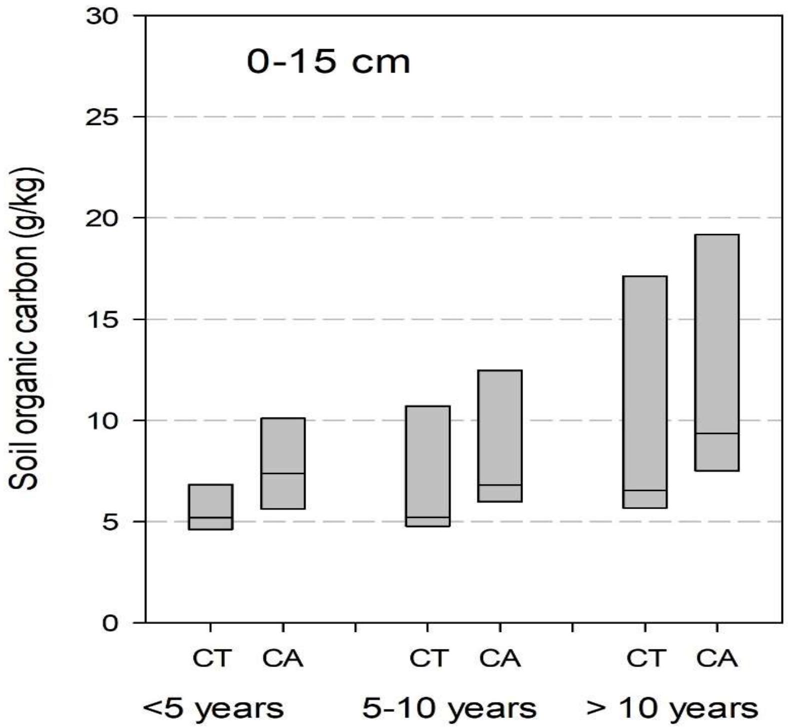
ICRISAT
INTERNATIONAL CROPS RESEARCH
INSTITUTE FOR THE SEMI-ARID TROPICS

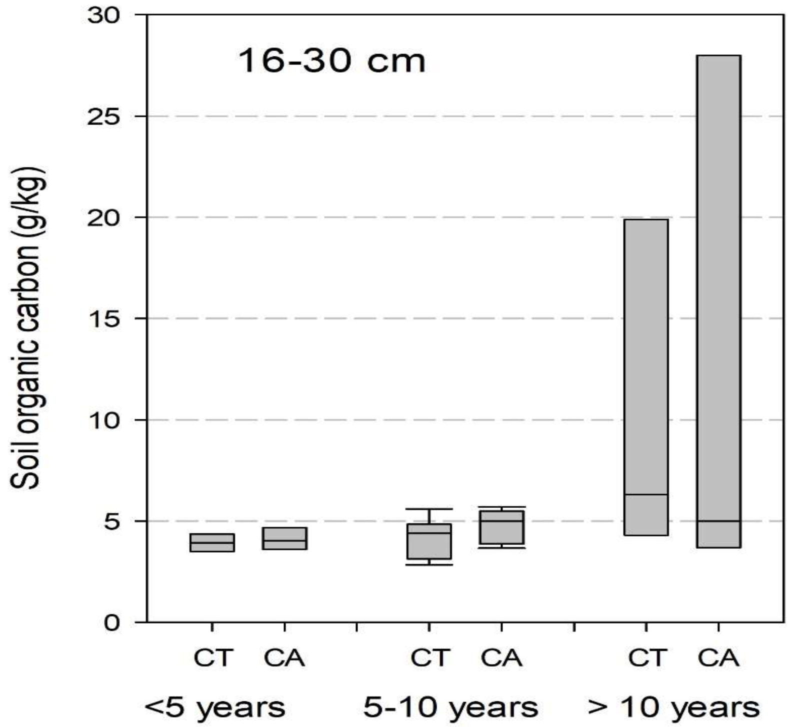
Soil health Indicators and Climate Action Delivered through Conservation Agriculture



Source: Jat et al (2023), Advances in Agronomy

Conservation Agriculture Impacts on Soil Organic Carbon in South Asia

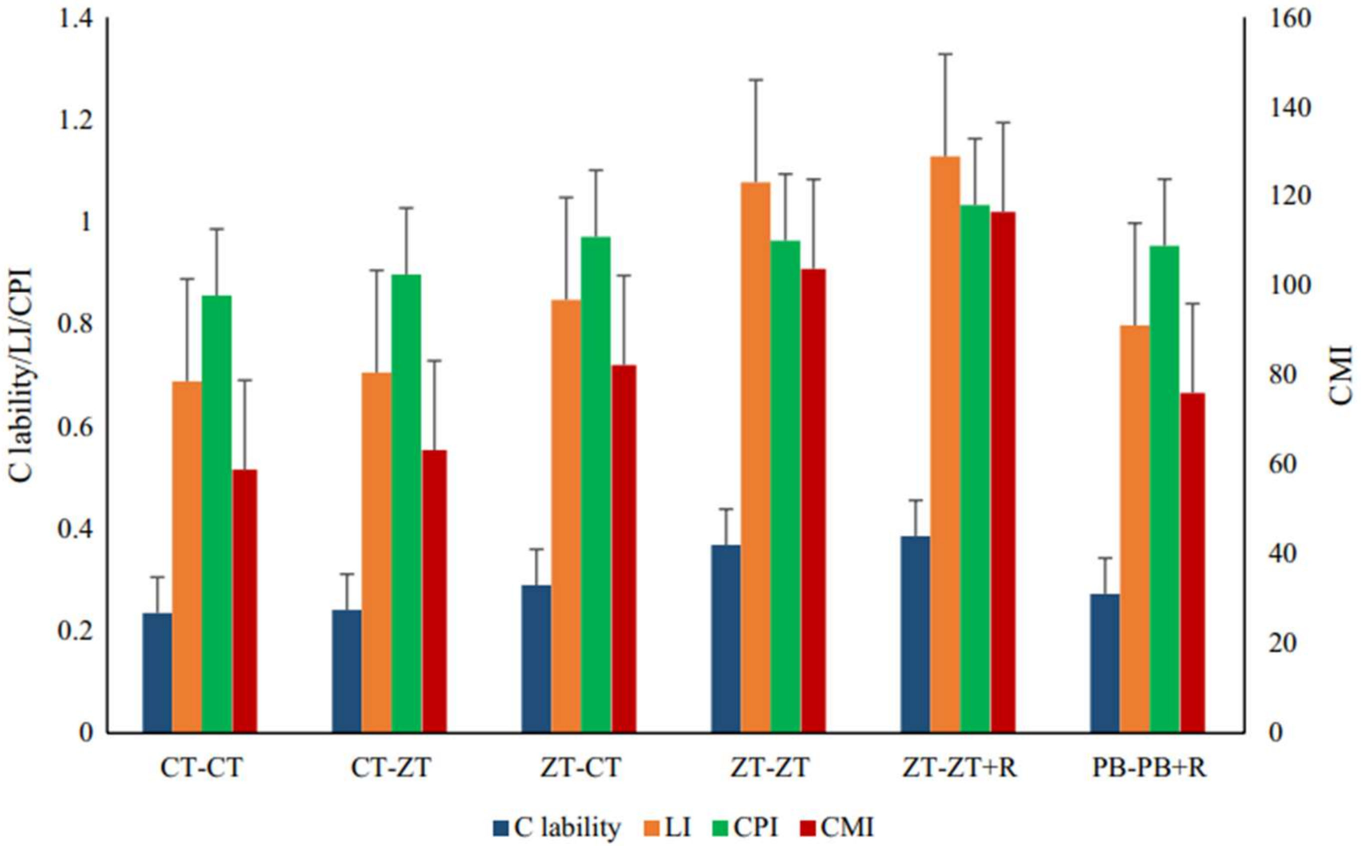




- 33 Studies across South Asia
- Major cropping systems
- Soil types
- Different duration (2-12 years)

Source: Jat et al (2023), Advances in Agronomy

Changes in SOC lability, lability index (LI), carbon pool index (CPI) and carbon management index (CMI) under long-term CA in RWCS



Source: Dey, Dwivedi, ----Jat et al (2023)

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Challenges Associated with SOC Sequestration

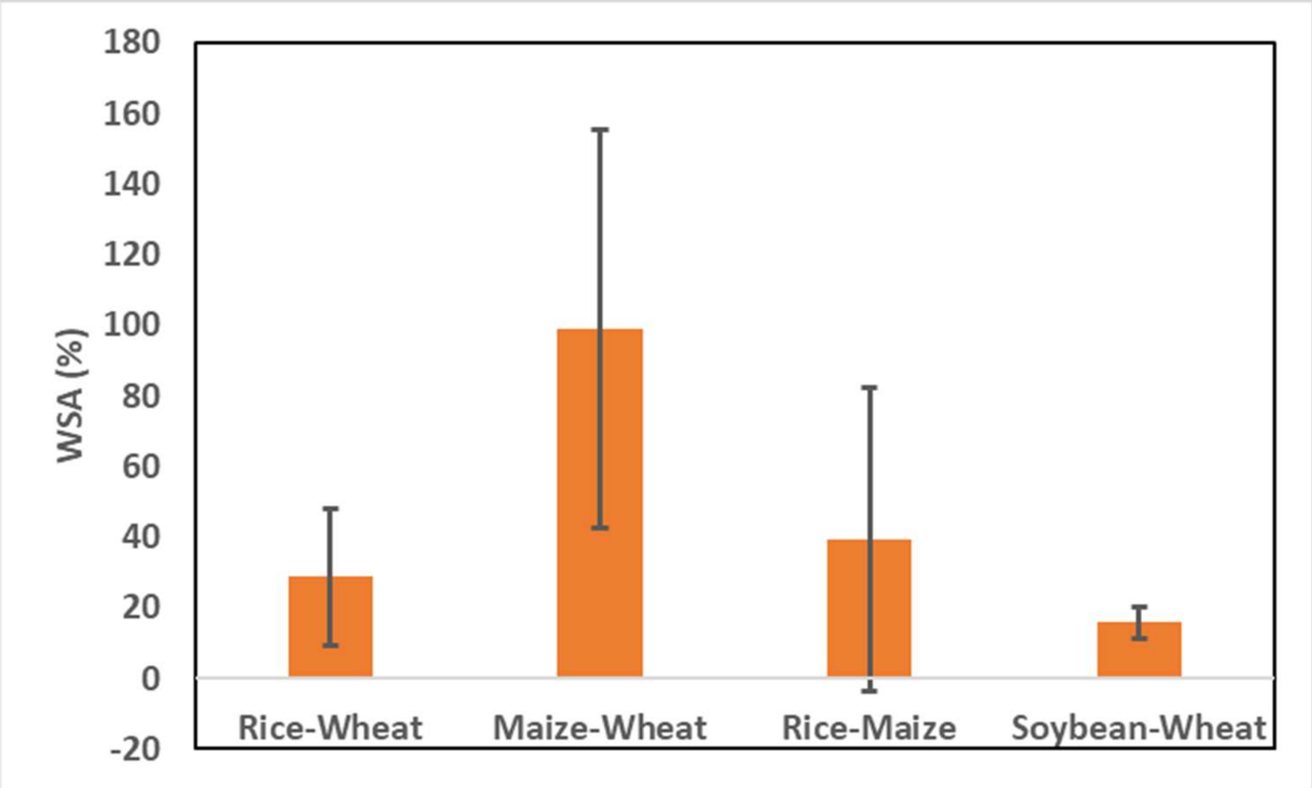
- Retention of C in a soil is not unlimited (C saturation)
- Carbon storage in soil is not permanent (Non-permanence)
- Socio-economic constraints

Source: Jat et al (2022)

Socioeconomic constraints to adoption of potential SOC sequestration practices.

SOC sequestration Practices	Adoption constraint	Major reasons for mismanagement (trade-offs)	Implications or risk of mismanagement
No open grazing	Lack of dedicated pastureland for grazing, shortage of fodder, poor economic conditions of farmers especially landless livestock farmers	Excessive uncontrolled grazing, community/social structure, lack of regulations	Results in bare fallow and soil surface exposure to wind and water erosion and loss of SOC
Scientific land use plans and sustainable soil management	Ineffective policies	Good quality soils used for other purposes such as brick making, urbanization	Loss of soil and SOC, virgin/forest soils are put under agricultural use
Zero or reduced tillage	Lack of knowledge and machinery, conventional tillage-based mindset legacy and misconceptions, lack of locally adapted packages	Conventional/intensive tillage (CT)-based mindset, lack of incentives for eco-system services	CT results in loss of SOC and GHG emissions
Crop residue retention/ recycling	Other economic usages of crop residue such as fodder, fuel and fencing/no cheaper and easy options of burning, lack of knowledge and capacity	Residue removed or burned	Wrong use of crop residue and burning results in loss of C and GHG emissions
Application of biochar	Technology constraint, economic constraints	Biochar application is not a common practice	Increase in GHG emissions, risk of respiratory diseases, toxicity
Balanced use of nutrients including organic amendment	Knowledge gap, non-availability, affordability	Imbalanced or inadequate and inefficient use of nutrients	Loss of soil fertility and sub-optimal crop yields due to loss of C and GHG emissions
Crop need based N application	Knowledge gap, fertilizer subsidy in many developing countries	Inefficient including either inadequate or excess use of N fertilizer	Low levels of SOC from inadequate N use or loss of SOC and increase in N_2O emissions from excess of N
Controlled water application	Poor irrigation infrastructure, bad policies such as heavy subsidy on energy and water	Inefficient water management	SOC loss and increased GHG emission from frequent soil wetting and drying
Use of crop varieties with SOC associated traits such as deep rooting	No breeding efforts for deep rooting traits	Use of varieties with shallow rooting	Inadequate root biomass
Fallow management: cover crop, weedy fallow	Poor land management and lack of financial incentives	Bare fallow	SOC loss and GHG emissions
Crop rotation optimization	Knowledge gap, poor infrastructure, lack of incentives	Sub-optimal crop rotation, i.e. rotations with long fallow or rotations with contrasting edaphic management requirement (rice-wheat rotation)	SOC loss of GHG emissions

Conservation Agriculture and Water Stable Aggregates (>0.25mm)



- **Percent increase in WSA under CA over CT in major cropping systems**
- **14 studies across South Asia**
- **Different soil types**
- **Different duration (2-10 years)**

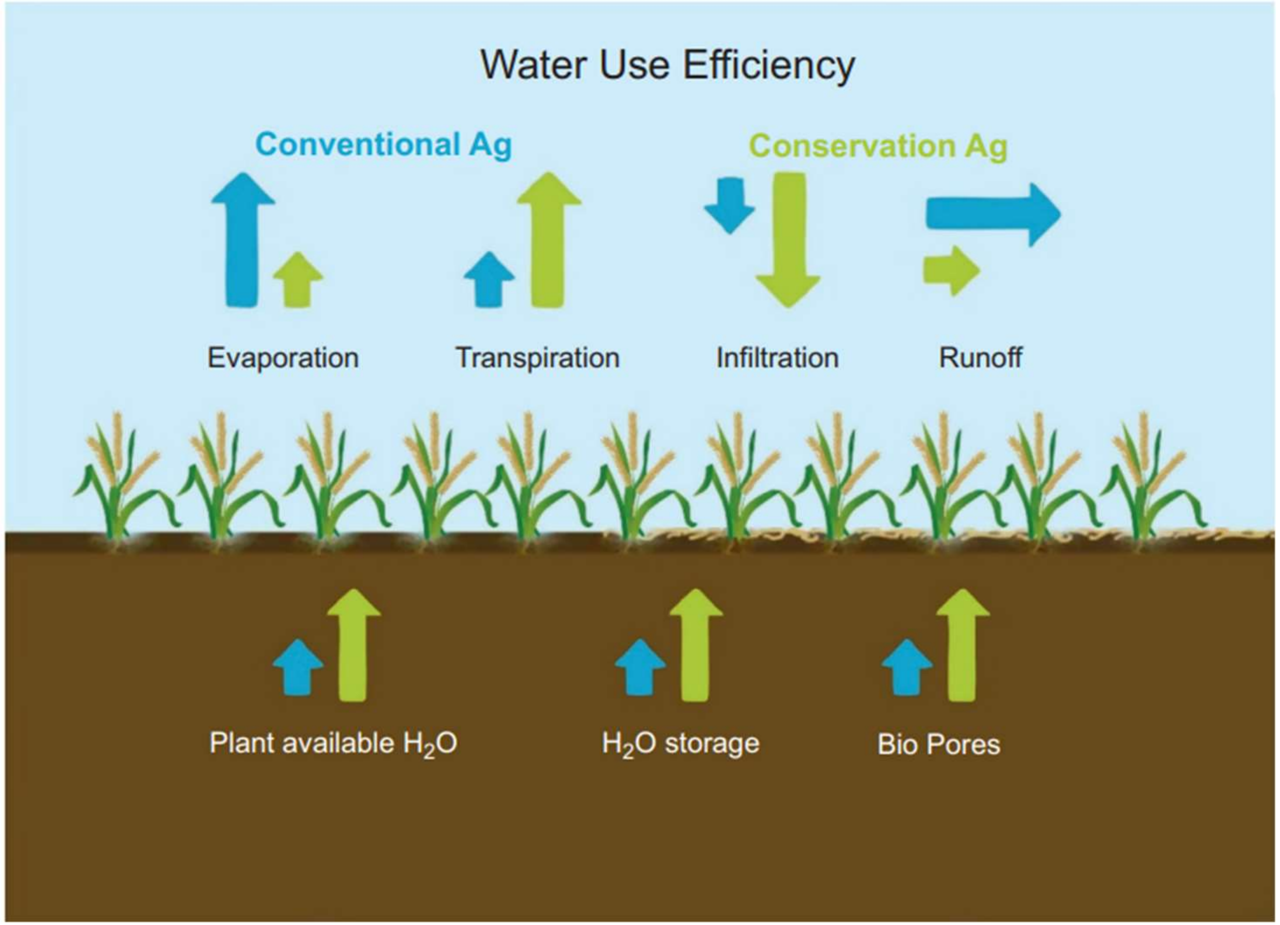
Source: Synthesized from Jat et al (2023), Advances in Agronomy, Courtesy: Mukund Patil (ICRISAT)

Conservation Agriculture and Hydraulic Conductivity (mm/hr)

Location	Cropping system	Soil type	Duration (years)	Soil depth (cm)	Hydraulic conductivity (mm h^{-1}) CT	CA	Δ (%)	References
Karnal, India	Rice-wheat	Loamy	8	0–15	3.18	10.5	+230	Patra et al. (2019)
Karnal, India	Maize-wheat			0–15	3.18	7.45	+134	
New Delhi, India	Maize-wheat	Sandy loam	2	0–15	10.9	13.6	+24.8	Choudhary and Behera (2020a,b,c)
				15–30	9.34	11.1	+18.4	
Uttarakhand, India	Maize-wheat	Sandy clay loam	4	0–7.5	14.3	16.3	+14.24	Bhattacharyya et al. (2006)
				7.5–15	13.3	15.5	+18.1	
				15–22.5	12.5	13.8	+7.47	
Madhya Pradesh, India	Soyabean-wheat	Clayey	7	0–7.5	7.70	26.4	+243	Hati et al. (2015a)
				7.5–15	5.61	14.2	+153	

Source: Jat et al (2023), Advances in Agronomy

Mechanisms for improved soil–plant–water relations in CA v/s CT systems



Source: Jat et al (2023), Advances in Agronomy

Conservation Agriculture (CA) on available micronutrients (DTPA-extractable (mg kg1) after 10 annual cropping cycles

	0–5 cm depth				5–15 cm depth			
	Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu
CT-RW	4.07b	14.1a	27.5a	2.21a	5.30b	10.6a	26.8a	4.09a
CA-RW+ Mb	7.25a	14.1a	8.09b	1.38a	7.83a	11.7a	19.8b	1.94a
CA-MW+ Mb	5.05ab	15.0a	10.1b	1.41a	8.40a	9.43a	17.7c	2.93

CT, Conventional till; RW, Rice-wheat; Mb, Mungbean; MW, Maize-wheat. Means followed by the same letter(s) within each column do not differ statistically ($P \leq 0.05$) using Duncan's Multiple Range Test.

Source: Roy et al., (2022)

Conservation Agriculture and soil microbial population after 3-cropping cycles

Treatment	Bacteria ($CFU \times 10^4 g^{-1}$ soil)	Fungi ($CFU \times 10^2 g^{-1}$ soil)	Actinomycetes ($CFU \times 10^4 g^{-1}$ soil)
CT-RW	74.7d	45.3d	35.5c
CA-RW	85.9b	63.7b	50.8b
CA-RWMb	94.3a	73.1ab	68.0a
CT-MW	81.4c	53.8c	44.9c
CA-MW	87.4b	66.5b	54.2b
CA-MWMb	95.5a	76.2a	70.3a

Where CT, Conventional till; CFU, Colony forming unit. Means followed by the same letter(s) within each column do not differ statistically ($P \leq 0.05$) using Tukey's HSD test.

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Source: Choudhary et al., 2018

Effect of CA practices on Soil microbial biomasses

Microbial biomasses	CA based rice–wheat-mungbean	Integration of mungbean	MW verses RW
MBC	117%	66%	48%
MBN	171%	142%	73%

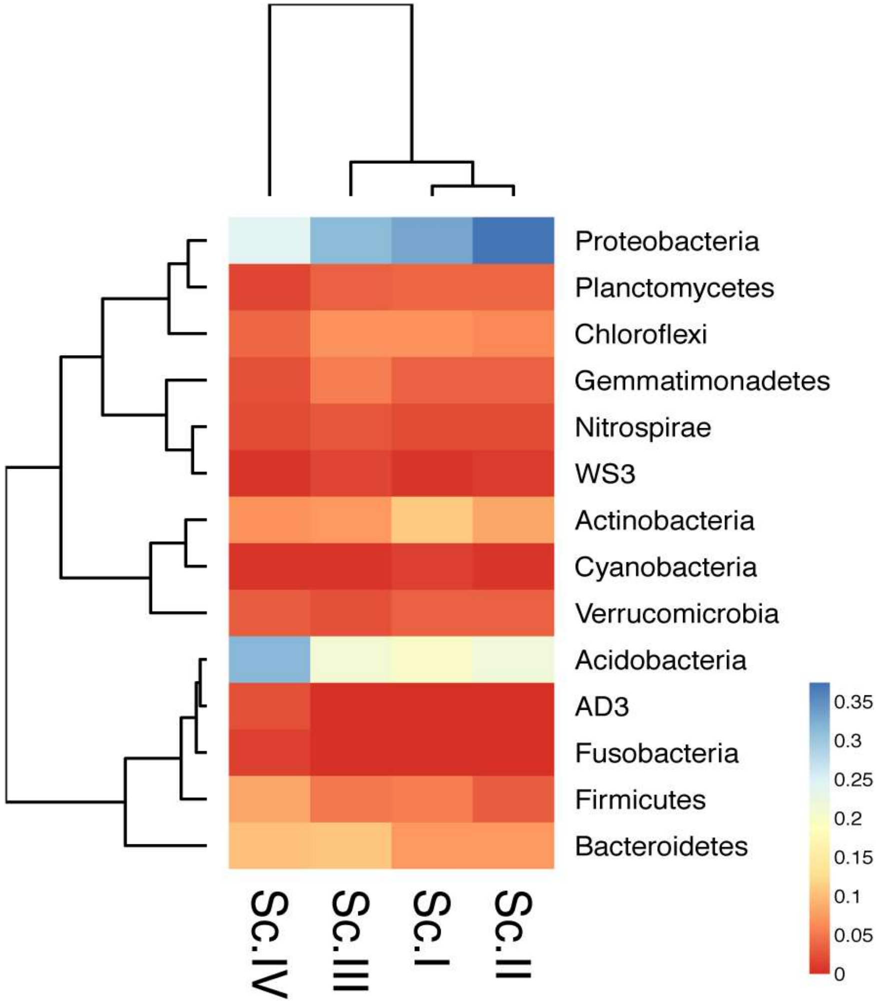
Biologically active fractions -sensitive indicators, predict direction and rate of change of soil quality earlier and better

Choudhary et al (2018), Applied Soil Ecology

Metagenomic study of soil bacterial communities

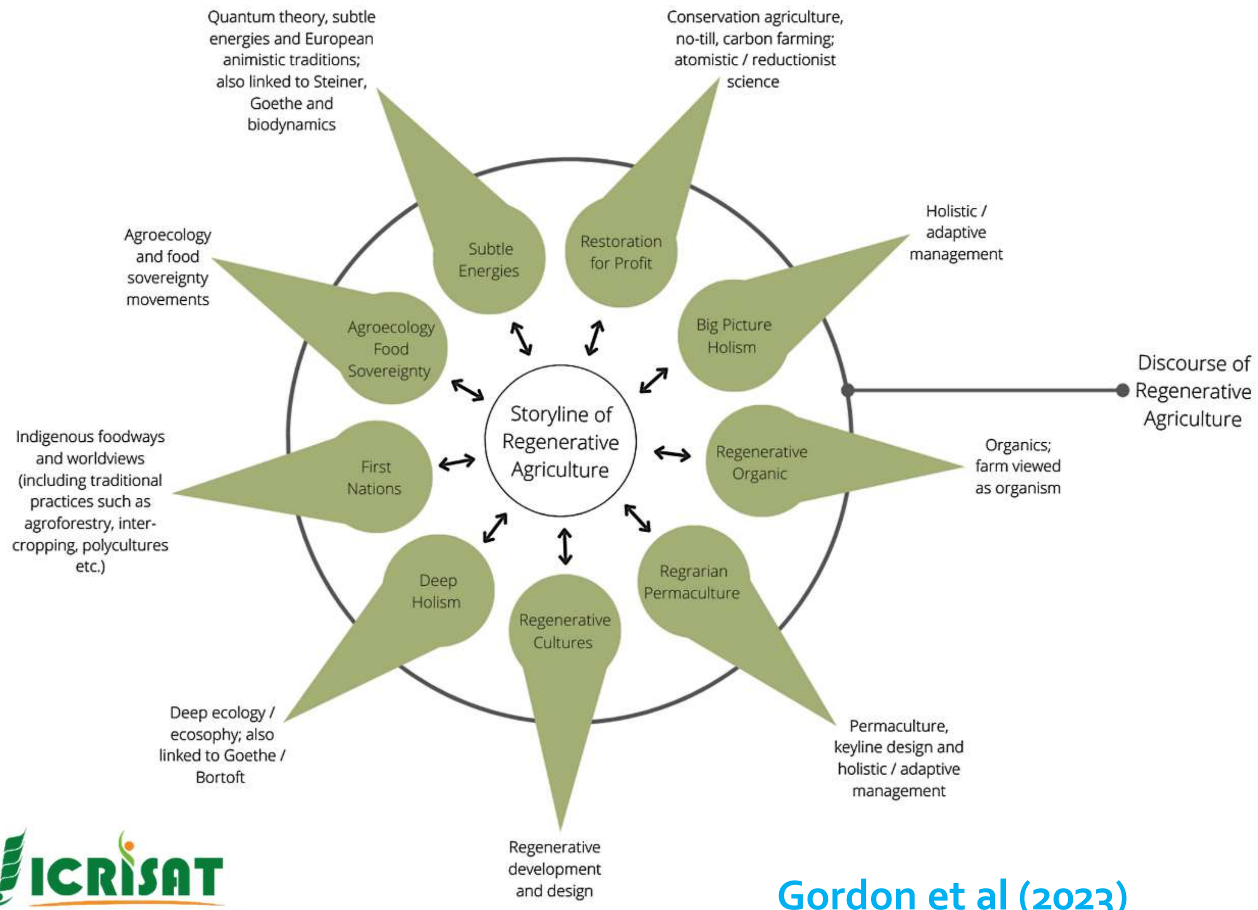
Heat map is showing distribution of dominating phyla in scenarios

- Alphaproteobacteria- Nitrifying (Nitrosomonas, nitrobacter), Rhizobium
- Gammaprotobacteria- N fixation (Azotobacter), Pseudomonas
- Betaprotobacteria- S oxidizing- thiobacillus
- Fermicutes- PGPR- Bacillus



Source: Choudhary et al., 2021

Discourses of Regenerative Agriculture



Gordon et al (2023)

Multiple component discourses may make RA vulnerable to co-optation and greenwashing, diluting its transformative potential

Four Tensions

- Genealogy and holism
- Equity and power
- Definition
- Departure

Should not indulge into the discourses

Remember what can help in:

- carbon sequestration
- reduce GHG emissions
- protect and enhance biodiversity
- improve water retention in the soil
- reduce agro-chemicals, and
- support farming livelihoods

Strategies to Address Tensions on Regenerative Agriculture

- **RA discourse coalition- a common neutral platform for learning, capacity, collective wisdom & action**
- **System-based approaches**
- **Multi-criteria analysis**
- **Well defined Theory of Change (ToC) at local, sub-national, national level**
- **Bridge knowledge and capacity gaps**
- **Get away from silver bullet and One Size Fits all based investments:** science evidence-based targeting and investments (Policy)
- **Integrate social and behavioural science communication:** No more apprehensions/perceived risks but have reality check

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Discovery to Delivery Strategy for Regenerative Agriculture

01

Quality science

Science for food systems transformation towards key SDGs

02

Strategic and complementing partnerships

Working together: NARS, CG, ARIs, Private sector, Global and regional institutions

03

Greater & pooled investments

Govts, philanthropists, Foundations, Corporates, Civil Society

04

Production to consumption continuum

Focus on One Health

05

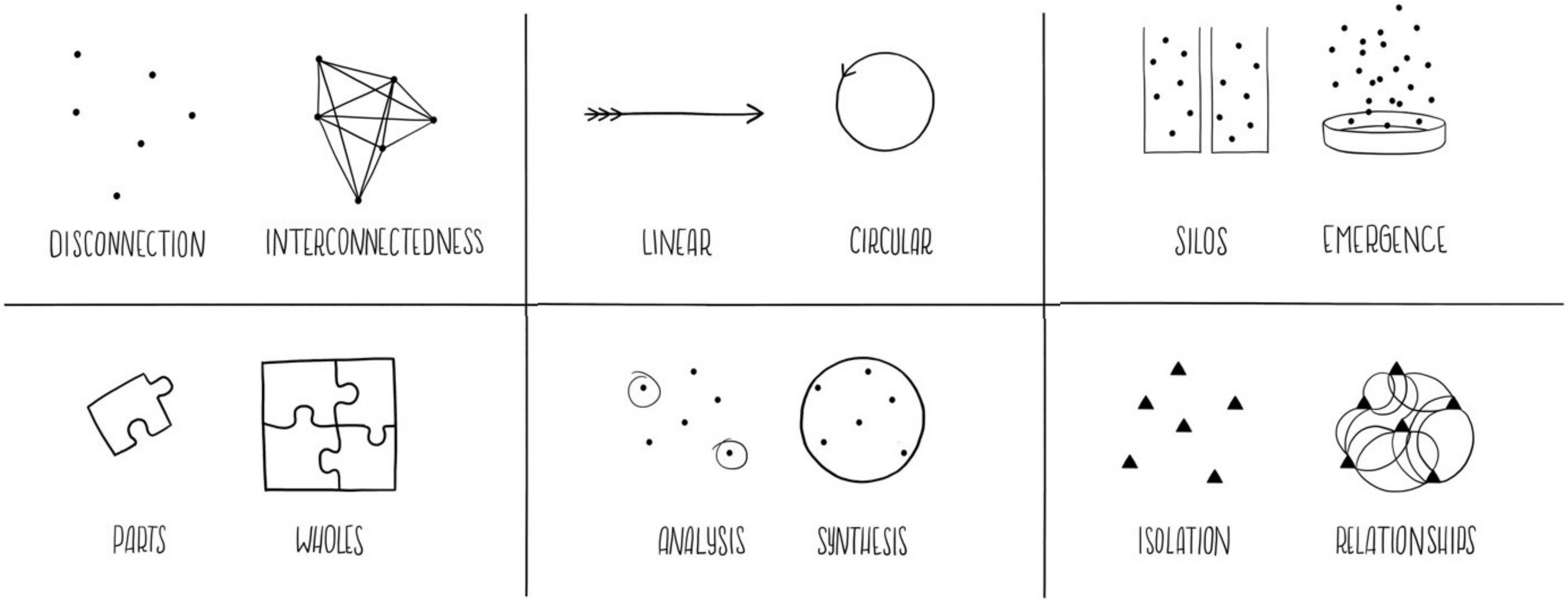
Science of Delivery

Linking research outputs with local, national, regional & global priorities with business models

Source: ML Jat and PB Shirsath

We Must Change the Way We Think

Not what, but how we do it



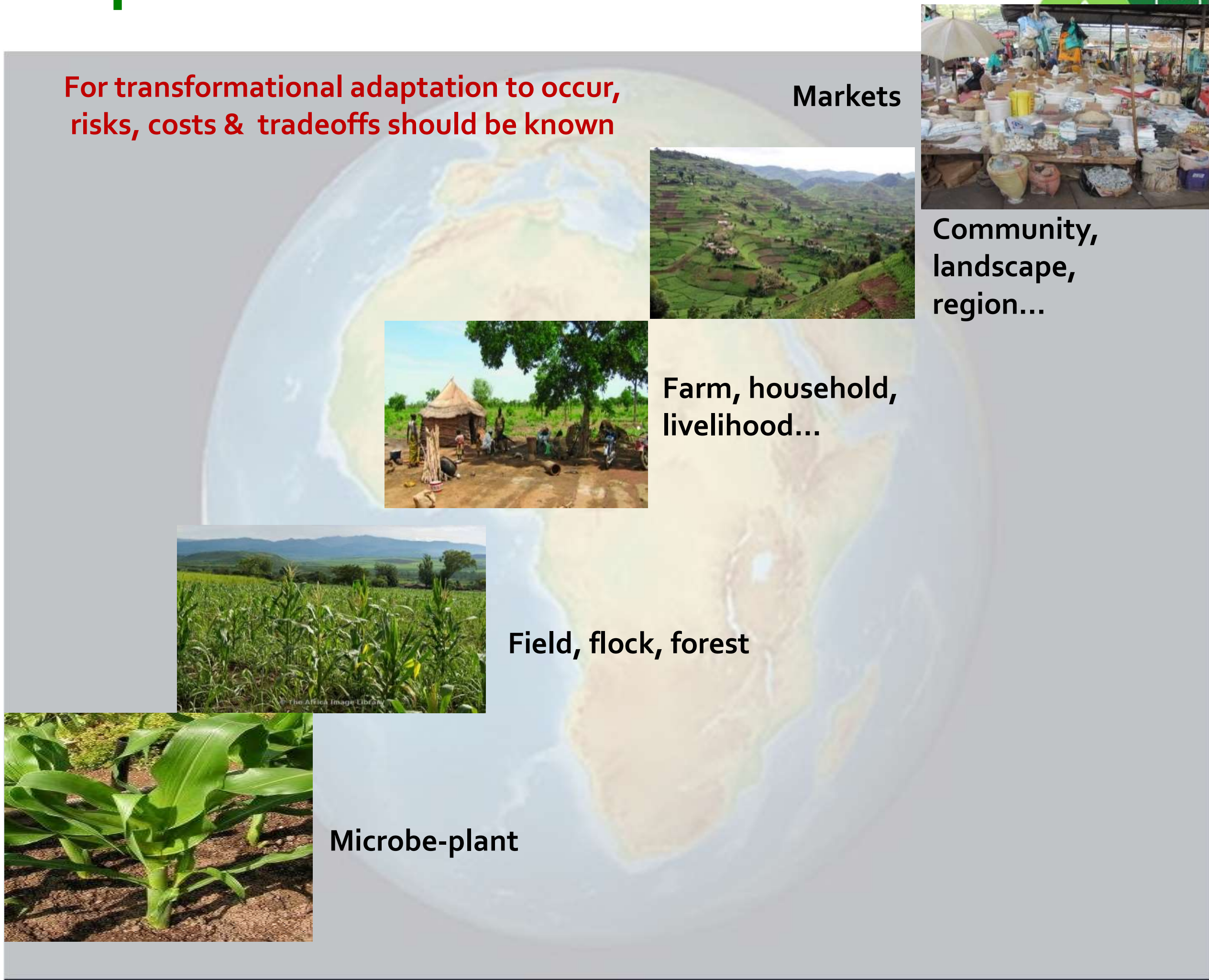
Systems’ Approach for Transformation

	Learning and Institutional development (Monitoring → Evaluation)	R&D approach	Entry points	Scale
Single loop learning	Learning & Doing more	Technology development	**Parameters** Mechanistic approaches Genetics, tools,	**Micro scale** Genes, Lab, research plot
Double loop learning	Learning & Adapting	Technology and strategy	**Feedbacks** Interactions driving internal systems **Design** Social structures and institutions	**Local scale** Farm & institutions
Triple loop learning	Learning & Transformation	Integrated Systems	**Intent** Goals and values that shape emergent direction	**Meta scale** Landscapes & SES

Source: Andre, Jat, Gizaw et al, ICRISAT

Moving from Plot to Landscapes

- Holistic & integrated approach at the farm and landscape level, working in partnership with all users/stakeholders.
- Three levels for making the shift towards Climate Resilient Agri-Food Systems, (i) farm, (ii) landscape and (iii) entire food system



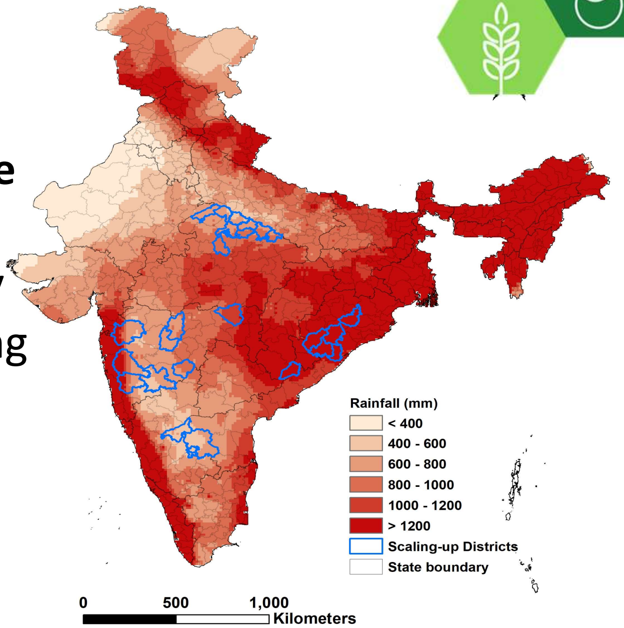
Source: Martin Moyo, ICRISAT

Regenerative Landscape Approach for Building Climate Resilience in Vulnerable Ecologies

- Farmer income: 3X
- Water table: Up from 26 m to 4.5 m
- Enhanced base flow by 150%
- Emission intensity: Down from 0.14 to 0.06
- Livelihoods (In-migration)
- Cropping intensity up from 110 to 180%
- Arresting land degradation
- Sustainable intensification of 35000 ha degraded fallow land
- Temperature regulation towards (1.5 °C targets)

Science evidence led impact with landscape management

- Seven agroecology with rainfall ranging 400-1500 mm
- 150K households
- 100K ha area

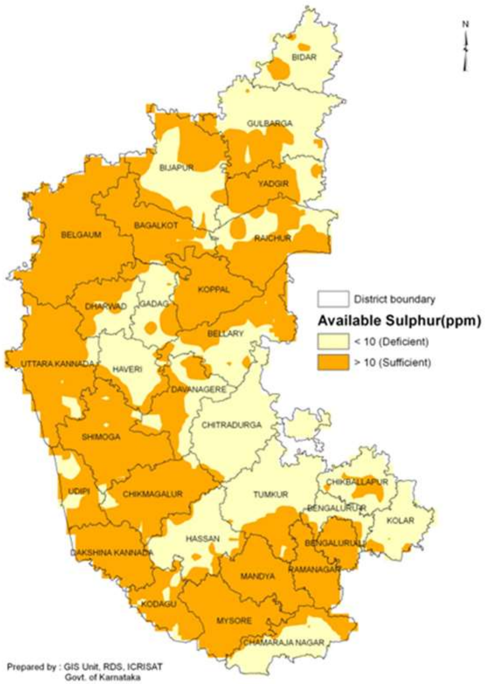


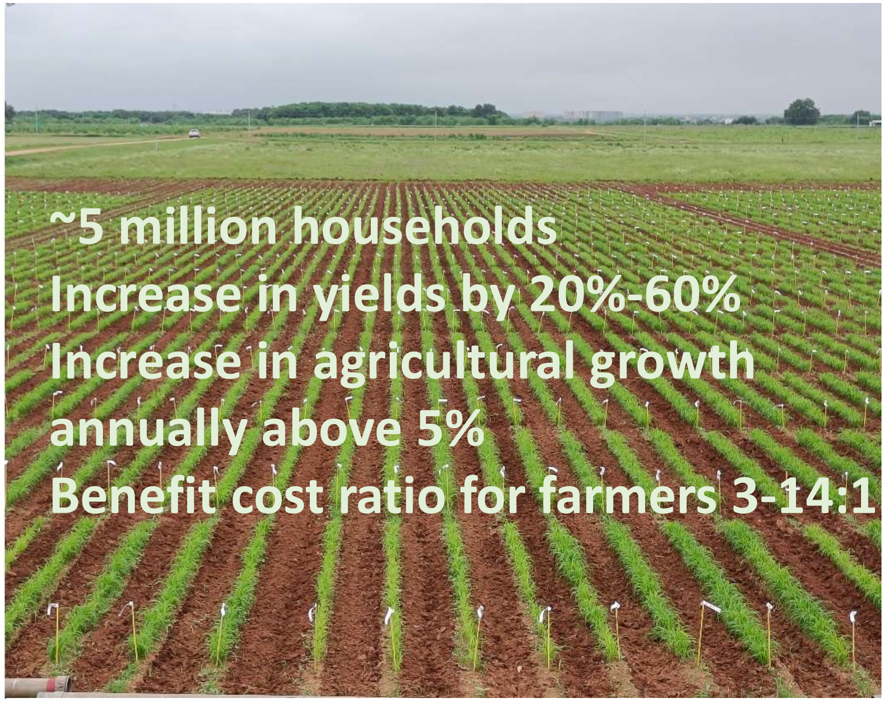
ICRISAT awarded 'UNDP-Mahatma Award 2023 for Biodiversity Conservation' for using regenerative landscape approach

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Ramesh Singh et al, ICRISAT

Karnataka, India Use-case of ISFM- farmer participatory approach: Impact at scale





Crop	**Yield gains**		
	FP	**ISFM**	**% inc**
Sorghum	1851	2427	**31**
Maize	3932	5157	**31**
Paddy	3977	4953	**25**
Pearl millet	1449	2082	**44**
Finger millet	1452	1849	**27**
Pigeonpea	543	732	**35**
Groundnut	1397	1832	**31**
Soybean	1524	1923	**26**
Cotton	1056	1284	**22**
Chickpea	758	1002	**32**

- **Other states (AP, Odisha, UP) have mainstreamed the outputs and learnings in their investment plans for scaling ISFM**
- **1.5 million ha in Andhra Pradesh through DoA**

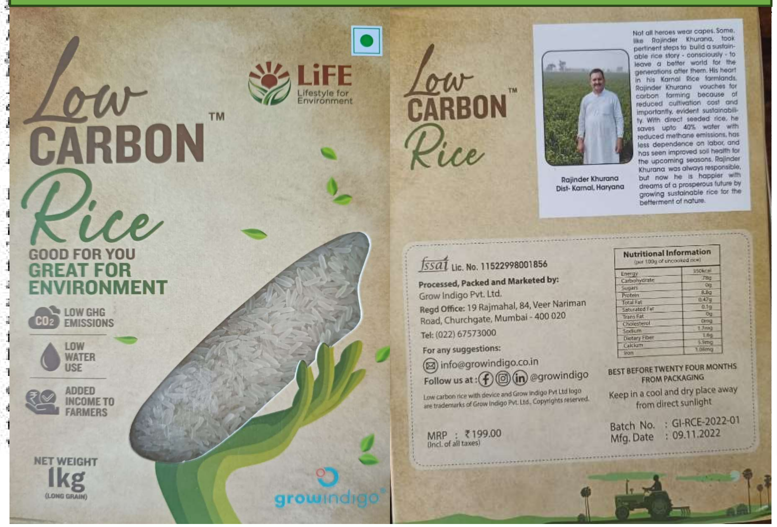
Resilient Agriculture-Vibrant Industry: Synergy for Climate Action through Cropping Carbon

- Carbon neutrality commitments
- Agriculture can provide larger carbon offsets
- Industry can benefit farmers through carbon credits and ESS from CRA
- Growing carbon markets (300 billion USD/year)
- Pull factor through incentive mechanism for low emission farming practices
- Valuation of ecosystem services and designing payment for ESS
- Approaches, tools, protocols, tracking, verification and enabling policies are needed for mainstreaming RA in investment plans

INTERVIEW: MAHUA ACHARYA, MD & CEO, CESL

'Market size for carbon credits trading around $300 bn/year'

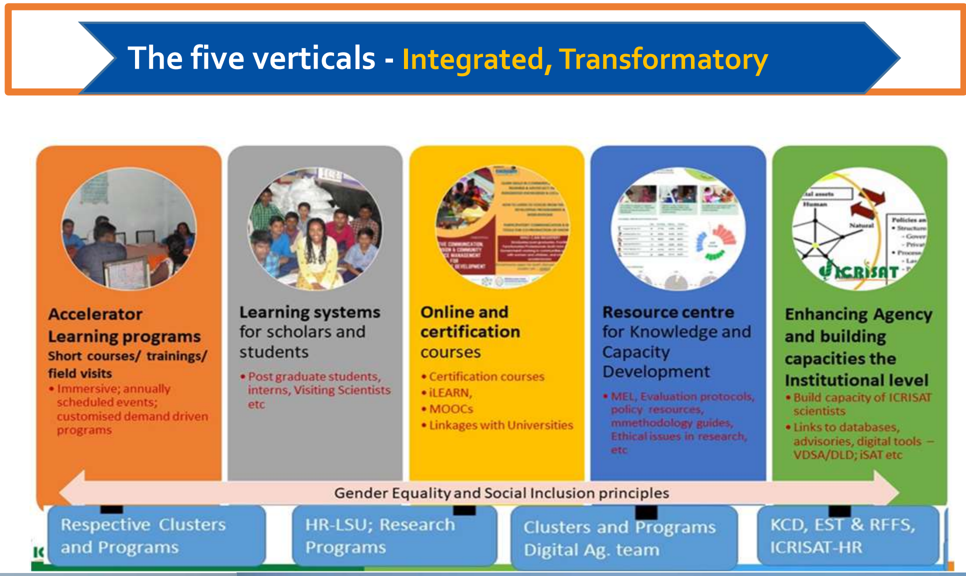
Green Credit- Government of India

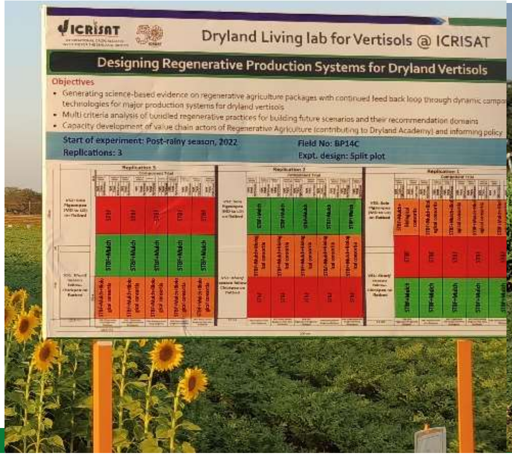


ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

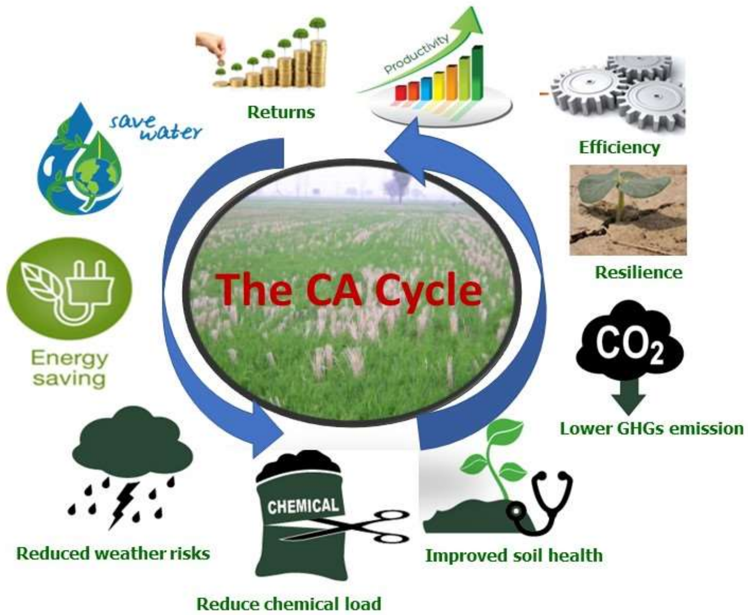
Capacity (Confidence, Consensus) Development

- A new cadre of RA-Community of Practitioners (RA-CoP) need to be developed
- Centre of Excellence on RA
- RA Living Labs
- Dryland Academy

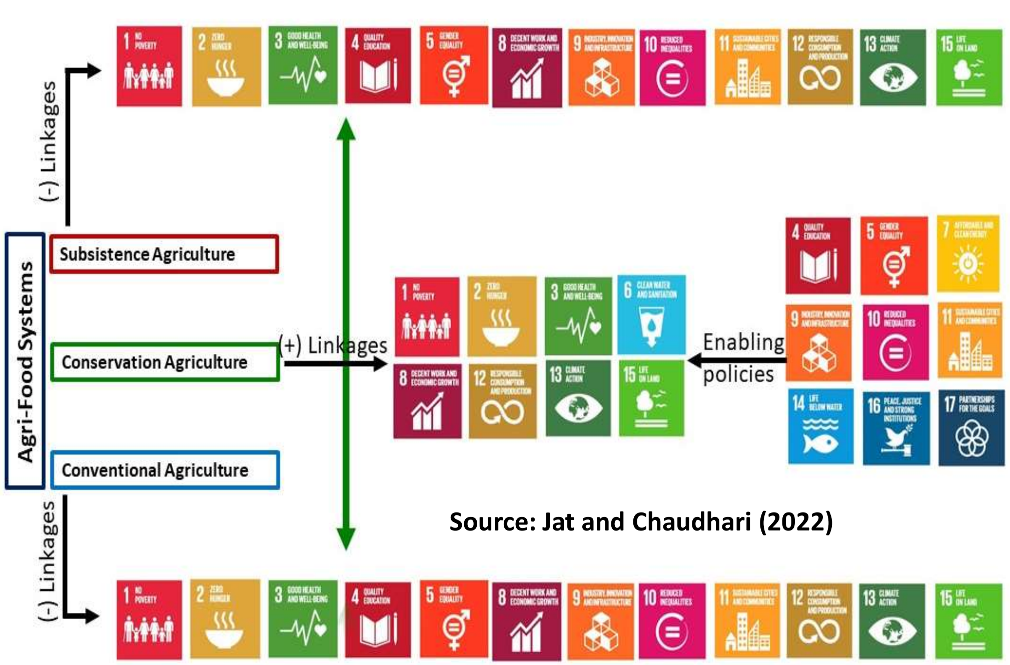




Science Evidence Based Policy and Investments



Jat et al (2020), Nature Sustainability



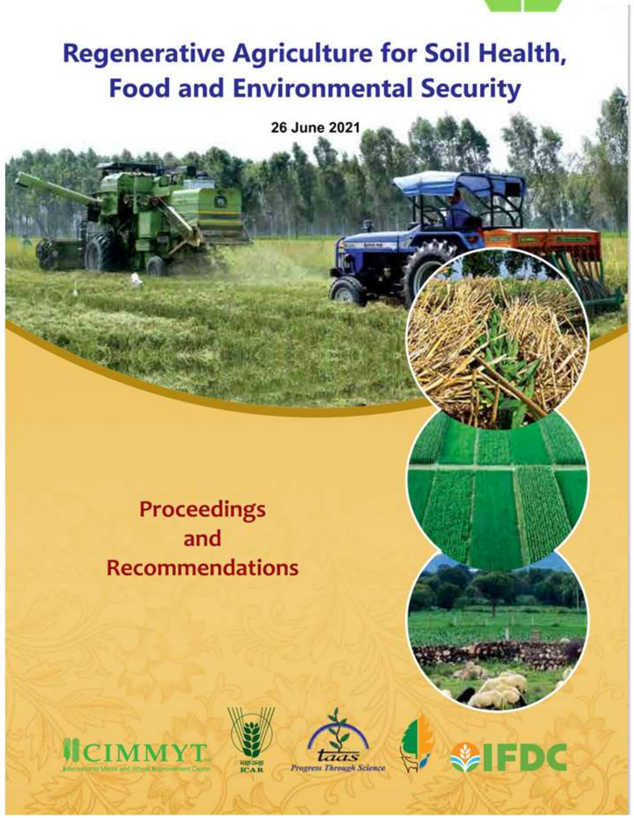
Source: Jat and Chaudhari (2022)

- **Optimization of CA (RA) requires attention to location-specific performance (Zhang, Wei, Sapkota, Jat et al, Field Crops Research 2022)**

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Key Messages

- Change of people's mindset is very critical, creating awareness and bridging knowledge and capacity gaps at all levels-Discourse coalition
- Soil health= combination of NRM, agronomic practices with holistic & systems' approach (Bio-physical, Technological, Socio-economic)
- A paradigm shift is needed from crops and cropping to Integrated faming systems at landscape and eco-region scale
- Strengthening RA research with focus on One Health
- Global/National Mission on RA
- Investments in Research and Innovation for Region/Location specific Practices with strong partnership (All actors need to work together)
- Carbon/nature credits- harmonized methods, tools, protocols and policies



ICRISAT

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Thank **YOU**

ML Jat, ICRISAT | mangilal.jat@icrisat.org