PROMOTION OF REGENERATIVE AGRICULTURE IN SAARC MEMBER STATES

Editors

Dr. Sikander Khan Tanveer
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SAARC

SAARC Agriculture Centre (SAC)

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SAARC Agriculture Centre
Dhaka, Bangladesh
www.sac.org.bd

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SAARC Agriculture Centre (SAC), Dhaka, Bangladesh held a three days "Regional consultation meeting on promotion of Regenerative Agriculture in SAARC Member States" from 04 to 06 August, 2025 in virtual mode. National focal point experts from the SAARC Member States, along with scientists of national and international research organizations and different universities working on different aspects of Regenerative agriculture, participated in this meeting.

Editors

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December, 2025

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Published by the SAARC Agriculture Centre, BARC Complex, Farmgate, Dhaka 1215, Bangladesh (http//www.sca.org.bd).

A catalogue record for the book is available from the SAARC Agriculture Centre Library, BARC Complex, Farmgate, Dhaka, Bangladesh.

ISBN: 978-984-35-9315-3

Citation:

Tanveer, S.K., Rashid, M.H., and Torophder, T.A (eds.). (2025). *Promotion of Regerative Agriculture in SAARC Member States.* SAARC Agriculture Centre, Bangladesh, 173 P.

Disclaimer

This book contains the papers and proceedings of the "Regional consultation meeting on promotion of Regenerative agriculture, in SAARC Member States" held on 04-06 August 2025 in virtual mode by the SAARC Agriculture Centre, Dhaka, Bangladesh. The focal point experts represented the respective Member States. The opinions expressed in this publication are those of the authors and do not imply any opinion whatsoever on the part of SAC, especially, concerning the legal states/status of any country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

Publication Assistance: Md. Abul Bashar, Senior Program Officer (Pub.), SAC

Cover Design: Ms. Sanjida Akhter, Graphics Designer, SAC

Printed by: Generation PPA, 188 Fakirapool, Motijheel, Dhaka.

Price: US$ 10 SAARC Countries
US$ 50 for other countries

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SAARC

Foreword

South Asia extends from the highlands of the Himalayas to the atolls of the Indian Ocean, having land mass of 6.4 million square kilometers. It is the home of more than 2.0 billion population. Burgeoning population, decereasing land holdings, deteriorating soil health and changing climatic conditions are the main issues of this region. Most of the population of this region is living below poverty line and world's largest share of poverty and malnutrition remain in this region. The region is predominantly composed of smallholder producers (having less than 2 ha) of land for cultivation. About 41% (532 million) of the total 1.3 billion multi-dimensionally poor people in the world are from this region. This region is facing food insecurity, malnutrition, and climate challenge issues (droughts, floods, heat shocks etc). Although this region has made great progress in food production, transforming it from a food-deficit to a food self-sufficient region, further efforts are required to sustain these gains

Depletion of natural resources, deterioration of soil health, climate and natural crises are jeopardising productivity and resilience of lands. Agriculture sector itself is the single largest driver of global biodiversity loss. It always requires environmental interventions and this can both damage and create opportunities for restoration. Regenerative agriculture is a holistic approach that aims to simultaneously promote above-and below ground carbon sequestration, lessens GHGs emissions, protects and enhances biodiversity in and around farms, improves water retaining in the soil, decreases the use of pesticides, improves nutrient use efficacy and support farming livelihoods.

It has also been proven that adaption of Regenerative agriculture can help to mitigate damage and restore ecosystems. This farming approach, restores soil health, improves biodiversity and water cycles and similarly strengthens climate resilience. It also tackles major challenges such as soil degradation, declining yields and overreliance on synthetic inputs, along with improving farmers' livelihoods. This farming approach is focused on restoring soil health and ecosystem vitality by working with nature. It sequesters carbon to combat climate change and creat resilient food systems. It aims to enhance land's ability to produce healthy food while improving the environmental resilience and increase farm profitability. It has also ecological benefits with enhanced ecosystems services. It is an outcome - based farming approach that generates agriculture products, while improving soil health, biodiversity, climate, water resources and supporting farming livelihoods.

Main practices under Regenerative agriculture include, low or no tillage, organic amendments (compost, manure, biochar), diverse crop rotations, cover cropping, agroforestry, managed livestock grazing and integrated pest management (IPM).

This book is the outcome of regional consultation meeting on promotion of Regenerative Agriculture in SAARC Member States. As SAARC Member States are facing a number of soil health and environmental issues. I hope, this publication will be helpful for the better understanding of regenerative agriculture issues of this region and about the different ongoing Regenerative Agriculture practices in the different SAARC Member States. It will be helpful to the scientists, extension workers and farmers for further research, promotion and adoption of Regenerative agriculture.

At the end, I congratulate all the team of SAC, especially Dr Sikander Khan Tanveer, Senior Program Specialist (Crops) for coordinating the regional consultation meeting on "Promotion of Regenerative agriculture in SAARC Member States" and compiling the relevant write-ups in the form of a book.

Thank you.

Dr. Md. HarunurRashid
Director, SAC

Contents

Abbreviations

ACI	Advanced Chemical Industries
ADS	Agriculture Development Strategy
AEI	Agricultural Engineering Institute
AGRs	Agricultural Genetic Resources
AWD	Alternate Wetting and Drying
AZRI	Arid Zone Research Institute
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BRRI	Bangladesh Rice Research Institute
CA	Conservation Agriculture
CBD	Convention of Biological Diversity
CCDABC	Centre for Crop Development and Agro-biodiversity Conservation
CEA	Central Environmental Authority
CEC	Cation Exchange Capacity
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Centre
CSA	Climate Smart Agriculture
CSISA	Cereal Systems Initiative for South Asia
CUIC	Up-Country Intensiving Cropping
DAE	Department of Agricultural Extension
DDSR	Dry Direct-Seeded Rice
DoA	Department of Agriculture
EASAC	The European Academies Science Advisory Council
EPM	Ecological Pest Management
FAO	Food and Agriculture Organization of the United Nations
FFSs	Farmers Field Schools
FYM	Farm Yard Manure
GAU	Gazipur Agricultural University
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Green House Gas
GIS	Geographic Information System
GLOFs	Glacial Lake Outburst Floods
GNH	Gross National Happiness
ICIMOD	International Centre for Integrated Mountain Development
ICRAF	International Centre for Research in Agroforestry
INM	Integrated Nutrient Supply and Management
IPCC	Intergovernmental Panel on Climate Change

IPM	Integrated Pest Management
IPNM	Integrated Plant Nutrient Management
IPNS	Integrated Plant Nutrient Systems
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IUCN	International Union for Conservation of Nature
LEDS	Low Emission Development Strategy
M.T	Metric Ton
MNFS&R	Ministry of National Food Security & Research
MoA	Ministry of Agriculture
MoAL	Ministry of Agriculture and Livestock
MRV	Measurement, Reporting and Verification
NAP	National Agricultural Policy
NAPEP	National Program for Enhancing Productivity
NARC	National Agricultural Research Centre
NCOA	National Centre for Organic Agriculture
NGO's	Non-Government Organizations
NSB	National Statistics Bureau
NSSC	National Soil Services Centre
OC	Organic Carbon
PGS	Participatory Guarantee Systems
PKVY	Paramparagat Krishi Vikas Yojana
PPPs	Public-Private Partnerships
R&D	Research & Development
R.A.	Regenerative Agriculture
RAPs	Regenerative Agriculture Practices
RNR	Renewable Natural Resources
RNR-RDCs	The Renewable Natural Resource Research and Development Centres
RPLC	Regenerative Production Landscape Collaboration
SAARC	South Asian Association for Regional Cooperation
SAFE	Society of Agriculture, Food and Environment
SAPA	Sector Adaptation Plan of Action
SAU	Shair -e- Bangla Agricultural University
SDGs	Sustainable Development Goals
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SRDI	Soil Resources Development Institute
USAID	United States Agency for International Development
WDSR	Wet Direct-Seeded Rice
WWF	World Wide Fund

Chapter - 1

Promotion of Regenerative Agriculture in SAARC Member States

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Introduction

The execution of the sustainable development principles is mainly significant in agriculture, which has a strong effect on the natural environment (Patil,S. and Hugar, L.B 2005; Pretty J.,2008). The specificity of agriculture are side effects of conducted agricultural activities, which are both positive and negative externalities (Mauerhofer, V. et al., 2013; Fritsche, U.R., and Iriarte, L.,2014). Agriculture is responsible for 37% of global GHGs emissions and it uses 70% of the world's water resources. Soils are being depleted at an alarming rate and around 12 million hectares are turning to be desert each year. Land degradation reduces agricultural productivity, releases stored carbon, worsens climate change, and this climate change is impacting food systems.

South Asia represents one of the world's most agriculturally significant regions, with farming systems that support over 2.0 billion people which accounts for 25% of the global population. Total population of this region will account for about half of the entire global population by 2050. Majority people of South Asia are living below the poverty line and this region accounts for 37% of the world's poor and similarly nearly half of the malnourished children of the world live in this region. Maximum poor people of this region live in rural areas and earn their living by agriculture and its allied activities. The region encompasses diverse agroecological zones-from the Himalayan highlands of Bhutan and Nepal to the deltaic plains of Bangladesh, the arid zones of Pakistan, and the tropical systems of Sri Lanka. Agriculture remains the backbone of rural livelihoods of this region, contributing 11-40% to national GDPs across SAARC Member States and employing 40-70% of the workforce.

Agriculture in this region is dominated by smallholders, 42% land mass is under agricultural operation and is the source of employment to over 50% of the population in the region (HDSA, 2015). Like other regions of the world, climate change is also affecting South Asia. Conventional agricultural practices-characterized by intensive tillage, monocropping, excessive chemical inputs, and poor water management-have led to severe environmental degradation. Over 33% of agricultural land across the region faces erosion, soil organic matter has declined by 30-50% in many areas, and groundwater depletion threatens irrigation sustainability. Climate change amplifies these challenges through increased temperature variability, erratic monsoons, floods, droughts, and salinity intrusion.

Conventional agricultural practices like tilling release carbon dioxide (CO_2) from the soil by exposing organic matter to the surface and thus promoting oxidation (Motgmery, David R.,2007). It is estimated that roughly a third of the total anthropogenic inputs of CO_2 to the atmosphere since the industrial revolution have come from the degradation of soil organic matter (Motgmery, David R., 2007) and that 30-75% of global soil organic matter has been lost since the adevent of tillage - based farming (Teague, W.R. et al., 2016). Emissions of GHGs, associated with conventional soil and cropping activities, represent 13.7% of anthropogenic emiisions, or 1.86 $Pg\text{-}Cy^{-1}$, while raising of ruminant livestock are 11.6% of anthropogenic emissions, or 1.58 Pg-CY^{-1} (Teague, W.R. et al., 2016). Conventional agricultural practices like tilling release carbon dioxide (CO_2) from the soil by exposing organic matter to the surface and thus promoting oxidation (Motgmery, David R.,2007). Moreover, runoff and siltation of water bodies associated with conventional farming promote eutrophication and emissions of methane (Teague, W.R. et al., 2016).

Adoption of Regenerative agriculture can be part of the solution as the main principles of RA include minimization of soil disturbance, maximization of soil cover, maximization of biodiversity and integration of livestock. By adopting no-till farming, agro-forestry, crop rotation, cover cropping and integrating livestock with the agriculture can help in restoration of soil health, sequestration of carbon and increase in biodiversity. RA also builds resilience to climate impacts by improving water retention, increasing biodiversity and creating healthier ecosystems. RA promotes practices that enhance soil health and nutrient cycling (Bill, B.C. et al., 2005). It is a holistic farming approach that restores soil health, enhances biodiversity, improves water cycles and strengthens climate resilience (Rhodes., 2017; FAO, 2021). It tackles major challenges such as soil degradation, declining yields and overreliance on synthetic inputs, while also improving farmers' livelihoods. Core practices of RA include low or no tillage, organic amendments (compost, manure, biochar), diverse crop rotations, cover cropping, agroforestry, managed livestock grazing and integrated pest management (IPM) (Kassam et al., 2019; LaCanne & Lundgren.,2018). These methods boost soil fertility, support nutrient cycling, reduce erosion and lower environmental impacts. RA blends traditional knowledge with modern technologies to promote sustainable and productive food systems (Giller et al., 2021).

Going beyond sustainability, RA actively reverses degradation caused by conventional practices, ensuring long-term food security and ecological restoration (Pretty et al., 2018). Core principles include: (1) minimizing soil disturbance through reduced or zero tillage; (2) maintaining continuous soil cover through mulching and cover crops; (3) promoting crop diversity through rotations and intercropping; (4) integrating livestock in managed grazing systems; (5) incorporating organic amendments and biological inputs; and (6) optimizing water use efficiency. These practices synergistically improve soil health, sequester carbon, enhance biodiversity, reduce greenhouse gas emissions, and build resilience against climate stressors while maintaining or improving farm productivity and profitability.

RA agricultural practices can help farmers of South Asia in increasing the yields, reduce dependency on expensive inputs like synthetic fertilisers and protect their livelihoods from extreme weather events. However, adoption of RA is hindered by high initial costs, knowledge gaps and insufficient policy support (FAO.,2022; Kerr et al., 2022; Pretty et al., 2020). RA can lift up the agriculture sector of this region and it can enhance resilence of production systems to biotic and abiotic stresses, particularly those arising from climate change. It can also enhance biodiversity in crop production systems above and below the ground to improve ecosystem services for better productivity and healther environment.

RA offers multiple interconnected benefits which are critical for South Asia's sustainable development. Eenvironmental benefits of RA include, carbon sequestration, reductions of GHGs emissions, water conservation, reductions in soil erosion, and biodiversity enhancement. RA practices can sequester 0.3-0.5 Mg C ha^{-1} year^{-1} in South Asian contexts, contributing to climate change mitigation. It increases soil organic carbon by 0.5-2.0 Mg ha^{-1} depending on practice combinations and duration. It helps water conservation, like mulching and conservation tillage improve water productivity by 15-30% in semi-arid regions. Permanent soil cover reduces soil erosion by up to 90% in vulnerable areas. Similarly diversified systems support beneficial soil microorganisms, pollinators, and natural pest predators.

Economic benefits of RA include, reductions in inputs costs, reductions in risks and through help in water saving. RA reduces expenditure on synthetic fertilizers (up to 50%), pesticides (30-40%), and fuel for tillage operations. Diversified systems reduce crop failure risks from climate variability. It helps in up to 60% reduction in irrigation water requirements in some systems. There is a growing demand for organically and regeneratively produced commodities but while transition periods, there may be yield penalties, but however with the passage of time yields stabilize and basically this increase is often due to improved soil health.

Social benefits of RA include, improvement in the livelihoods of the farmers through reduced costs and provision of premium prices. RA, through diverse, resilient production systems ensures stable food supplies. It improves nutritional quality, as regeneratively produced foods often have higher nutrient density. It can be a source of rural employment, because it includes labor-intensive practices which needs labor. Similarly it can be a source of knowledge revival as RA is an integration of traditional farming wisdom with modern science.

Methodology

Approach

This synthesis is based on the regional consultation meeting on “Promotion of Regenerative Agriculture in SAARC Member States” held virtually from August 4-6, 2025, organized by the SAARC Agriculture Centre (SAC), Dhaka, Bangladesh.

Participants

The consultation meeting involved, national focal point experts from different SAARC Member States (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka). Scientists from national agricultural research organizations, and from international organizations (CIMMYT,IRRI, IWMI and ICRISAT), and faculty members of different Agricultural Universities of different SAARC Member States, working on different aspects of RA.

Data Collection and Analysis

Primary sources of data are country-specific presentations by national focal points, technical papers on regenerative practices in each member state, case studies of successful RA implementation and policy documents and strategic plans from SAARC Member States.

Secondary sources includes published research literature on Regenerative Agriculture in South Asia, Meta-analyses of Conservation agriculture impacts, Reports from international organizations (FAO, World Bank, CGIAR) and Governments statistics on agriculture, soil health, and climate.

While analysis framework includes, comparative analysis of RA practices across countries, identification of common challenges and opportunities, gap analysis in research, policy, and implementation and SWOT (Strengths, Weaknesses, Opportunities, Threats) assessment for regional RA promotion.

Validation

Findings were validated through, Experts review during consultation sessions, peer discussions among country representatives, and cross-referencing with published scientific literature.

Country-Specific Practices of Regenerative Agriculture in South Asia

Bangladesh

Key Practices:

1. **Integrated Crop-Livestock Systems**: Combining rice cultivation with poultry, fish, and cattle for nutrient recycling.

2. **Conservation Agriculture in Barind Tract:** Zero tillage and residue retention in drought-prone northwestern region.

3. **Climate-Smart Agriculture:** Stress-tolerant rice varieties (flood-tolerant, salt-tolerant, drought-tolerant).

4. **Organic Farming Initiatives:** Government's National Organic Agriculture Policy (2016) promoting chemical-free farming.

5. **Agroforestry in Coastal Areas:** Integrating salt-tolerant trees with crops in saline zones.

Success Story: Conservation agriculture in Barind Tract has improved soil moisture retention by 30% and increased wheat yields by 15-20% while reducing irrigation water use.

Bhutan

Key Practices:

1. **Organic Farming:** Complete transition from synthetic to organic fertilizers as per Low Emission Development Strategy (LEDS) for Food Security 2021.
   - **Target:** 5% annual reduction in chemical fertilizer use.
   - 25% annual increase in organic fertilizer production through 2030.

2. **Sustainable Land Management (SLM):**
   - Converted 3,368 hectares of shifting cultivation to orchards (2006-2012).
   - Restored 3,345 hectares of degraded lands to forests.

3. **Fodder Tree Integration:** Fodder trees planted along field borders in southern districts, combining fodder production, crops, and livestock.

4. **Multiple Cropping Systems:**
   - Rice-based systems in valleys.
   - Maize-based systems in mid-hills.
   - Potato-based systems in highlands.
   - Multi-storied cropping integrating vegetables, cereals, and tree crops

5. **Climate-Resilient Crop Development:** Research on drought-tolerant and cold-tolerant varieties.

6. **Traditional Practices:** Anchored in the country's deep-rooted cultural values of environmental harmony and guided by forward-looking policies, Bhutan is well-positioned to lead in climate-smart and biodiversity-enhancing farming systems.

Success Story: Bhutan maintains carbon-negative status. RA emerges as a promising paradigm for Bhutan. rooted in traditional ecological knowledge and supported by scientific innovation.

India

Key Practices:

1. **Zero Budget Natural Farming (ZBNF):** Indigenous practice promoted in several states:
   - Uses on-farm inputs (cow dung, urine, jaggery, pulse flour).
   - Eliminates external input costs.
   - Promoted in Andhra Pradesh, Karnataka, Himachal Pradesh.

2. **Conservation Agriculture:** Large-scale adoption in Indo-Gangetic Plains:
   - Zero tillage in rice-wheat systems.
   - Happy Seeder technology for stubble management.
   - Laser land leveling for water efficiency.

3. **Organic Farming Programs:**
   - **Paramparagat Krishi Vikas Yojana (PKVY):** Government scheme supporting organic farming clusters.
   - Mission Organic Value Chain Development for North Eastern Region (MOVCDNER).
   - Organic certification through National Programme for Organic Production (NPOP).

4. **System of Rice Intensification (SRI):** Water-saving rice cultivation method.

5. **Agroforestry:** National Agroforestry Policy (2014) promoting tree integration.

Success Story: Andhra Pradesh's Zero Budget Natural Farming program has reached over 600,000 farmers across 6 million acres, demonstrating large-scale viability of regenerative approaches.

Maldives

Key Practices:

- Composting of organic household waste.
- Home garden diversification.
- Organic vegetable production for local consumption.
- Integrated farming in community gardens.

Nepal

Key Practices:

1. **Organic Fertilizers:**
   - Compost: Made from crop residues, animal manure, and household waste.
   - Vermicompost: Increasing adoption for high-value crops.
   - Biochar: Emerging practice using agricultural waste.
   - Jholmal: Liquid organic fertilizer (fermented plant materials, cow dung, urine).

2. **Conservation Agriculture in Terai:** Zero tillage, residue retention, and crop rotation in maize-wheat systems.

3. **Direct-Seeded Rice:**
   - Dry Direct-Seeded Rice (DDSR): Cost-effective, water-saving alternative.
   - Challenges: Weed infestation, poor establishment.

4. **Legume Integration:**
- Rice-lentil rotation and relay cropping.
- Lentil mixed with field pea or mustard.
- Maize-soybean intercropping.

5. **Mulching Practices:** Justicia adhatoda leaves in rice nursery beds for water conservation and organic matter

6. **Alternate Wetting and Drying (AWD):** Optimizing water use in rice without yield loss

7. **Agrobiodiversity Conservation:**
- On-farm, in-situ, and ex-situ conservation of landraces.
- Community seed banks.
- Participatory plant breeding.
- Focus on millets, barley, sorghum, tubers, traditional varieties.

Success Story: Community seed banks in mountain districts have preserved remarkable crop varieties while improving farmer seed sovereignty and resilience.

Pakistan

Key Practices:

1. **Conservation Agriculture Machinery:**
- Super/Pak Seeder: Over 2,000 units adopted in rice-wheat areas.
- Incorporates rice residues and sows' wheat in single pass.
- Eliminates stubble burning, reducing smog and air pollution.
- Saves water (30-40%), time (10-15 days), and fuel costs.
- Happy Seeder: Direct wheat sowing into rice stubble.
- Zero Tillage Drills: Widely used for wheat after rice.

2. **Regenerative Cotton Production:**
- WWF-Pakistan Programs: Better Cotton, Regen-Cotton, Organic Cotton.
- Reduced tillage operations.
- Minimized water and fertilizer use.
- Integrated pest management.
- Regenerative Production Landscape Collaborative (RPLC) partnership.

3. **Climate-Smart Agriculture (CSA):** Government promotion of water-efficient, low-emission practices.

4. **Crop Residue Management:** Addressing stubble burning through mechanical incorporation.

5. **Organic Amendments:** Growing interest in compost and farmyard manure among farmers seeking to reduce input costs.

Success Story: Super Seeder adoption in Punjab has eliminated rice stubble burning on over 500,000 acres, significantly reducing smog while improving soil health and farmer profitability.

Sri Lanka

Key Practices:

1. **Zero/Minimum Tillage:** Reducing soil disturbance in rice and vegetable production.

2. **Organic Amendments:**
   - Government is actively promoting livestock manure production and utilization.
   - Compost application in plantation and food crop sectors.
   - Biochar trials in research stations.

3. **Agroforestry Systems:**
   - Gliricidia-based systems: Nitrogen-fixing tree integrated with crops.
   - IUCN Project: Agroforestry in tea and coconut plantations.
   - Traditional mixed systems (Chena cultivation).

4. **Crop Diversification:**
   - Rice rotation with pulses, oilseeds, vegetables, sugarcane, bananas.
   - Intercropping: banana with ginger/turmeric/pineapple; crops under coconut.

5. **Cover Cropping**: Leguminous covers in plantation crops (tea, coconut).

6. **Mulching:** Organic mulches for moisture conservation and weed suppression.

7. **Water Management:**
   - Traditional tank-based irrigation systems.
   - Agro-wells in dry zone.
   - Efficient irrigation for high-value crops.

8. **Smart Farming:** Digital and geospatial tools for precision agriculture.

9. **Traditional Practices:**
   - Chena cultivation: Shifting cultivation managed to minimize environmental impact.
   - Indigenous intercropping methods in paddy and coconut lands.

Success Story: Gliricidia-based agroforestry in tea plantations has improved soil nitrogen levels by 30-40% while reducing synthetic fertilizer dependency and providing fuelwood for tea processing.

Common Regenerative Practices in South Asia

Despite diverse agro-ecological conditions, several regenerative practices are commonly being adopted across SAARC Member States:

Conservation Agriculture

Zero or Minimum Tillage: Reduces soil disturbance, preserves soil structure, and minimizes carbon emissions. Widely practiced using specialized equipment

- **Zero Tillage Drills:** Direct seeding without prior tillage.
- **Happy Seeder:** Sows wheat directly into rice stubble (Pakistan, India).
- **Super/Pak Seeder:** Single-pass operation that incorporates rice residues and sows' wheat simultaneously (Pakistan has over 2,000 units)

Benefits: Reduced land preparation costs (30-40%), fuel savings, time savings (10-15 days), improved soil moisture retention, and reduced smog from stubble burning.

Residue Retention: Leaving crop residues on fields provides multiple benefits:

- Soil cover protection from erosion and temperature extremes.
- Organic matter addition (0.3-0.5 Mg C ha^{-1} $year^{-1}$).
- Weed suppression.
- Moisture conservation.

Challenge: Residue competition for fodder use, particularly in mixed crop-livestock systems.

Organic Amendments

Composting: Widely practiced across all member states using farm waste, crop residues, and animal manure. Typical composition includes:

- Crop residues (40-50%).
- Animal manure (30-40%).
- Soil/ash (10-20%).
- Water for moisture maintenance.

Vermicomposting: Increasingly popular for high-quality organic fertilizer production using earthworms *(Eisenia fetida, Eudrilus eugeniae)*. Benefits include:

- Nutrient-rich output (N: 1.5-2%, P: 1-1.5%, K: 1-1.5%).
- Improved soil microbial activity.
- Better plant growth hormones.

Biochar: Emerging practice using pyrolyzed organic materials:

- Improves soil water retention (20-30%).
- Enhances cation exchange capacity.
- Provides long-term carbon sequestration.
- Reduces nutrient leaching.

Jholmal (Nepal): Liquid organic fertilizer prepared by fermenting plant materials, cow dung, and urine. Rich in NPK and micronutrients, applied as foliar spray or soil drench.

Farmyard Manure (FYM): Traditional practice of applying decomposed animal manure, widely used but declining due to reduced livestock integration.

Crop Diversification and Rotation

Legume Integration: Incorporating nitrogen-fixing legumes improves soil fertility and breaks pest cycles:

- Rice-lentil rotation (Bangladesh, Nepal, India).
- Wheat-mungbean rotation (Pakistan, India).
- Maize-soybean intercropping (Nepal, India).
- Cotton-chickpea rotation (Pakistan, India).

Multi-cropping Systems:

- **Crop rotation:** Sequential planting of different crops (rice-wheat-maize).
- **Mixed cropping**: Growing two or more crops simultaneously in the same field.
- **Strip cropping:** Different crops in adjacent strips.
- **Multi-storied cropping**: Crops of different heights grown together (common in Bhutan, Sri Lanka).

Benefits: Enhanced nutrient cycling, pest and disease suppression, risk diversification, improved soil health.

Cover Cropping and Mulching

Cover Crops: Growing crops primarily for soil health rather than harvest.

- **Leguminous covers:** Sesbania, cowpea, mungbean for nitrogen fixation.
- **Grass covers:** Sorghum, millet for biomass production.
- **Brassicas:** Mustard for bio fumigation.

Mulching Practices:

- **Organic mulches:** Crop residues, leaves, grass clippings.
- **Living mulches:** Low-growing crops maintained between main crops.
- **Plastic mulching:** Used in high-value vegetable production (though not strictly regenerative)

Specific Examples:

- **Nepal:** *Justicia adhatoda* leaves used as mulch in rice nurseries.
- **Sri Lanka:** Gliricidia leaves used as green manure in tea and coconut plantations.
- **Bhutan:** Fodder tree leaves for mulching and soil improvement.

Benefits: Soil moisture conservation (30-40%), weed suppression, temperature moderation, organic matter addition.

Agroforestry Systems

Integration of trees with crops and livestock provides multiple benefits:

Types Practiced:

- **Alley cropping:** Crops grown between rows of trees (common in Sri Lanka, Bhutan).
- **Boundary planting:** Trees along field borders for fodder and timber.
- **Home gardens:** Multi-storied systems with trees, shrubs, and crops.
- **Silvopasture:** Trees integrated with grazing lands.

Common Tree Species:

- **Nitrogen-fixing:** Gliricidia, Leucaena, Sesbania, Acacia.
- **Fruit trees:** Mango, Banana, Papaya, Coconut.
- **Fodder trees**: Ficus, Morus, Grewia.
- **Timber species:** Teak, eucalyptus, bamboo.

Examples:

- **Bhutan:** Fodder trees intercropped on agricultural land, combining fodder, crops, and livestock.
- **Sri Lanka:** Coffee, banana, ginger, turmeric, or pineapple under mature coconut plantations.
- **Nepal:** Agroforestry promoted through government biodiversity programs.

Benefits: Carbon sequestration, biodiversity conservation, additional income sources, microclimate improvement, soil erosion control.

Integrated Pest Management (IPM)

Ecological pest management reducing chemical pesticide dependency:

Practices:

- **Biological control:** Use of natural predators and parasitoids.
- **Botanical pesticides:** Neem, tobacco, garlic extracts.
- **Cultural practices:** Crop rotation, trap cropping, timing of planting.
- **Mechanical control:** Hand-picking, traps, barriers.
- **Resistant varieties:** Use of pest-resistant crop varieties.

Benefits: Reduced pesticide costs (30-50%), improved biodiversity, safer food production, enhanced natural pest control.

Water Management Practices

Alternate Wetting and Drying (AWD): Practiced in rice cultivation to optimize water use:
- Reduces water use by 15-30% without yield penalty
- Decreases methane emissions
- Promoted in Bangladesh, Nepal, Sri Lanka

Efficient Irrigation:
- **Drip irrigation:** High-value crops in water-scarce areas.
- **Sprinkler irrigation:** Vegetables and field crops.
- **Rainwater harvesting:** Collection and storage for supplemental irrigation.

Moisture Conservation:
- Mulching for reduced evaporation.
- Contour bunding to reduce runoff.
- Farm ponds for water storage.

Direct Seeding of Rice

Transitioning from transplanted rice to direct seeding:

Types:
- Dry Direct-Seeded Rice (DDSR): Seeds sown in dry soil, then irrigated.
- Wet Direct-Seeded Rice (WDSR): Seeds sown in puddled soil.

Benefits: Water savings (20-30%), labor reduction, faster establishment, reduced methane emissions.

Challenges: Weed management, uneven germination, lower yields in some contexts.

Adoption: Increasingly practiced in Nepal, Pakistan, India, Sri Lanka.

Table. Regenerative Agriculture Status Across SAARC Member States.

Country	Key Practices	Policy Framework	Main Challenges	Success Stories
Bangladesh	Conservation agriculture, agroforestry, rice-fish systems, composting, reduced tillage	NAP 2018, Organic Policy 2016, Delta Plan 2100, NAP 2023-2050	Small farms (0.5 ha), groundwater depletion, knowledge gaps, policy fragmentation	CSISA zero tillage (100,000+ ha), UBINIG organic villages, coastal agroforestry
Bhutan	Organic farming, agroforestry, integrated livestock, traditional varieties, SLM	100% organic by 2035, LEDS 2021, RNR Strategy 2040, SAPA 2016	Mountain terrain (2.93% cultivable), limited mechanization, market access	SLM project (3,300+ ha converted), LEDS organic fertilizer targets
India	Zero Budget Natural Farming (ZBNF), Conservation Agriculture, Organic Farming Programs, System of Rice Intensification (SRI) and Agroforestry.	National Policy for Farmers (2007), National Agroforestry Policy (2014), Soil Health Card Scheme and Pradhan Mantri Krishi Sinchayee Yojana.	Scale of adoption still limited compared to total cultivated area, Yield gaps during transition period discourage farmers, Inadequate market infrastructure for organic produce, Extension system gaps in training on RA practices and Subsidy structures favoring conventional inputs.	Andhra Pradesh's Zero Budget Natural Farming program has reached over 600,000 farmers across 6 million acres, demonstrating large-scale viability of regenerative approaches.
Maldives	Composting of organic household waste, Home garden diversification, Organic vegetables production for local consumption and Integrated farming in community gardens.	Climate Resilient Farming Practices Project (2018-2023), Under this project introduction of smart irrigation controllers to optimize water use, Implementation of a variety of successful resource conservation practices by the Government, like integration agroforestry in Addu City and Fuvahmulah composting programs in Loamu Atoll and likewise adoption of mulching and	Extremely limited agricultural land availability, Reliance on traditional methods, Soil salinity issues, Water scarcity, High costs of agricultural inputs, Predominantly rain fed agricultural practices, Limited access to freshwater resources, Salinity of groundwater poses significant challenges to sustainable agriculture, Irrigation depends primarily on rainwater harvesting, Desalination addresses water shortages, but its high operational costs and	Home backyard garden diversification, Conservation agricultural practices in irrigated areas include use of Drip irrigation systems and Mulching practices. In rainfed areas, promotion of agroforestry particularly coconut-based farming, and rainwater harvesting technologies i.e. Community – level

Country	Key Practices	Policy Framework	Main Challenges	Success Stories
		minimal tillage practices in the northern atolls. Distribution of low-cost drip irrigation kits. National Action Plan on Sustainable Agriculture (2019-2023), Tax Exemptions on Imports of Conservation Tools and Organic Fertilizers and similarly Agricultural Development Master Plan (2020-2030).	energy requirements present challenges for widespread adoption, particularly for small-scale farmers, Limited use of mechanized machinery, primarily due to small size of agricultural plots and high costs associated with importing and maintaining such equipment.	rainwater harvesting systems (i.e. storage structures such as tanks and ponds), which collect and store rainwater during the wet season for use during drier periods.
Nepal	Biodiversity conservation, community seed banks, agroecology, agroforestry	Agriculture Development Strategy, biodiversity conservation policies	40% biodiversity loss, low organic matter (50%+ farms), residue burning	Community seed banks, participatory plant breeding, mid-hills agroforestry
Pakistan	Super Seeder technology, regenerative cotton, reduced tillage, crop rotation	Emerging RA policies, WWF programs, RPLC collaboration	Water scarcity, soil degradation, conventional practices dominance	2,000+ Super Seeders, WWF Better Cotton, 60% water savings
Sri Lanka	Zero tillage, cover crops, mulching, plantation agroforestry, smart farming	National Agriculture Policy 2021, organic farming initiatives	Erosion (33%+ land), weak extension, economic constraints, policy gaps	Gliricidia agroforestry, SARP project, IUCN tea/coconut programs

Gaps of Regenerative Agriculture in South Asia

Despite growing interest and adoption, significant gaps hinder the widespread scaling of Regenerative agriculture across South Asia:

Knowledge and Awareness Gaps

1. **Farmer Awareness:** Limited understanding of RA principles, benefits, and practices among smallholder farmers.

2. **Extension Worker Training:** Agricultural extension staff lack comprehensive training on RA techniques.

3. **Technical Knowledge:** Insufficient knowledge on practice-specific details (e.g., composting ratios, cover crop management).

4. **Language Barriers:** RA information primarily available in English, not in local languages.

5. **Gender Dimensions:** Limited understanding of how RA practices affect men and women differently.

Research and Development Gaps

1. **Long-Term Studies:** Scarcity of long-term (>10 years) field trials demonstrating RA impacts.

2. **Context-Specific Research:** Limited research on RA adaptation to diverse agro-ecological zones.

3. **Economic Analysis:** Insufficient economic viability studies, cost-benefit analyses, and return on investment data.

4. **Yield Comparisons:** Need for more rigorous yield comparison studies between RA and conventional systems.

5. **Carbon Measurement:** Limited capacity for measuring and verifying carbon sequestration.

6. **Biodiversity Assessment:** Inadequate monitoring of biodiversity impacts of RA practices.

7. **Water Quality Studies:** Insufficient research on RA effects on water quality and aquatic ecosystems.

8. **Scaling Pathways:** Limited research on how to scale RA from pilot projects to landscape level.

Policy and Institutional Gaps

1. **Dedicated RA Policies:** Most countries lack specific policies focused on Regenerative agriculture.

2. **Subsidy Misalignment:** Agricultural subsidies still favor synthetic fertilizers and pesticides.

3. **Institutional Coordination:** Weak coordination among ministries, research institutes, and extension services.

4. **Monitoring Systems:** Absence of monitoring, reporting, and verification (MRV) systems for RA adoption.

5. **Land Tenure:** Insecure land tenure discourages long-term investments in soil health.

6. **Regulatory Frameworks:** Inadequate regulations for organic certification, carbon credits, and quality standards.

Economic and Market Gaps

1. **Initial Investment:** High upfront costs for machinery, organic inputs, and knowledge acquisition.

2. **Transition Period:** Economic risks during 2-3 year transition period with potential yield reductions.

3. **Market Access:** Limited market linkages and premium prices for regeneratively produced commodities.

4. **Certification Costs:** High costs of organic and regenerative certification prohibitive for smallholders.

5. **Financial Services:** Lack of credit and insurance products tailored to RA farmers.

6. **Carbon Markets:** Underdeveloped agricultural carbon markets in South Asia.

7. **Value Chains:** Weak value chains for organic inputs (compost, biofertilizers) and outputs.

Technical and Infrastructure Gaps

1. **Machinery Availability:** Limited access to specialized equipment (zero tillage drills, seeders, mulchers).

2. **Machinery Affordability:** High costs of conservation agriculture equipment beyond smallholder reach.

3. **Local Manufacturing:** Insufficient local manufacturing capacity for RA equipment.

4. **Input Supply:** Inadequate supply chains for quality organic inputs, cover crop seeds, biofertilizers.

5. **Soil Testing:** Limited access to affordable, timely soil testing services.

6. **Water Infrastructure:** Inadequate irrigation infrastructure for efficient water management.

7. **Storage Facilities:** Lack of storage for organic produce and inputs.

Social and Cultural Gaps

1. **Risk Aversion:** Farmer reluctance to experiment with new practices due to livelihood risks.

2. **Traditional Practices:** Disconnect between traditional knowledge and modern RA science.

3. **Labor Availability:** Some RA practices (e.g., composting, mulching) are labor-intensive amid rural labor shortages.

4. **Gender Roles:** Unequal participation of women in decision-making despite their significant farm labor.

5. **Youth Migration:** Rural-urban migration reducing available labor for agriculture.

6. **Community Organization:** Weak farmer organizations limiting collective action for RA adoption

Data and Information Gaps

1. **Baseline Data:** Insufficient baseline data on soil health, biodiversity, and ecosystem services.

2. **Adoption Rates:** Lack of reliable data on RA practice adoption rates across countries.

3. **Impact Monitoring:** Inadequate systems for monitoring RA impacts on soil, water, biodiversity, and livelihoods.

4. **Documentation:** Poor documentation of traditional RA practices and indigenous knowledge.

5. **Digital Platforms:** Limited digital platforms for RA knowledge sharing and farmer networking.

Climate and Environmental Gaps

1. **Climate Vulnerability:** Insufficient integration of RA with climate adaptation strategies.

2. **Extreme Events:** Limited research on RA resilience to extreme weather events.

3. **Pest Management:** Gaps in ecological pest management knowledge for specific crop-pest systems.

4. **Water Scarcity:** Inadequate adaptation of RA practices to water-scarce environments.

5. **Degraded Lands:** Limited focus on RA for restoring severely degraded and marginal lands.

Future R&D Priorities in Relation to Regenerative Agriculture

To accelerate Regenerative agriculture adoption and maximize its benefits, the following research and development priorities are recommended:

Research Priorities

1. **Context-Specific Practice Optimization:**
- Adapt RA practices to diverse agro-ecological zones (arid, semi-arid, humid, mountain).
- Optimize practice combinations for specific cropping systems (rice-wheat, cotton-wheat, maize-based).
- Develop region-specific guidelines for cover crop selection, composting, and mulching.

2. **Crop Variety Development:**
- Breed varieties suited to RA systems (e.g., competitive with weeds in no-till, responsive to organic nutrients).
- Develop climate-resilient varieties (drought-tolerant, flood-tolerant, heat-tolerant).
- Preserve and promote traditional varieties adapted to low-input systems.

3. **Soil Health Research:**
- Long-term monitoring of soil organic carbon, microbial diversity, and nutrient cycling under RA.
- Develop rapid, affordable soil health assessment tools for farmers.
- Research on biochar production and application for different soil types.
- Study soil-plant-microbe interactions in regenerative systems.

4. **Integrated Pest Management:**
- Develop ecological pest management strategies for major crop-pest systems.
- Research on beneficial insects, biological control agents, and botanical pesticides.
- Study pest dynamics in diversified cropping systems.

5. **Water Management:**
- Optimize alternate wetting and drying (AWD) protocols for different rice varieties and regions.
- Research on water-saving technologies compatible with RA (drip, micro-sprinkler).
- Study groundwater recharge potential of RA practices.

Livestock Integration Research

1. **Crop-Livestock Integration:**
- Develop integrated systems that optimize nutrient cycling between crops and livestock.
- Research on managed grazing practices for South Asian contexts.
- Study fodder production from cover crops and crop residues.

2. **Manure Management:**
- Optimize composting and vermicomposting techniques for different livestock types.
- Research on biogas production integrated with organic fertilizer generation.
- Study nutrient retention and pathogen reduction in manure processing.

Agroforestry and Biodiversity Research

1. **Tree-Crop Integration:**
- Identify optimal tree species, spacing, and management for different agro-ecologies.
- Research on nitrogen-fixing trees for soil fertility improvement.
- Study microclimate effects of trees on crop productivity.

2. **Biodiversity Assessment:**
- Monitor above-ground and below-ground biodiversity in RA vs. conventional systems.
- Research on pollinator conservation and habitat provision in RA landscapes.
- Study functional biodiversity (beneficial insects, soil organisms) supporting ecosystem services.

3. **Agrobiodiversity Conservation:**
- Document and conserve traditional crop varieties and landraces.
- Research on participatory plant breeding integrating farmer knowledge.
- Study nutritional quality of traditional vs. modern varieties.

Carbon and Climate Research

1. **Carbon Sequestration:**
- Establish long-term carbon monitoring sites across agro-ecological zones
- Develop region-specific carbon sequestration models for RA practices
- Research on measurement, reporting, and verification (MRV) protocols for agricultural carbon

2. **Greenhouse Gas Emissions:**
- Quantify GHG emissions (CO_2, CH_4, N_2O) from RA vs. conventional systems
- Optimize practices to minimize emissions (e.g., AWD for CH_4 emissions reduction)
- Study net climate impact considering all GHGs.

3. **Climate Resilience:**
- Research on RA system resilience to droughts, floods, heat waves.
- Study crop performance under future climate scenarios.
- Develop early warning and adaptation strategies for climate extremes

Socio-Economic Research

1. **Economic Viability:**
- Conduct comprehensive cost-benefit analyses of RA adoption.
- Study profitability across farm sizes and agro-ecologies.
- Analyze transition period economics and risk mitigation strategies.

2. **Market Development:**
- Research on consumer willingness to pay for regeneratively produced foods.
- Study value chain development for organic and regenerative products.
- Analyze certification schemes and their accessibility for smallholders.

3. **Social Impacts:**
- Study gender dimensions of RA adoption and benefits.
- Research on youth engagement in regenerative farming.
- Analyze labor requirements and employment effects of RA.

4. **Farmer Decision-Making:**
- Study factors influencing RA adoption and dis-adoption.
- Research on farmer learning networks and knowledge diffusion.
- Analyze role of social norms and peer effects in practice adoption.

Technology and Innovation Research

1. **Machinery Development:**
- Design affordable, locally manufacturable RA equipment for smallholders.
- Adapt existing machinery for small farm sizes and diverse terrains.
- Research on custom hiring models and machinery cooperatives.

2. **Digital Tools:**
- Develop mobile apps for RA practice guidance and decision support.
- Research on remote sensing for monitoring soil health and carbon sequestration.
- Study precision agriculture technologies compatible with RA.

3. **Biological Inputs:**
- Research on locally produced biofertilizers and biopesticides.
- Develop quality standards and production protocols.
- Study microbial inoculants for enhancing nutrient availability.

Policy Research

1. **Policy Analysis:**
- Evaluate effectiveness of existing policies supporting RA.
- Study subsidy reforms to incentivize regenerative practices.
- Analyze policy coherence across agriculture, environment, and climate sectors.

2. **Institutional Arrangements:**
- Research on effective extension models for RA (farmer field schools, peer learning).
- Study public-private partnerships for scaling RA.
- Analyze roles of NGOs, farmer organizations, and private sector in RA promotion.

3. **Certification and Standards:**
- Develop South Asia-appropriate regenerative agriculture standards.
- Research on low-cost certification mechanisms (participatory guarantee systems).
- Study market recognition and premium pricing for certified products.

Regional Collaboration Research

1. **Comparative Studies:**
- Cross-country comparisons of RA adoption pathways and outcomes.
- Study successful models transferable across SAARC Member States.
- Analyze policy lessons and best practices regionally.

2. **Knowledge Networks:**
- Establish regional research networks for data sharing and collaboration.
- Develop common protocols for RA monitoring and evaluation.
- Create regional databases on RA practices, impacts, and economics.

Conclusion: Pathways Forward for South Asia

South Asia stands at a critical juncture in its agricultural development trajectory. Conventional intensive farming has delivered food security gains but at severe environmental costs-degraded soils, depleted water resources, lost biodiversity, and increased climate vulnerability. Regenerative agriculture offers a viable alternative that can restore ecosystem health while maintaining productivity and enhancing farmer livelihoods.

This regional synthesis reveals that South Asia possesses significant assets for RA transition: rich traditional knowledge of sustainable practices, growing networks of successful demonstrations, emerging policy frameworks, and increasing farmer awareness.

However, realizing RA's full potential requires addressing persistent barriers: knowledge gaps demand intensive capacity building; policy fragmentation needs integrated governance; economic constraints require restructured subsidies and credit; market limitations necessitate certification and value chain development; and technological gaps call for appropriate mechanization and biological inputs.

The pathway forward lies in regional cooperation through the SAARC framework. Shared challenges create opportunities for collective solutions-knowledge exchange through innovation hubs, harmonized policies and standards, and collaborative research addressing common agroecological zones. The SAARC Agriculture Centre can catalyze this cooperation by facilitating knowledge exchange, coordinating research priorities, supporting policy dialogue, and mobilizing resources.

Priority actions for the future include: (1) establishing RA innovation hubs in each member state networked for knowledge sharing; (2) developing national RA policies with regional coordination; (3) restructuring agricultural subsidies to support regenerative transitions; (4) creating regional RA certification standards and market platforms; (5) investing in context-specific research and appropriate technology; (6) implementing farmer-to-farmer learning at scale; and (7) mobilizing climate finance for RA through NDC implementation.

The transition to Regenerative agriculture will not happen overnight. It requires patience, sustained investment, and political commitment. But the alternative-continuing degradation of natural resources-threatens South Asia's agricultural future and food security. The region's 2.0 billion people, 70% dependent on agriculture, deserve farming systems that regenerate rather than deplete, that build resilience rather than vulnerability, and that provide sustainable livelihoods while protecting environmental health.

Regenerative agriculture is not just an agricultural technique it represents a fundamental shift in how South Asia relates to its land, water, and biodiversity. By embracing this paradigm, SAARC Member States can lead globally in demonstrating that productive agriculture and environmental regeneration are not contradictory but complementary goals. The time for action is now, and the pathway is clear through regional cooperation, farmer empowerment, and commitment to leaving healthier soils for future generations.

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Chapter - 2

Promotion of Regenerative Agriculture in SAARC Member States: Bangladesh Perspective

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Summary

Given the nation's dense population and shrinking per capita land availability, conventional farming practices, marked by intensive or excessive chemical use, monocropping and improper land management, have led to soil degradation, water pollution and reduced biodiversity. In response, RA is emerging as a holistic, outcome-based approach that restores soil health, enhances biodiversity, sequesters carbon, reduces greenhouse gas emissions and builds resilience against climate stressors. Herein, discusses current efforts, challenges and policies surrounding RA in Bangladesh, reflecting on agroecological practices such as crop rotation, reduced or zero tillage, composting and agroforestry. It also explores technological and infrastructural limitations that affect adoption, especially among smallholder farmers. The document emphasizes the need for collaborative research, policy support and farmer engagement to scale up regenerative farming practices and ensure sustainable agricultural development.

Introduction

Bangladesh, a deltaic country in South Asia, is home to over 170 million people and heavily reliant on agriculture. Agriculture plays a vital role in ensuring food and nutrition security, employment and poverty reduction in Bangladesh. In Fiscal Year 2023-24, the sector contributed 11.55% to national GDP, with 44.42% of the employed population engaged in agricultural activities, predominantly small and marginal farmers (Labour Force Survey Report, BBS, 2025). While rice remains the dominant crop, the sector is gradually shifting towards high value crops, livestock and fisheries to meet increasing demand (FAO., 2022; BBS., 2023). However, it faces numerous challenges, including population pressure, land degradation, declining soil fertility, wide yield gaps, low productivity, weak market linkages, biodiversity loss and climate vulnerability (IPBES., 2019; BARC., 2021). Despite these issues, agricultural production has steadily increased, supported by improved irrigation, fertilizer use, research breakthroughs in climate resilient crops, and better fish and livestock production (World Bank., 2023; Alam et al., 2020). These achievements stem from increased investments, policy reforms, technological innovation and the hard work of farmers. Nonetheless, environmental concerns persist due to overuse of agrochemicals (chemical fertilizers and pesticides), monoculture practices, improper land management and intensive tillage, have led to soil degradation, water pollution and reduced biodiversity (Rahman & Zhang., 2018; FAO & UNEP., 2021). These challenges are exacerbated by climate change, which increases the vulnerability of farmers through frequent floods, droughts and salinity intrusion (MoEFCC., 2023; IPCC., 2022).

The depletion of natural resources, deterioration of soil health and increasing climate and natural crises are undermining land productivity and resilience (FAO., 2021). Although the agriculture sector is the single largest driver of global biodiversity loss ((IPBES., 2019), it has been proven that the adoption of regenerative agriculture can help mitigate this damage and restore ecosystems (Lal., 2020) (Table 1 & 2).

Regenerative Agriculture (RA) is a holistic farming approach that restores soil health, enhances biodiversity, improves water cycles and strengthens climate resilience (Rhodes., 2017; FAO., 2021). It tackles major challenges such as soil degradation, declining yields and overreliance on synthetic inputs, while also improving farmers' livelihoods. Core practices include low or no tillage, organic amendments (compost, manure, biochar), diverse crop rotations, cover cropping, agroforestry, managed livestock grazing and integrated pest management (IPM) (Kassam et al., 2019; LaCanne & Lundgren., 2018). These methods boost soil fertility, support nutrient cycling, reduce erosion and lower environmental impact (Giller et al., 2021).

RA blends traditional knowledge with modern technologies to promote sustainable and productive food systems (Giller et al., 2021). However, its adoption is hindered by high initial costs, knowledge gaps and insufficient policy support (FAO., 2022; Kerr et al., 2022; Pretty et al.,2020). Future priorities include scaling up practices, creating supportive policies, advancing technology and improving farmer education. With the right support, RA can help build resilient, productive and environmentally sustainable agrifood systems worldwide.

In Bangladesh, where agriculture faces the stress from overexploitation, and the climate change, RA offers a promising path toward resilient, inclusive, and eco-friendly food systems (Islam & Gathala., 2023). Going beyond sustainability, it actively reverses degradation caused by conventional practices, ensuring long-term food security and ecological restoration (Pretty et al., 2018).

This paper presents the promotion of RA in Bangladesh by synthesizing stakeholder experiences and perspectives. It assesses the current status, policy framework, and existing practices, identifies key challenges and opportunities, and proposes a mechanism for developing and managing future Research and Development (R&D) initiatives.

Table 1. A Comparison of the Different Agricultural Systems

Aspect	Regenerative Agriculture	Conservation Agriculture	Sustainable Agriculture	Organic Agriculture	Conventional Agriculture	Subsistence Agriculture	Commercial Agriculture
Definition	Farming that restores ecosystems and enhances soil health	Farming that conserves soil, water and biodiversity	Farming that meets current needs without compromising future generations	Farming without synthetic chemicals, GMOs	Industrial farming using synthetic inputs	Farming for household consumption	Farming for profit and market
Primary Goal	Regenerate soil, water and biodiversity	Preserve soil and reduce erosion (soil conservation)	Balance environment, economy and society	Promote ecological balance and biodiversity/ eco-friendly	Maximize yields and profit	Household food security	Economic return
Use of Chemicals	Avoids synthetic inputs; uses biological amendments	Minimized or targeted use	Balanced or reduced input use	No synthetic inputs	Heavy use of fertilizers, pesticides, herbicides etc.	Minimal or traditional use	Extensive use
Soil Management	Composting, cover crops, holistic grazing	No-till or minimal tillage, cover crops	Crop rotation, integrated soil fertility	Composting, crop rotation	Intensive tillage, monoculture	Traditional methods	Mechanized and intensive
Environmental Impact	Positive; improves biodiversity, carbon sequestration	Lower impact, on soil and water conservation	Moderate to low	Low; eco-friendly	High (pollution, soil degradation, greenhouse gas emissions)	Low but less productive	High if not managed properly
Productivity	Moderate, improving over time	Moderate yields, long term resilience	Moderate to high	Moderate yields, high quality	High, short term yields	Low yields	High yields
Market Orientation	Premium regenerative markets, long term resilience	Both commercial and subsistence	Balanced	Niche/organic markets	Commercial	Household level	Export and large-scale markets
Technology Use	Innovative, nature based tech (holistic grazing)	Moderate, eco-friendly	Integrated, appropriate technology	Low-tech or appropriate technology	High, including GMOs	Traditional tools	Advanced technology
Sustainability	Very High	Moderate to High	High	High	Low	Low	Low to Moderate
Examples	Regenerative cotton, agroecological farms	Zero till wheat in South Asia	Agroforestry, IPM practices	Organic rice, vegetables	Large monoculture farms	Tribal farming in hilly areas	Tea, cotton, or jute estates

Key Differences and Overlaps

- *Regenerative vs. Conservation:* Regenerative actively rebuilds soil (regenerating degraded land) and improves resources whereas conservation reduces tillage and preventing degradation. Regenerative includes livestock integration (holistic grazing) and agroforestry, which are optional in conservation.
- *Organic vs. Regenerative:* Organic avoids synthetics; regenerative actively rebuilds soil.
- *Sustainable vs. Regenerative:* Sustainable maintains resources; regenerative improves them.
- *Conservation vs. Conventional:* Conservation reduces tillage; conventional often relies on it.

Table 2. Comparison among Regenerative Agriculture (RA), Conservation Agriculture (CA) and Climate Smart Agriculture (CSA)

Aspect	Regenerative Agriculture (RA)	Conservation Agriculture (CA)	Climate Smart Agriculture (CSA)
Definition	A holistic approach focused on restoring soil health, biodiversity and ecosystem services while improving farm productivity.	A farming system emphasizing minimal soil disturbance, permanent soil cover, and crop rotations to conserve soil and water.	An integrated approach to address food security and climate change by adapting to and mitigating climate impacts while increasing productivity.
Primary Goal	Restore and enhance ecosystems (soil, water, biodiversity) while improving farm resilience and carbon sequestration.	Sustainable land management by reducing erosion, improving soil health and maintaining yields.	Triple win: Sustainably increase productivity, adapt to climate change and reduce greenhouse gas (GHG) emissions.
Key Principles	i) Soil health (organic matter, microbial activity) ii) Biodiversity enhancement iii) Water cycle restoration iv) Carbon sequestration v) Reduced chemical inputs	i) Minimal soil disturbance (no-till/low-till) ii) Permanent soil cover (mulching, cover crops) iii) Crop rotations/ diversification	i) Productivity (food security) ii) Adaptation (resilience to climate change) iii) Mitigation (reduce emissions)
Common Practices	- Cover cropping - Agroforestry - Holistic grazing - Composting - No-till farming - Polycultures	- No-till or reduced tillage - Cover crops - Crop rotation - Residue retention	- Drought tolerant crops - Precision farming - Agroforestry - Water efficient irrigation - Carbon farming
Soil Health	Central focus – rebuilds soil structure, fertility, and microbial life.	Core principle – avoids degradation through minimal disturbance.	Part of resilience strategy – improves soil to withstand climate stresses.
Climate Focus	Carbon sequestration, reversing climate change by rebuilding soil organic carbon.	Reduced degradation, maintaining soil carbon and preventing erosion.	Adaptation and mitigation, reducing agricultural emissions while coping with climate variability.
Biodiversity	Actively promotes biodiversity (e.g. polycultures, agroecology).	Supports biodiversity indirectly via crop rotations and reduced chemicals.	Encourages diversification for resilience but not always a primary focus.
Scalability	Often adopted by small to large farms, but requires knowledge & transition time.	Widely adopted in large-scale farming (e.g. U.S., Brazil, Australia).	Broad applicability, from smallholders to large scale farms, policy driven.
Policy and Certification	Less standardized, but some certifications (e.g. Regenerativen Organic Certified).	Well established (e.g. FAO promotes CA globally).	Supported by FAO, World Bank and national climate policies.

All three (RA, CA and CSA) promote sustainable soil management, reduced tillage and crop diversity. They overlap in practices like cover cropping and agroforestry.

Which One to Choose?

- For ecosystem restoration and carbon farming → Regenerative Agriculture (RA)
- For erosion control and sustainable tillage practices → Conservation Agriculture (CA)
- For climate adaptation and policy aligned farming → Climate Smart Agriculture (CSA)

Current Status of Regenerative Agriculture in Bangladesh

Awareness and Adoption

The concept of Regenerative agriculture is gradually gaining ground in Bangladesh. While not always labeled as *regenerative*, many ongoing practices (Table 3) align with its principles, including:

- **Conservation agriculture-** Reduced tillage and mulching are practiced in some regions, particularly in the northern area to improve soil organic carbon (Haque et al., 2021; CIMMYT., 2020; Jat et al., 2020).
- **Crop rotations and diversification-** Farmers are increasingly adopting crop rotations like rice-legume systems and intercropping to break pest cycles and improve soil fertility (BARI., 2022; Rahman et al., 2020).
- **Composting and vermicomposting-** Traini ng farmers in composting and vermiculture to reduce synthetic input dependency (DAE, 2023; Islam et al., 2021; Hossain et al., 2020)
- **Agroforestry and intercropping-** Silvopasture and alley cropping are being promoted in coastal and hilly areas to combat salinity and erosion (BFRI., 2020; Rahman et al., 2019)
- **Integrated farming systems-** Crop-livestock-fish integration models are being practiced to enhance resource efficiency and farm income (FAO., 2019; Khan et al., 2018).

Table 3. Adoption of Regenerative agriculture practices

Name of the Practices	Adoption Rate	Key Regions	Leading Organizations
Zero tillage	15% (wheat)	Northwest part	CIMMYT, BWMRI, DAE
Cover cropping	<5%	Barind, Haor	BRAC, Practical Action
Organic fertilizers	8% (urban fringe)	Narsingdi	UBINIG, Kazi Farms
Agroforestry	10% (coastal)	Sundarbans	NGOs, Forest Department

Source: CIMMYT., 2020; BWMRI., 2021; Practical Action., 2021; UBINIG., 2020; BFRI., 2020

Challenges in adoption of RA practices by the farmers are

- **Limited awareness/Knowledge gaps**: Farmers and extension workers often lack knowledge, awareness, or training on RA practices and their long term benefits, which is a critical barrier to diffusion of innovation (Uddin et al., 2021).
- **Soil degradation and declining fertility:** Intensive chemical farming, monocropping, and erosion reduce soil organic matter and cause loss of arable land annually (Rahman & Hasan., 2021). Monoculture and pesticide overuse also threaten agrobiodiversity (DoE., 2021).
- **Water scarcity and pollution:** The overuse of groundwater for irrigation, particularly for Boro rice, is depleting aquifers at an alarming rate (Shamsudduha et al., 2020). Furthermore, pesticide and fertilizer runoff contaminate surface water (WARPO., 2020; Islam et al., 2019).
- **Climate change vulnerability**: Bangladesh faces floods, salinity intrusion and droughts that threaten consistent implementation of regenerative agriculture (MoEFCC., 2022; IPCC., 2022).
- **Small landholdings and Economic barriers**: Fragmented farms (average 0.5 ha) hinder mechanized RA adoption, and transition costs for organic inputs discourage poor farmers (World Bank., 2021).

- **Policy gaps/fragmentation**: There is no dedicated national RA policy or subsidies; limited coordination exists between agricultural, environmental and rural development policies (FAO., 2022).

Research and Development (R&D)

Several public and private institutions are engaged in research and demonstration projects related to soil health restoration through organic matter incorporation, reduced tillage practices in rice-wheat systems, biological pest control and biofertilizer development, and climate-resilient cropping systems. Key organizations including Bangladesh Agricultural Research Council (BARC), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Soil Resource Development Institute (SRDI), and Department of Agricultural Extension (DAE). Universities like Bangladesh Agricultural University (BAU), Gazipur Agricultural University (GAU), and Sher-e-Bangla Agricultural University (SAU) are conducting regenerative agriculture related experiments and promoting farmer participatory research. Also, few international organizations (FAO, CIMMYT, ICIMOD, etc.) are supporting regenerative agriculture related pilot projects under climate smart and agroecological farming themes. Successful practices and pilots project in Bangladesh are:

- **Conservation Agriculture Techniques (a subset of RA):** Applied in wheat, maize and rice systems for zero tillage, crop rotation and water saving purposes. Farmers using zero tillage and cover crops in wheat in the northwestern regions, adopted by 20-30% yield increases (Roy et.al., 2009).
- **Agroforestry Systems:** Trees integrated with crops and livestock for soil erosion control and diversified income. ICRAF (World Agroforestry Centre) promotes agroforestry models in drought prone Barind tract. Coastal farmers in Satkhira have improved soil health by integrating shrimp farming with mangrove agroforestry.
- **Organic Compost Use (Jashore, Gazipur, Narsindi):** Farmer led initiatives with NGO supports (e.g., Practical Action, CARE Bangladesh) in organic farming and soil restoration. Farmer adoption organic farming (vermicomposting, green manuring etc.) is limited but growing, especially among smallholders practicing organic farming (~50,000 farmers in regions like Tangail and Dinajpur).
- **Rice-Fish-Azolla Systems (Wetlands):** Diversified production enhancing soil and nutrition.

Policies and Institutional Framework Supporting Regenerative Agriculture

Although Bangladesh does not yet have a dedicated policy on regenerative agriculture, however, different RA related policies, plans and strategies which support its core principles are given as under:

- **National Agricultural Policy (2018):** Encourages sustainable intensification, climate smart farming and natural resource conservation but lacks specific regenerative agriculture provisions/measures.
- **National Organic Agriculture Policy (2016):** Promote sustainable and environmentally friendly agricultural practices.
- **National Forest Policy (2016):** Encourages integration of trees into farmland.
- **Bangladesh Delta Plan (2100)**: Prioritizes regenerative and nature-based solutions, and also highlights soil and water conservation.

- **National Adaptation Plan of Bangladesh (2023-2050):** Highlights ecosystem restoration, carbon sequestration and resilient farming.
- **Bangladesh Climate Change Strategy and Action Plan**: Promotes the climate resilient agriculture and carbon mitigation, indirectly support to RA.
- **Soil Health Strategy:** Encourages organic inputs, reduced chemical dependence and biological soil fertility enhancement.

Bangladesh Agricultural Research Council (BARC) plays a coordination role in aligning regenerative agriculture within national Research & Development and extension priorities through National Agricultural Research System (NARS). Department of Agricultural Extension (DAE) promotes integrated farming and soil health management that overlap with regenerative agriculture goals. Bangladesh Agricultural Research Institute (BARI) and SAARC Agriculture Centre (SAC) are collaborating to test and implement regenerative agriculture (RA) practices like biochar and green manuring in Bangladesh. NGOs and private sector like BRAC, Practical Action, UBINIG, PRAN, ACI and others promote agroecology, farmer field schools (FFSs) and organic farming. These initiatives aim to enhance soil health, improve crop yields and promote sustainable farming practices in Bangladesh.

Key Regenerative Agricultural Practices in Bangladesh

Soil Management

- **Reduced or Zero tillage**: This practiced experimentally applied in wheat-maize-rice systems in north western regions of Bangladesh. In Barind tract area/region, a conservation agriculture technique was introduced by BARI and CIMMYT under Cereal Systems Initiative for South Asia (CSISA) project that improved water use efficiency (up to 30% save), increased yields and improved soil structure (Sarkar et al., 2012; Hossain et al., 2014; Timsina et al., 2018; Jat et al., 2019).
- **Organic amendments**: Widespread use of compost, vermicompost, green manure and crop residues in soil enhances the soil fertility and reduces chemical fertilizer dependency. An NGO named as UBINIG Initiative developed an organic village in Narsingdi, where complete shift to organic farming using compost and biopesticides to get higher yields and also maintain better soil health (UBINIG., 2018; Hoque et al., 2020).
- **Mulching and soil cover**: This practice is commonly applied in vegetable and orchard farming to conserve moisture and suppress weeds, as documented in various farmer field schools and Department of Agricultural Extension (DAE) training modules (DAE., 2019).

Crop Management

- **Crop diversification and rotations**: This is implemented to break pest cycles and restore soil nutrients. Mixed cropping and intercropping are gaining ground in hilly and flood-prone areas. The Sustainable Agriculture and Food Security (SAFE) Project run by Practical Action in haor (wetland) regions has promoted crop diversification and organic fertilizers, leading to improved yields and soil fertility (Practical Action., 2020; Rahman et al., 2021).
- **Cover crops**: There is limited adoption on research stations and pilot farms, but the use of leguminous cover crops is growing, with studies showing benefits for soil nitrogen levels (Jahan et al., 2021; BARI., 2020; BARI., 2022).

- **Organic practices in vegetable clusters:** Farmers in Jashore and Gazipur are practicing mixed cropping, compost use, mulching, and trap crops. These practices are supported by Safe Agro Food Efforts (SAFE) and participatory guarantee systems (PGS) initiatives, which verify their organic claims (SAFE., 2021; Alam et al., 2023).
- **Integrated pest/nutrient management (IPM/INM)**: These are widely promoted across Bangladesh through Department of Agricultural Extension (DAE) programs, enhancing soil and crop health while reducing chemical inputs (DAE., 2021).
- **Biological inputs:** Use of Trichoderma, Rhizobium and bio-pesticides is increasing under both public and private sector initiatives (BARI., 2019; Rahman & Begum., 2020; Khatun et al., 2021).

Agroforestry and Integrated Systems

- **Homestead agroforestry**: This is a common and traditional practice in rural households, combining trees, crops, and livestock for subsistence and income, a system well-documented by the Bangladesh Agriculture University (Kabir & Webb., 2009; Islam et al., 2015; Miah et al., 2016; BFD., 2020).
- **Gher farming**: Integrated rice-fish-vegetable systems in coastal regions (Khulna, Bagerhat, Satkhira etc.) have shown improved productivity and ecosystem resilience (Ahmed & Garnett., 2011; Belton et al., 2011; Rahman et al., 2013; Rahman et al., 2018; Ahmed et al., 2018).
- **Hill Tracts and Char Areas:** Trees are integrated with crops and livestock for erosion control and diversified income. Such systems have been implemented and studied by IUCN and the Forest Department in Cox's Bazar, Rangamati and Jamuna chars (IUCN., 2015; IUCN., 2019; MoEFCC., 2021; BFD., 2021).
- **Silvopasture**: This is practiced in limited forms, with significant scope for expansion, as identified in reports on potential land use systems in Bangladesh (Kabir et al., 2017; Zaman et al., 2019; Hasan et al., 2020).

Key Regenerative agriculture Practices in Some Hotspots of Bangladesh

Barind and Drought Prone Areas (Northwestern Part of Bangladesh)

Districts: Rajshahi, Chapainawabganj, Naogaon, Dinajpur & others (cover 18 districts with 2.28 million hectares land).

Key features

- Drought in long period, low rainfall (≤1500 mm/year).
- High groundwater depletion (water table dropping every year).
- Dominant crops: rice, wheat, mango, mustard and pulses.

Table 4. RA practices in Barind and Drought prone areas

Practices	Adoption Rate	Impact	Leading Organizations
Zero tillage in Wheat	25% (Dinajpur)	20-30% water savings	CIMMYT, DAE
Cover cropping (Mungbean after rice)	10%	Improves soil N (30%)	BRAC, BARI
Agroforestry (Mango + Lentils)	15%	40% income rise	FAO, Local Cooperatives

Source: Bokhtiar et. al., 2023; Bokhtiar & Samsuzzaman., 2023; CIMMYT., 2020; MoP., 2018

Challenges

- Farmer's reluctance to shift from Boro rice is well documented, as it is a high profit but water-intensive crop (Qureshi et al., 2015).
- Lack of affordable drip irrigation systems remains a significant barrier to scaling water-efficient RA practices.

Haor and Flash Flood Areas

Districts: Sunamganj, Kishoreganj, Netrokona, Sylhet & Others (cover 7 districts with 1.66 million hectares land)

Key features

- Seasonal flooding (May - Oct), dry winters.
- Fragile ecosystem, high poverty.
- Dominant crops: Boro rice, fish, floating gardens.

Table 5. Regenerative agriculture practices in Haor and Flash flood areas

Practices	Adoption Rate	Impact	Leading Organizations
Floating gardens (*Baira*)	30% (Sunamganj)	200% income rise	Practical Action, HELVETAS
Fish-Rice polyculture	20%	35% higher yields	WorldFish, DAE
Organic compost (Water hyacinth)	15%	Reduces urea use by 50%	Local NGOs

Source: Bokhtiar et. al., 2023; Bokhtiar & Samsuzzaman., 2023; Practical Action., 2019; WorldFish., 2018; MoP., 2018.

Challenges

- Post flood soil erosion and nutrient loss degrade land productivity.
- Limited winter crop options that are both profitable and suitable for RA principles.

Coastal Zone (Southwest and Southern Bangladesh)

Districts: Khulna, Satkhira, Bagerhat, Patuakhali and Others (cover 19 districts with 2.77 million hectares land).

Key features

- 30% farmland salinity-affected (up to 15 dS/m).
- Cyclone and tidal surge risks.
- Dominant crops: Shrimp, saline tolerant rice, coconut.

Table 6. Regenerative agriculture practices in Coastal zone

Practices	Adoption Rate	Impact	Leading Organizations
Shrimp-Rice rotation	40% (Satkhira)	50% higher profits	USAID, BRAC
Sundarbans-based Agroforestry	10%	Carbon sequestration	Forest Dept., IUCN
Salt tolerant cover crops	5%	Reduces salinity by 20%	BARI, SRDI

Source: Bokhtiar et. al., 2023; Bokhtiar & Samsuzzaman., 2023; IUCN., 2019; MoP., 2018

Challenges

- Conventional shrimp farming often conflicts with Regeneraive agriculture due to chemical use and water management issues (Islam et al., 2021).
- Few market linkages for produce from saline Regenerative agriculture systems limit farmer incentives.

Chattogram Hill Tracts (CHTs)

Districts: Rangamati, Bandarban, Khagrachari (3 districts and 1.33 million hectares land cover)

Key features
- Sloping land, high erosion risk.
- Indigenous farming systems.
- Dominant crops: Jhum (shifting cultivation), turmeric, pineapple etc.

Table 7. Regenerative agriculture practices in CHTs

Practices	Adoption Rate	Impact	Leading Organizations
Contour farming + alley cropping	25%	Reduces erosion by 60%	UNDP, CARITAS
Organic turmeric cultivation	30% (Bandarban)	Premium quality turmeric	NGOs, Exporters
Jhum alternatives (Agroforestry)	15%	Restores soil in 5 years	FAO, Local Communities

Source: Bokhtiar et. al., 2023; Bokhtiar & Samsuzzaman., 2023; FAO., 2019; MoP., 2018

Challenges
- Land tenure issues limit long-term investments in RA, as noted in studies on indigenous communities (Rasul *et al*., 2019).
- Poor road access severely hinders market access for high-value RA products.

Urban Areas (Peri-Urban + Urban Zones)

Districts: Dhaka, Gazipur, Narsingdi and Others (cover in 7 districts with 1.98 million hectares land).

Key features
- High demand for organic produce.
- Small landholdings, labour availability.
- Dominance in Vegetables, dairy, poultry etc.

Table 8. Regenerative agriculture practices in Urban areas

Practices	Adoption Rate	Impact	Leading Organizations
Urban rooftop gardens	5% (Dhaka)	5-8% city vegetable demand	Dhaka South & North City Corporation, DAE
Vermicomposting (Narsingdi)	15-20%	Cuts fertilizer costs by 30-40%	Kazi Farms, DAE
Integrated crop-Livestock farming	15%	Circular economy model	BRAC, BAU

Source: Bokhtiar et. al., 2023; Bokhtiar & Samsuzzaman., 2023; IUCN, 2019; MoP., 2018

Challenges
- Land scarcity limits the expansion of urban RA initiatives.
- High pesticide residues in peri-urban soils from conventional farming pose a challenge to transitioning to organic RA.

Key Takeaways in Each Hotspot Region

Table. 9 Priority actions for each Hotspot region

Regions	Top RA Priority	Policy Needs
Barind and Drought Prone Areas	Zero tillage + drought resistant crops	Subsidies for RA machinery
Haor and Flash Flood Areas	Floating gardens + fish-rice systems	Flood resilient RA packages
Coastal Zones	Saline agroforestry	Carbon credit schemes
Chattogram Hill Tracts	Contour farming + organic spices	Land rights for indigenous farmers
Urban Areas	Urban composting hubs	RA zoning laws

Source: Bokhtiar et. al., 2023; Bokhtiar & Samsuzzaman., 2023; MoP., 2018

Factors influencing the adoption of Regenerative Agriculture

The adoption of RA is influenced by a complex interplay of challenges and enabling factors. The following points outline these key influencers, supported by relevant literature and reports.

i) **High dependence on rain-fed agriculture:** A significant portion of agriculture in Bangladesh is rain-fed and exposed to increasing vulnerability to climatic variability. This dependency acts as a critical push factor for adopting more resilient systems like RA, which enhances water infiltration and soil moisture retention (FAO.,2011). For instance, in large parts of Bangladesh and India, monsoon inconsistencies directly threaten crop stability, creating a pressing need for practices that build farm level resilience (IPCC., 2022).

ii) **Low agricultural productivity:** Stagnating and sub-optimal yields of staple crops across the region are often linked to widespread soil degradation, including organic matter depletion and micronutrient deficiencies (Lal., 2015). This productivity gap underscores the potential of RA to restore soil health, thereby closing yield gaps and improving long-term food production capacity (Giller et al., 2021).

iii) **Poverty and food security:** With a substantial proportion of the population engaged in agriculture and facing poverty, the sector is directly tied to livelihood and food security. Sustainable intensification through RA practices is increasingly seen as a pathway to achieve "*double wins*", improving ecosystem health while securing livelihoods and nutritious food supplies for smallholder farmers (Pretty & Bharucha., 2014).

iv) **Climate change impacts:** Bangladesh is identified as a climate change hotspot, experiencing a rise in the frequency and intensity of extreme weather events such as floods, droughts and heatwaves (SAARC., 2019). These escalating risks make the climate resilience benefits of RA, such as improved soil water holding capacity and enhanced farm biodiversity, a compelling reason for its promotion as a climate adaptation strategy (Rodale Institute., 2014).

v) **Growing awareness:** A rapidly expanding body of scientific literature and farmer-facing communication is highlighting the co-benefits of RA. These include not only climate resilience and productivity but also critical ecosystem services like carbon sequestration to mitigate climate change and the restoration of agricultural biodiversity (Schreefel et al., 2020). This growing evidence base is crucial for building stakeholder confidence.

vi) **Initiatives and programs:** Regional and national organizations are playing a pivotal role in facilitating this transition in Bangladesh. Institutions such as SAARC Agriculture Centre (SAC) and International Centre for Integrated Mountain Development (ICIMOD) have been instrumental in promoting sustainable land management and conservation agriculture practices across the country. Through pilot projects, knowledge sharing and targeted policy advocacy, these bodies have supported Bangladesh in addressing the challenges of agricultural sustainability and climate resilience (SAC., 2020).

vii) **Certification schemes:** Market based instruments are increasingly gaining traction as powerful drivers of sustainable agriculture in Bangladesh. International certification schemes, such as *regenagri*, offer a structured framework for standardizing regenerative practices, enhancing credibility and creating vital market linkages for sustainably produced goods (regenagri, 2023). For Bangladeshi farmers, this presents an opportunity to access premium prices and tap into international export markets, thereby creating a direct economic incentive for the widespread adoption of RA practices.

Merits and Demerits of Regenerative Agriculture

Merits and Opportunities

a) **Environmental**: RA enhances soil carbon storage (carbon sequestration), a critical process for mitigating GHG emissions, as highlighted by the IPCC (2019) in its special report on climate change and land. It reduces the use of agrochemicals, leading to improved soil health through increases in organic matter, microbial activity, nutrient cycling and water retention (Lal, 2020). This approach fosters biodiversity conservation by encouraging crop diversification and supporting natural enemies of pests, thereby revitalizing degraded lands (Kremen & Miles., 2012). The system builds climate resilience, reducing flood risk and enhancing drought tolerance, which contributes directly to long term food security (FAO., 2019).

b) **Economic**: Over time, RA lowers input costs and enhances crop resilience, by reducing dependency on synthetic fertilizers and pesticides. This builds ecosystem services and ensures resource sustainability through long term productivity, often leading to better yields and economic returns (DeLonge et al., 2016). Furthermore, there is a growing demand for organic and sustainable products; urban consumers and export markets (e.g. for jute, spices) increasingly prefer eco-friendly produce, creating new market opportunities.

c) **Social**: Regenerative agriculture can lead to improved nutrition and create employment opportunities. It empowers smallholders, particularly women and youth, through knowledge sharing and community-based practices, thereby reducing external dependency (Altieri & Toledo., 2011). Many existing traditional and indigenous methods (e.g., floating gardens, crop rotation) align perfectly with RA principles, providing a strong foundation for integrating these valuable knowledge systems into modern frameworks.

d) **Alignment with SDGs**: The principles and outcomes of RA directly support multiple Sustainable Development Goals (SDGs), including Goal 2 (Zero Hunger), Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action) (United Nations., 2015).

e) **Research and Development**: Significant opportunity exists for Bangladesh to identify the most effective, context specific regenerative agricultural practices. To fast-track this process, leveraging regional knowledge exchange is critical. Bangladesh should systematically examine India's experience with its Paramparagat Krishi Vikas Yojana (PKVY) and farmer led natural farming movements, extract key lessons from Nepal's established agroecology and agroforestry models, and carefully evaluate the outcomes of Sri Lanka's organic farming initiatives. This comparative learning will be invaluable for developing a robust, evidence-based strategy for RA in Bangladesh that addresses its specific challenges, such as soil salinity, water management and intensive cropping systems.

Demerits/Challenges and Constraints

a) **High transition costs**: The initial phase of transitioning to RA requires significant investments in new training, equipment and can lead to yield depressions, which may discourage farmers from adoption despite long-term benefits (DeLonge et al., 2016).

b) **Awareness and technical capacity**: A major barrier is the lack of awareness and technical know-how among farmers and extension personnel regarding Regenerative agriculture principles. This is compounded by a lack of financial mechanisms or incentives to support the transition from conventional practices (Pannell et al., 2006).

c) **Knowledge and financial barriers**: The combination of limited knowledge and insufficient financial resources is consistently cited as a primary barrier to adoption, especially for resource poor smallholders (Knowler & Bradshaw., 2007).

d) **Small and fragmented land holdings**: The prevalence of small and fragmented landholdings in many regions complicates the scaling of RA practices. Furthermore, some RA practices are labour intensive (e.g., cover cropping, composting), making them challenging to implement on small farms without efficient labour management (Giller et al., 2021).

e) **Availability of RA friendly technologies and tools:** There is limited access to appropriate technologies and farm machinery designed specifically for regenerative practices, creating a technological gap for farmers (Kassam et al., 2019).

f) **Market linkages**: The absence of premium pricing or recognized certification systems for regenerative products means farmers often do not receive a financial reward for their sustainable efforts, weakening the economic incentive (Loconto & Fouilleux., 2013).

g) **Standardization and certification**: Developing robust, credible, and universally accepted standards and certification schemes is crucial for building consumer trust and scaling up RA, but this process remains a significant challenge (Newton et al., 2020).

h) **Insufficient coordination**: There is often a disconnect between research institutions, extension services and policy making bodies, leading to inefficient dissemination of knowledge and poorly aligned support systems (Birner., 2009).

Developing Mechanism for Further Research and Development (R&D) on Regenerative Agriculture

Strengthening Research Framework

- Encourage collaboration among National Agricultural Research System (NARS) organizations/institutes in Bangladesh, BARC is prioritized RA in their research agenda. Research priorities may be soil health restoration (carbon sequestration, organic matter dynamics), integrated crop-livestock systems, low input sustainable nutrient and pest management, biochar, compost and regenerative soil amendments, performance of indigenous crop varieties and mixed cropping systems, climate resilient practices for stress (flood, salinity, drought etc.) prone areas, and econometric studies comparing regenerative agriculture vs conventional agriculture etc.
- Establish a wide RA Research Network under BARC to facilitate multi location trials, data sharing and innovation exchange.
- Create a NARS RA innovation hubs: Partnership with NARS institutes [institutes like Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Wheat and Maize Research Institute (BWMRI), etc.] in Bangladesh with other organizations like SAARC Agriculture Centre (SAC, Dhaka), International Centre for Integrated Mountain Development (ICIMOD, Nepal) to promote the exchange of innovations and best practices.

Capacity Building

- Nationwide cross training of researchers, extension workers and farmers across via workshops, demonstration plots, and fellowships. This includes implementing regenerative agriculture knowledge exchange programs, such as farmer-to-farmer learning initiatives (showcasing successes like vermicomposting in Bangladesh), on a recurring basis.

- Integration of RA modules in agricultural universities and training institutes.
- Digital tools like mobile apps for RA best practices.

Policy Advocacy and Incentives

- **Subsidy reforms:** Redirect chemical fertilizer subsidies to RA inputs (compost, biochar etc.).
- **Carbon credit schemes:** Reward farmers for soil carbon storage (e.g., Bangladesh's climate smart agriculture policy).

Funding and Partnerships

- Mobilize funding from international donor organizations for collaborative RA research.
- Encourage public-private partnerships for scaling up farmer led regenerative innovations.

Way to Promote Regenerative Agriculture in a Scientific Manner

Policy and Institutional Support

- Develop national strategy on RA to provide a unified vision, guidelines and measurable goals.
- Mainstream RA into existing national agriculture policies, climate adaptation plans and food security strategies.

Science-Based Approaches

a) Design pilot projects and conduct long term demonstration trials across agro ecological zones to generate scientific evidence on the benefits of RA practices.

- **Bangladesh:** Regenerative trials in salinity affected Satkhira or flood prone Haor basins.
- **Regional Scaling:** Replicate successful models (e.g., India's Zero Budget Natural Farming) in Bangladesh.

b) Data Driven Decision Making:

- Utilize remote sensing (GIS) and digital tools to monitor carbon sequestration, biodiversity gains, and water use efficiency.
- Countrywide RA database for best practices.

Farmer Centric Demonstration and Incentives

- Set up model regenerative farms and demonstration plots across districts with farmer participatory approaches.
- Provide incentives like carbon credits, organic certification and subsidies for cover crops, composting and agroforestry.

Public-Private Partnerships (PPPs)

- **Private Sector**: Engage companies like PRAN (Bangladesh) for RA based supply chains.
- **NGOs**: BRAC, CARE Bangladesh can train farmers in RA techniques.

Monitoring, Reporting and Learning (MRL)

- Establish a regional Monitoring, Reporting and Verification (MRV) mechanism to track the adoption and impact of RA.
- Regular review meetings and adaptive learning approaches involving farmers, researchers and policymakers.

Media and Awareness Campaigns

- **Documentaries and Farmer Stories:** Highlight RA success cases (e.g., Bangladesh's "Barind Tract" Conservation agriculture).
- **RA Strategy Meeting:** Annual conference to align national strategies.

Future Strategies for the Promotion of Regenerative Agriculture in Bangladesh and SAARC Context

To promote RA in a systematic and scientific manner, Bangladesh may pursue the following:

Policy Integration and Institutional Strengthening

- Develop a national policy framework for regenerative agriculture.
- Integrate/Incorporate regenerative agriculture into existing agricultural, soil and environmental policies/plans.
- Strengthen institutional coordination among ministries, research institutes and extension services.

Capacity Building and Public Awareness/Campaigns

- Train extension agents, farmers, and agri. entrepreneurs on regenerative agriculture practices.
- Develop region specific guidelines and training modules, farmer to farmer extension, and regenerative agriculture curriculum in agricultural education.
- Organize field demonstrations and Farmer's Field Schools (FFSs).
- Highlight the benefits of RA produced food for health and environment through campaigns.

Research and Innovation

- Expand/Increase R&D funding for adaptive regenerative practices/technologies to local agro-ecologies.
- Promote participatory research with farmers and local communities through farmer centric extension services via mobile and community groups.
- Strengthen soil health monitoring systems for long-term trials.
- Enhance funding and coordination for soil health research.
- Strengthen adaptive research and extension interface with context specific Regenerative agriculture technologies.
- Strengthen research on indigenous RA related document for the traditional practices (e.g., floating gardens).
- Engage agribusinesses in promoting RA (e.g., PRAN, ACI) through Public-Private Partnerships (PPPs).

Financial, Certification and Market Support

- Provide green subsidies or incentives for regenerative agriculture adoption (e.g., compost, biofertilizers, cover crops, and other organic inputs/products) as like inorganic/chemical fertilizers.

- Facilitate access to climate finance (e.g., World Bank projects) for carbon credit schemes and carbon markets.
- Support certification and market access for regenerative products and value chains.
- Develop regenerative product labeling and linkages with green markets.

Regional Collaboration

- Exchange knowledge and share experiences, and best practices with other nations.
- Engage in collaborative projects, joint training programs through regional funding mechanism and policy coordination.
- Develop monitoring and evaluation indicators to assess RA outcomes (soil health, biodiversity, carbon sequestration).
- Harmonize organic/RA standards cross border certification for trade benefits.

Experiences and Views from Regenerative Agriculture Stakeholders

- **Farmers**: Early adopters report better soil moisture and reduced costs, but demand/need for training, access to organic inputs, and market linkages for RA products. Farmers practicing RA report lower input costs and better long term yields. Farmers involved in pilot projects in Rangpur, Rajshahi and Khulna report improved soil fertility and reduced input costs. Farmer's Field Schools (FFS) and participatory research platforms are emerging as effective models for RA dissemination.
- **Researchers**: Call for long term trials on RA's economic viability. BARI, BRRI, BWMRI and BINA scientists stress the need for long term soil experiments and integration of indigenous knowledge. Agroecology learning centers under NGOs like UBINIG, Practical Action and NABIC are promoting RA aligned practices.
- **Policymakers**: Recognize RA's potential but prioritize food security over transition risks. Recommend inclusion of RA in agricultural education and curricula.
- **Private Sector:** Organic and regenerative value chains are emerging but underdeveloped.

Conclusion

Regenerative agriculture offers a sustainable solution to Bangladesh's agricultural challenges by improving soil health, boosting climate resilience, and increasing productivity. Though still in its early stages, RA is gaining momentum and requires stronger policy support, financial incentives and regional collaboration. The growing interest across countries reflects its potential to address climate change, food security, and sustainability challenges, though adoption rates remain largely unmeasured or undocumented. A coordinated, science-based approach integrating research, policy, and grassroots action can establish regenerative agriculture as a key driver of resilient and inclusive food systems in South Asia.

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Chapter - 3

Promotion of Regenerative Agriculture in Bhutan

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Summary

Bhutan's agriculture, though central to national food security and rural livelihoods, faces growing challenges from ecological fragility, land degradation, climate variability, and socioeconomic constraints. With only 2.93% of land cultivable and increasing environmental pressure on mountainous farming systems, Regenerative agriculture has emerged as a promising solution. This paper explores the policy framework, traditional practices, technological interventions, and environmental dynamics shaping regenerative agriculture in Bhutan. Drawing on national reports, scientific studies, and institutional data, it highlights key drivers, constraints, and strategic recommendations for transitioning toward soil restoration, agro-biodiversity enhancement, and climate-resilient farming. It also examines shifting cultivation practices, sustainable land management (SLM) interventions, input use trends, and integration of livestock systems in the broader context of Bhutan's organic and sustainable agriculture vision. The findings underscore the need for context-specific innovations, capacity building, market development, and policy coherence to realize the full potential of regenerative agriculture in Bhutan.

Keywords: Agroecological Practices, Regenerative agriculture, Sustainable land management, Soil fertility

Introduction

Bhutan's agriculture sector remains the cornerstone of rural livelihoods, food security, and national development. As of 2024, it provides employment to 41.7% of the population and contributes 14.96% to the Gross Domestic Product (NSB., 2024a). In 2023, the Gross Value Added (GVA) of the Renewable Natural Resources (RNR) sector, including agriculture, livestock, and forestry stood at Nu 37,312.31 million, showing a substantial rise from Nu 33,422.58 million in 2022 (NSB., 2024b). Despite its critical role, the sector operates within a narrow geographical margin and only 2.93% of Bhutan's total land area of 38,394 km² is cultivable (NSSC & PPD, 2011).

The agriculture system in Bhutan is largely subsistence-based and highly sensitive to environmental, topographical, and socioeconomic constraints (McCarthy, 2001). Much of the cultivable land is situated on steep mountain slopes exceeding 30 degrees-classified as marginal for cultivation and better suited for forestry (Parker et al., 2017). Farming is also challenged by low soil fertility, erratic climatic patterns, limited mechanization, and fragmentation of landholdings (Chhogyel & Kumar., 2018). These constraints are compounded by increasing impacts of climate change, including glacial lake outburst floods (GLOFs), loss of irrigation sources, prolonged droughts, increased pest and disease incidence, and wildlife-induced crop damage (Komori et al., 2012; PPD., 2016).

Bhutan's diverse agroecological zones, spanning elevations from 150 to 4,600 meters above sea level (MoA., 1992), support a wide range of crops such as rice, maize, wheat, potatoes, vegetables, and fruits. However, dryland farming systems, common on upland slopes, are particularly vulnerable to soil erosion, nutrient depletion, and water scarcity. Additionally, the loss of traditional crop genetic resources further limits adaptive capacity and increases exposure to climatic shocks (Katwal et al., 2015).

Table 1. Major Agroecological Zones of Bhutan. Source adapted from (MoA, 1992)

Agro-Ecological Zone	Altitude (meters)	Temperature (°C)			Rainfall (mm/year)
		Monthly Max	Monthly Mean	Annual Mean	
Alpine	3,600–4,600	12	-0.9	5.5	< 650
Cool Temperate	2,600–3,600	22.3	0.1	9.9	650–850
Warm Temperate	1,800–2,600	26.3	0.1	12.5	850–1,200
Dry Sub-Tropical	1,200–1,800	28.7	3	17.2	850–1,200
Humid Sub-Tropical	600–1,200	33	4.6	19.5	1,200–2,500
Wet-Subtropical	150–600	34.6	11.6	23.6	2,500–5,500

The Sector Adaptation Plan of Action (SAPA) under the Ministry of Agriculture and Forests projects a temperature rise of up to 3.5°C by the 2050s**,** accompanied by increased but erratically distributed precipitation (NBC., 2009). These projected changes will likely alter Bhutan's agroecosystems significantly, impacting productivity and ecological resilience (Shrestha et al., 2012). Nonetheless, Bhutan has responded with climate-resilient measures such as the development and dissemination of drought-tolerant, high-yielding, and disease-resistant varieties in rice, maize, and wheat, as well as promotion of crop diversification, water harvesting, dryland cropping, and agroforestry (SNV & DoA., 2015).

From a socioeconomic standpoint, agriculture remains a feminized sector, with 52.5% of women engaged in farming compared to 34.8% of men. Yet, women also bear the disproportionate burden of rural poverty and drudgery. The national unemployment rate stood at 3.5% in 2024**,** with female unemployment (4.3%) significantly higher than that of males (2.9%) (World Bank., 2025). While Bhutan has halved its poverty rate from 28% in 2017 to 11.6% in 2022**,** poverty continues to be a predominantly rural phenomenon**,** with 87% of the poor living in rural areas and inequality levels remaining high (World Bank., 2025).

In terms of sectoral performance, crop production contributed 6.57% to GDP in 2023, while livestock accounted for 5.91% (NSB., 2024b). However, the growth of the agricultural sector is modest, projected at 1.52% in 2024 and 1.49% in 2025 (MoF., 2025). Although the crop sub-sector is expected to recover with a growth contribution of 0.05%, this remains fragile given the previous year's negative performance (-0.90%) (MoF., 2025).

Given these multidimensional challenges such as ecological degradation, climate variability, gendered rural vulnerabilities, and stagnating productivity, Regenerative agriculture emerges as a promising paradigm for Bhutan. Rooted in traditional ecological knowledge and supported by scientific innovation, regenerative agriculture offers a holistic approach to restoring soil health, enhancing biodiversity, increasing resilience to climate change, and revitalizing rural economies. In the Bhutanese context, it aligns well with the nation's constitutional mandate for environmental conservation and Gross National Happiness (GNH) philosophy, offering an integrative pathway for sustainable agricultural transformation.

Methodology

This study adopts a qualitative, desk-based research approach, drawing primarily on secondary sources such as national policy documents, government reports, and peer-reviewed literature. Data and insights were compiled from key publications by the Ministry of Agriculture and Livestock (MoAL), National Statistics Bureau (NSB), National Soil Services Centre (NSSC), and the National Centre for Organic Agriculture (NCOA). The analysis included synthesis of relevant statistics on land use, crop and livestock prod uction, soil fertility, and climate impacts, alongside a review of Bhutan's policy frameworks including the RNR Strategy 2040, SAPA 2016, and the Food and Nutrition Security Policy 2023. This integrative review allowed for a comprehensive understanding of the drivers, constraints, and potential pathways for advancing regenerative agriculture in Bhutan.

Policy Support for Regenerative Agriculture

Bhutan's commitment to Regenerative agriculture is rooted in its robust national policies that prioritize sustainability, climate resilience, and organic farming. The National Framework for Organic Farming (2006) laid the foundation by promoting ecologically sound agricultural practices such as composting, biodiversity conservation, and biological pest control, all are integral to regenerative systems (DoA., 2007). Building on this, the Department of Agriculture has promoted organic agriculture as a priority agricultural program and as of 2024, the National Centre for Organic agriculture has reported 338 registered organic operators from which 241 have been certified. In terms of area, the National Centre for Organic Agriculture (NCOA) has reported 9057.5921 acres registered as organic areas from which 7347.565 acres certified (NCOA., 2024). Moreover, strategic climate and natural resource policies such as the RNR Strategy 2040 and Bhutan's Second Nationally Determined Contribution (2021) further reinforce regenerative outcomes, as they advocate for climate-smart, low-emission agriculture, agroforestry, and ecosystem-based land management (MoAF., 2021b; RGoB., 2021).

The Food and Nutrition Security Policy 2023, is another important policy document that supports Regenerative agriculture in Bhutan. The policy outlines 11 strategic policy interventions such as promotion of soil health, biodiversity conservation, biodiversity restoration, climate resilient agriculture and sustainable agriculture which directly aligns with the core principles of Regenerative agriculture (MoAL, 2023).

Additionally, the RNR Sector Adaptation Plan of Action 2016 (SAPA 2016) aligns with Regenerative agriculture through its focus on ecosystem resilience, biodiversity conservation, and sustainable land management to address climate vulnerabilities. Key synergies of the plan include Soil and Water Regeneration, Agrobiodiversity and Traditional Knowledge, Ecosystem-Based Adaptation, Community-centered Resilience.

The Pesticide Act of Bhutan 2000 ensures an integrated pest management with limited and efficient use of pesticides in the country and also to minimize deleterious effects to human being and the environment consequent to the application of pesticides (MoA, 2000). Studies have reported that prolonged use of agrochemicals in agriculture leads to the accumulation of their residues in the soil, potentially causing significant contamination of both the soil and the food chain (Aktar et al., 2009; Jayaraj et al., 2016). Moreover, overuse of agrochemicals have threatened soil health due to soil degradation (Jie et al., 2002), which has caused adverse impacts on soil microbial diversity and activities (Dutta et al., 2010; Littlefield-Wyer et al., 2008). Since soil biological activities and beneficial microorganisms play a crucial role in maintaining status of soil health (Lehman et al., 2015), the Pesticide Act is a very important policy document for sustaining soil health and agriculture production in the country.

Climate-Resilient Regenerative Agriculture Practices

Research and Development on Climate Resilient Crop Varieties

Since the 1960s, the Government of Bhutan has actively promoted the cultivation of modern crops and crop varieties to address the growing food demand (NBC.,2015). This transition was supported by the Department of Agriculture's research and extension system, which focused on identifying and disseminating high-yielding crop varieties aimed at enhancing agricultural productivity, reducing dependency on food and input imports, and improving national food sufficiency and security (Ghimiray & Vernooy., 2017).

Agricultural research in Bhutan initially centred on introducing exotic crop varieties and modern cultivation practices. The Renewable Natural Resources Research and Development Centres (RNR-RDCs), under the Department of Agriculture, have since played a pivotal role in crop improvement research, particularly in the conservation and development of crop genetic resources for both field and horticultural crops (Ghimiray & Katwal.,2013).

As of December 2015, Bhutan had introduced and imported 297 varieties across 46 different crops. The country's primary staple crops - rice, maize, and wheat - have seen significant adoption of improved varieties. For instance, improved rice varieties now cover approximately 42% of the total rice-growing area, particularly in regions below 1,800 meters above sea level (Ghimiray., 2012; Shrestha., 2004).

Similarly, modern maize varieties, notably Yangtsipa, account for 49% of the cultivated maize area (Shrestha et al., 2006). Although no formal studies have been conducted on wheat, expert assessments suggest a high adoption rate of modern varieties, especially in wetland systems. Contrary to assumptions of traditional reliance, Bhutanese subsistence farming today incorporates a substantial use of modern crop varieties (Ghimiray & Vernooy., 2017). To date, over 180 improved crop varieties have been developed and released through Bhutan's agricultural research and development efforts. These include 41 varieties of cereals, oil crops, and grain legumes; 75 varieties across 28 vegetable crops; and 65 varieties of 22 fruit crops (CoRRB., 2009).

In line with efforts to diversify and climate-proof agriculture, Quinoa was introduced to Bhutan in 2015 with support from the Food and Agriculture Organization (FAO). This initiative aimed to integrate Quinoa into Bhutan's mountain agriculture as a climate-resilient crop to complement traditional cropping systems dominated by potato and maize, and to enhance national food and nutritional security (Katwal & Bazile., 2020). Ten quinoa varieties were evaluated across two distinct mountain agro-ecological zones during the 2016 and 2017 cropping seasons. By 2018, four of these varieties were officially released to expedite its adoption (Parker et al., 2017). Quinoa cultivation has since expanded rapidly. In 2024, Bhutan harvested approximately 40 metric tonnes (MT) of Quinoa, a notable increase from 13 MT in 2023. Concurrently, the area under Quinoa cultivation rose from 28 acres in 2023 to 102 acres in 2024 (NSB., 2025), underscoring the growing relevance of this crop in Bhutan's agricultural landscape.

Policy Ban on Shifting Cultivation

Shifting cultivation has been a traditional practice in Bhutan and other parts of tropical Asia, but its impacts on biodiversity and agriculture are complex and detrimental (Namgyel et al., 2008). Studies show that shifting cultivation has led to soil erosion, reduced productivity, and socio-economic challenges for many regions (Karim & Mashhor Mansor., 2011). In Bhutan, where more than 38 % of the land area is protected and serves as biodiversity hotspot in the eastern Himalayas (Wang., 2008), shifting cultivation and other subsistence land use activities are viewed as conflicting with conservation efforts of biodiversity management of national parks (Kramer et al., 1997; Struhsaker., 1998). Bhutan initiated efforts to reduce shifting cultivation in 1969 with the enactment of the Bhutan Forestry Act, imposed a complete ban during the 70th Session of the National Assembly in 1995, and had largely eradicated the practice within protected areas by the late 1990s (Giri., 2004).

Shifting cultivation has a profound effect on soil nutrients and biodiversity in tropical forests. Although the practice initially raises soil pH and certain nutrient levels through ash deposition (Gafur et al., 2000; Thokchom et al., 2024), it ultimately causes long-term reductions in soil organic matter, phosphorus, and exchangeable sodium (Wood et al., 2017). Additionally, soil carbon stocks may decline by as much as 50% compared to undisturbed forests (Baul et al., 2023).

Biodiversity is also affected, with tree species richness declining rapidly after initial clearing and continuing to decrease gradually over time (Wood et al., 2017). Soil erosion can remove up to 27% of topsoil nutrients in a single year. While some nutrient losses may be addressable through amendments, biodiversity declines and species composition changes are more challenging to reverse (Gafur et al., 2000).

Recent studies show an expansion and intensification of shifting cultivation in Laos, leading to increased carbon emissions, particularly from converting intact forests (Chen et al., 2023). In Mexican tropical dry forests, traditional shifting cultivation cycles emit about three times more carbon per ton of maize produced compared to permanent cultivation (Salinas-Melgoza et al., 2017). Globally, shifting cultivation and wood harvesting each contributed 19% to annual land use change emissions in the last decade (Stocker et al., 2014).

Sustainable Land Management (SLM) Interventions

Bhutan faces significant challenges in land utilization, primarily due to its rugged topography and limited cultivable land. Only 9.70% of the country's total land area is considered suitable for cultivation, and in practice, a mere 2.93% is under active cultivation. This agricultural land is predominantly located on gentle to moderately steep slopes (Norbu, 2003), though cultivation is also reported on highly fragile and steep terrains with slope gradients reaching up to 40 degrees (Gyeltshen., 2010).

Rain-fed agriculture is practiced on steep hilly areas, while irrigated paddy fields are limited to small, isolated patches along the main river valleys (NEC., 2008). Consequently, most farming activities take place on sloping drylands, where soil erosion poses a critical constraint to sustainable agricultural production (Norbu., 2003). Land degradation, particularly due to nutrient depletion, soil erosion, and landslides, has been identified as a major barrier to sustainable land use in Bhutan (Turkelboom et al., 2001). Compounding this issue is the limited landholding size - 56% of Bhutanese households own just 1 to 5 acres, while 2.6% are landless (Tobgay., 2005).

To address these challenges, Bhutan accessed support through the Global Environment Facility (GEF) under Operational Program 15, with assistance from the World Bank. The Sustainable Land Management (SLM) Project, implemented from 2006 to 2012, was supported by a US$ 7.6 million grant (Norbu., 2013). This initiative resulted in the conversion of 3,368.42 hectares of shifting cultivation areas into orchards and other sustainable land uses, and 3,345.67 hectares of barren and degraded lands into community and private forests (NSSC., 2012).

One of the key benefits of SLM is its effectiveness in reducing topsoil loss, a major pathway for soil carbon depletion in cultivated lands (WB.,2011). According to global estimates, annual soil erosion results in carbon emissions ranging from 0.02 to 0.44 Gt per year, with Asia accounting for the highest soil loss at 74.0 Gt annually. These emissions are closely linked to poor land management practices such as erosion, excessive tillage, crop residue removal, and inadequate drainage (NSSC., 2009).

Evidence from SLM demonstration plots established in 2009 revealed a clear difference in soil erosion rates under various land management systems. The bare reference plot recorded the highest soil loss at

24.6 t/ha, followed by 6.42 t/ha under traditional practices. In contrast, SLM-managed plots experienced a significantly lower soil loss of 3.36 t/ha (NSSC., 2009).

Recognizing the immediate needs of smallholder farmers, SLM practices have also promoted the integration of fodder grasses such as Guatemala grass, Napier, tall fescue, Italian ryegrass, cocksfoot, and Desmodium along hedgerows to provide quick seasonal returns and livestock feed (Norbu., 2013). Recent assessments indicate that SLM interventions hold 50-60% potential for soil carbon sequestration, making them a promising tool for both climate mitigation and agricultural sustainability (NSSC., 2022).

During the 12th Five-Year Plan (2018–2023), significant progress was made in implementing various Sustainable Land Management (SLM) interventions. Among the major activities, terracing covered 2,682.91 acres out of the 2,879-acre target, while terrace consolidation achieved 976.16 acres against a target of 3,683 acres. Contour hedgerow planting exceeded its target with 1,522.94 acres completed. Other interventions included orchard terracing (22.35 acres), surface stone removal (419.06 acres), and fallow land reversion (1,275.88 acres). Several untargeted but impactful practices such as check dam construction (179 acres), landslide stabilization (215.89 acres), and organic nutrient management (433.95 acres) were also implemented (NSSC., 2024).

Table 2. Types and Area of ALD/SLM interventions from 2005 to 2023 ((NSSC, 2024)

Sl.No.	**Type of ADL/SLM Interventions**	**2005-2017 (Acre)**	**12FYP Target (Acre)**	**Achievements in the 12FYP (2018-2023) in Acres**					
				2018-19	2019-20	2020-21	2021-22	2022-23	**Total**
1	Terracing (bench/dryland)	646.63	2879.00	459.53	844.83	1378.55	0.00	0.00	**2682.91**
2	Terrace consolidation	27.00	3683.00	85.62	374.87	515.67	0.00	0.00	**976.16**
3	Orchard terracing	0.00	365.00	6.00	0.00	16.35	0.00	0.00	**22.35**
4	Contour hedgerow	3658.90	798.00	800.93	247.94	474.07	0.00	0.00	**1522.94**
5	Contour stone bund	795.50	164.00	41.00	4.60	36.55	0.00	0.00	**82.15**
6	Orchard basin making	115.00	0.00	46.70	41.85	0.00	0.00	0.00	**88.55**
7	Surface stone removal	7.00	669.00	6.85	382.40	29.81	0.00	0.00	**419.06**
8	Check dams	200.00	0.00	179.00	0.00	0.00	0.00	0.00	**179.00**
9	Orchard establishment	2457.90	0.00	48.00	58.50	4.50	0.00	0.00	**111.00**
10	Landslide stabilization (plantation)	8021.30	0.00	209.00	0.00	6.89	0.00	0.00	**215.89**
11	Integrated plant nutrient management (FYM, vermi-compost, bio-fertilizers)	552.50	0.00	433.95	0.00	0.00	0.00	0.00	**433.95**
12	Water source protection	81.40	0.00	7.00	0.00	23.90	0.00	0.00	**30.90**
13	Improving ground cover & soil fertility through legume promotion	0.00	0.00	0.00	0.00	206.11	0.00	0.00	**206.11**
14	Fallow land reversion	0.00	0.00	0.00	578.10	697.78	0.00	0.00	**1275.88**

Soil Fertility and Nutrient Management

Soil fertility and nutrient management remain critical challenges for sustainable agriculture in Bhutan, primarily due to the country's fragile mountainous ecosystem. A nationwide study by the National Soil Services Centre (NSSC, 2010), revealed that 3 to 21 tonnes per hectare of fertile topsoil are lost annually due to soil erosion. This is particularly concerning as mountain soils in Bhutan are typically shallow, poorly developed, acidic, and inherently low in fertility (Romeo et al., 2015).

Land degradation, characterized by soil erosion, landslides, and biophysical and chemical deterioration, poses a significant constraint to sustainable land use. These issues stem from a combination of factors including unsustainable land management practices, overgrazing, deforestation, population pressure, and unfavourable geological conditions, exacerbated further by intensifying monsoon patterns and climate variability (Rinzin., 2008).

Table 3. Nitrogen, Organic carbon and Organic matter etc in Dryland, Wetland and Orchard

Soil Variables	Dryland	Wetland	Orchard
Nitrogen (%)	1.65	1.19	1.54
Organic carbon (%)	2.33	1.78	2.09
Organic matter (%)	2.35	1.72	2.12
Carbon:Nitrogen ratio	1.23	1.29	1.31
Available Phosphorous (mg/kg)	1.97	1.58	1.83
Available Potassium (mg/kg)	2.15	1.33	1.45
Total Exchangeable Bases (me/100g)	2.03	1.41	1.51
Cation Exchange Capacity (me/100g)	2.14	1.14	1.99
Base Saturation (%)	1.98	2.19	1.47

Source: Chhetri et al., 2020.

To address soil fertility constraints, Bhutan has relied on the import and distribution of chemical fertilizers. Fertilizer imports have grown steadily, from 319 metric tonnes in 1976–77 to 2,425 MT in 2000, reaching 3,604 MT by 2020. Between 2000 and 2021, annual imports have fluctuated between 2,400 and 3,600 MT. However, the per hectare fertilizer use in Bhutan remains low, at approximately 13.41 kg/ha of arable land and 36 kg/ha of cultivated land - significantly below regional averages. For comparison, fertilizer use in Nepal is 86.9 kg/ha, Bangladesh 318.5 kg/ha, India 175 kg/ha, Pakistan 156 kg/ha, Sri Lanka 138.3 kg/ha, and China 393.2 kg/ha. Moreover, only 37% of Bhutanese farmers apply agrochemicals, covering just 19% of cultivated land (NSSC, 2022).

In light of Bhutan's commitment to environmental sustainability, the Low Emission Development Strategy (LEDS) for Food Security 2021 prioritizes a gradual transition from synthetic to organic fertilizers as a key climate mitigation measure. The strategy targets a 5% annual reduction in chemical fertilizer use and a 25% annual increase in organic fertilizer production through 2030 (MoAF., 2021a).

Table 4. Annual organic fertilizer production targets (2023-30) (MoAF, 2021a)

Financial Year	2023	2024	2025	2026	2027	2028	2029	2030
Production (MT)	3200	4000	5000	6250	7813	9766	12208	15260

To meet these ambitious goals, Bhutan has adopted a multifaceted strategy focused on enhancing organic fertilizer production. This includes operationalizing existing production units at full capacity, establishing new facilities, and improving production efficiency and nutrient quality. The strategy also promotes household-level composting, ensures rigorous quality control, develops efficient marketing and distribution systems, and introduces subsidized electricity tariffs to lower production costs (NSSC., 2022).

Crop Diversification and Agro-biodiversity

Multiple cropping is commonly practiced by the Bhutanese farmers in many different forms such as crop rotation, sequential cropping, mixed and strip cropping and multi-storied cropping. Past studies have estimated that 52% of the area under legumes is intercropped (NSSC., 1999), over 15% of the area under maize is under maize-maize sequential cropping and the estimated area under maize-potato intercropping is 35% (Shrestha et al., 2006).

The farming systems practices in the country are also categorized into three distinct systems in terms of the most dominant food crops cultivated. The three distinct systems are the rice-based system, maize based system and potato-based system. The types of farming practices and the choice of succeeding crops are thus determined by the main crop. A range of multiple practices are adopted in these three systems. Rice based cropping system is exclusively done in the irrigated terraced wetlands. Maize and potato-based systems are primarily practiced in the non-irrigated steep rainfed drylands. Maize and potato-based systems are invariably intercropped with different crops

Willow and White clover mixed planting- in the temperate zone planting of fodder Willow trees *(Salix babylonica)* around the permanent pasture of White Clover (*Trifoliumrepens*) is a common practice in high altitude Dzongkhags (districts) particularly in Bumthang and Haa, where livestock rearing is important. It is an agroforestry system that integrates livestock which is a source of food and farm yard manure. Willow trees are planted along the field border for winter fodder and which also serves as a live fence. It also provides fuel wood and fencing poles. Willow trees are planted about 15-20% of the size of the area of white clover. The white clover fields are used as pasture for grazing cattle during April to September.

Fodder trees intercropped in agriculture land- It is specific intercropping system and another form of agroforestry which combines fodder trees, crops and animals. It is dominant in southern Dzongkhags where different types of fodder trees are planted along the borders of the cultivated land and degraded areas. The most commonly planted fodder trees are different Ficus species, fodder banana, broom grass *(Thysanolaena maxima)* including many other species (Katwal., 2013).

Table 5. Multiple cropping in relation to major food crop based systems (Katwal, 2013)

Categories	Crops	Type of Multiple Cropping	Additional Information
Rice Based System	Rice-Rice	Crop rotation	Practiced in small scale in mid altitudes
	Rice-Wheat	Crop rotation	Widespread in mid and low altitude areas
	Rice-Mustard	Crop rotation	Widespread in mid altitude areas
	Rice-Maize	Crop rotation	Popular in humid and wet subtropical agro-eco-zones
	Rice-Potato	Crop rotation	Popular in warm temperate areas in the irrigated wetland
	Rice-Vegetables	Crop rotation	Popular in warm temperate areas in the irrigated wetland
	Rice-Onion	Crop rotation	Onion is a newly introduced crop in the rice system
	Rice-Early Chilly	Crop rotation	Popular in low altitude areas of Trashiyangtse and Mongar Dzongkhags
	Rice-Dhaincha/Niger	Crop rotation	Popular in wet subtropical areas for greening manuring
Maize Based System	Maize + Potato	Intercropping	Popular in eastern region of the country
	Maize + Soybeans	Random mixed cropping	

Categories	Crops	Type of Multiple Cropping	Additional Information
	Maize + Millet	Random mixed cropping	Practice in humid and wet subtropical areas in the dryland
	Maize–Soybeans	Crop rotation	Practiced in areas at 1200–1800 m asl
	Maize–Legumes	Crop rotation	Rajma beans, Urd beans, Cowpea, Peas are common
	Maize–Mustard	Crop rotation	Done in small scale
	Maize–Upland rice	Crop rotation	Popular in parts of Pemagatshel and Samdrupjongkhar; maize is planted in January, upland rice sown in June after harvesting maize. Rice ready for Thri festival
	Maize–Buckwheat	Crop rotation	Practiced in dry and humid subtropical zone, in dryland
	Maize–Barley + Mustard	Random mixed cropping	Green mustard plants are fed to animals during winter
	Maize + Ginger	Line Sown Mixed	Popular in dry and humid subtropical areas
	Maize + Vegetables	Random mixed cropping	Mainly cucurbits and beans are planted
	Maize + Tuber crops	Mixed	Popular in humid and wet subtropical agro-eco-zones
Potato Based System	Potato + Maize	Intercropping	Major forms of cropping system in east
	Potato–Mustard	Crop rotation	Popular in high altitude areas
	Potato–Turnips	Crop rotation	Popular in high altitude areas
	Potato–Barley/Wheat	Crop rotation	Popular in high altitude areas
	Potato–Buckwheat	Crop rotation	Popular in high altitude areas
	Potato–Buckwheat–Wheat	Crop rotation	Practiced in drylands in Paro and Haa Dzongkhags
	Potato–Maize (Fodder)	Crop rotation	Practiced in drylands in Paro and Haa Dzongkhags

Livestock Integration and Emission Management

The 1985 national cattle breeding policy differentiated between the agroecological zones, it proposed Brown Swiss × (local) Siri crossbreeding in the high altitudes; Jersey × Siri crossbreeding in other areas with relatively better market access; and using local breeds in remote areas that have harsh environmental conditions.

A major objective of dairy crossbreeding was to increase household incomes. Farms in the intensive areas, with mainly crossbreds and pure Jerseys, used 3.8 times more cash inputs for livestock and had 4.0 times higher cash outputs from livestock than farms in the extensive area, with few crossbreds, and 2.6 times more cash inputs and 1.8 times higher livestock cash outputs than farms in the semi-intensive area, with about equal numbers of local and crossbred cattle.

A second objective of the crossbreeding programme was to try to reduce the environmental load of cattle by promoting keeping fewer but more productive cattle and reducing grazing in CPR (Samdup et al., 2010). The overall cattle population has seen only a half a percentage point (0.50%) rise between the years 1994 and 2018, due mainly to the rise in the exotic cattle population. During the same period, the exotic cattle population increased manifold (269.54%) from 29,981 in 1994 to 116,733 numbers in 2018. However, the indigenous cattle population has decreased by more than a quarter (-29.40%)

within 24 years. The exotic crossbred cattle are fast replacing indigenous breeds of cattle as a result of government policies and promotional programs favouring exotic as opposed to indigenous cattle breeds (Namgay et al., 2021).

Agriculture and livestock activities contributed 552.87 Gg CO_2e, corresponding to 14.49% of total national emissions in 2015. The majority of the sector's emissions were from livestock that emitted 389.47 Gg of CO_2e, of which enteric fermentation accounted for 348.90 Gg of CO_2e or about 63.03%. In comparison, manure management contributed only 40.98 Gg of CO_2e (7.41%), and similarly, rice cultivation emitted 52.98 Gg of CO_2e (9.58%) (NEC, 2021).

Constraints to Regenerative Agriculture in Bhutan

Technical Constraints

Limited farming infrastructure and mechanization: Bhutan's steep, mountainous terrain and small terraced fields make mechanization difficult. Studies reported that mountainous topography has hindered complete mechanization, pushing farmers towards manual and draft power. Low mechanization and basic tools limit farmers' ability to adopt labour-saving regenerative practices. Small fragmented plots exacerbate this (the majority of fields are tiny terraces). Relatedly, irrigation and post-harvest infrastructure are weak. A recent review finds roughly 25–30% of farms lack reliable irrigation, and inadequate storage leads to post-harvest losses (exacerbating risk and discouraging experimentation (W. Gyeltshen et al., 2022).

Limited inputs and resources: Transition to regenerative systems often requires access to organic fertilizers, biofertilizers, and biopesticides. Shortage of organic inputs and effective alternatives to synthetic pesticides for key crops like potatoes, rice and apples have been a major concern in agriculture. Until recently farmers often use chemical fertilizers to maintain yields, despite government goals of natural farming (a mismatch partly due to lack of accessible bio-inputs). Although steps are underway (e.g. planned bio-fertilizer plants), current supply remains low (Tashi., 2022).

Economic constraints

Low profitability and high opportunity cost: Bhutanese agriculture offers very slim margins. Farm yields are low and input costs (even organic inputs) are high; by contrast imported food is often cheaper. This price competition makes it economically unattractive to invest in labor - or knowledge - intensive regenerative methods without guaranteed returns. Farmers report that low profitability per season reduces interest in farming at all, organic or not (Tashi., 2022).

Labour shortages and rural out-migration: Bhutan's farm labour force is shrinking. Over recent decades the farming population fell from 82% to 57% of households (Tashi., 2022). Chronic labour scarcity (53% of farmers cite it as a major constraint) means regenerative practices that require more hands on labour (e.g. manual weeding, compost making) are harder to scale (Tiwari et al., 2017). Farmers often leave plots fallow because no one is available to work them (Chhogyel & Kumar., 2018).

Poor market access and value chains: Regenerative agriculture often relies on marketing higher-value "green" products (organic fruits, agroforestry goods, etc.), but Bhutanese value chains are underdeveloped. Farmers face "inefficient market linkages" and high transaction costs. Furthermore, Bhutan's export market for niche organic crops is still small; most farmers have no premium market to reward regenerative products, especially if yields are modest.

Environmental Constraints

Soil fertility and erosion: The rugged ecosystem inherently has shallow, low-fertility soils. Conventional and organic alike, Bhutanese soils suffer nutrient depletion (especially where heavy rains wash away topsoil). Regenerative agriculture aims to rebuild soil, but doing so at scale is slow. Without initial soil amendments or terracing improvements, any given plot can only tolerate limited annual output (Chhetri et al., 2020).

Human–wildlife conflict: As noted, forested Bhutan has abundant wildlife, which increasingly encroach onto farmland. Wild boars, deer and monkeys cause crop losses; surveys show that wild animal depredation is a major reason farmers abandon fields (Gyeltshen et al., 2022). This is an environmental constraint because it reduces the area farmers can reliably cultivate using sensitive organic methods.

Strategic Recommendations and Way Forward

Focus on Bhutan-specific agroecological innovations: Direct research toward organic/regenerative techniques suitable for Bhutan's mountains: e.g. cover crops and legume rotations to build soil organic matter, on-farm composting, crop-livestock-agroforestry integration, and water-harvesting irrigation (building on traditional terracing). Likewise, invest in breeding and seed improvement for Bhutan's diverse crop portfolio (including the "nine national cereals" and local fruits) to enhance resilience.

Strengthen laboratories and resource centres: Upgrade soil and seed testing labs to provide feedback on soil health and seed purity (especially for open-pollinated or heirloom varieties). Ensure efficient regulatory and certification systems (public or group certification) by equipping technical staff. Invest in digital platforms (mobile apps, SMS weather alerts) to give farmers timely agro-met info and market prices, bridging the research-extension gap (MoAF., 2021b).

Enhance research-extension linkages: Poor researcher-farmer communication has been a bottleneck. Build formal networks connecting researchers, extension agents and farmers – for example, joint field days or innovation platforms. Use Bhutan's RNR centres and Gewog Extension offices to trial and disseminate findings. Strengthen training researchers and extension officials to support this knowledge flow (MoAF., 2021b).

Implement Farmer Field Schools and peer-learning: Establish farmer-led learning groups (FFS), study tours (e.g. visits to successful organic villages or to Sikkim's organic farms), and farmer-to-farmer exchanges. Participatory approaches (innovation platforms, community trials) help tailor practices to local conditions. Bhutan's tradition of labour-sharing networks can also be leveraged: studies show that communities with strong labour-exchange institutions adapt more easily to labour-intensive organic methods (Tshotsho et al., 2022).

Branding and marketing local products: Bhutan's diverse organic products (chili, buckwheat, dairy, pulses, medicinal herbs) can be branded and marketed domestically and abroad. Encourage the formation of farmer cooperatives or producer companies focused on organic/regenerative crops. These groups can aggregate supply, invest in shared storage/processing, and achieve scale. Conduct value-chain studies (as recommended in the organic framework) to identify bottlenecks and support weak linkages and also strengthen intermediaries (e.g. farmer-entrepreneurs, aggregators) who link farmers to markets (DoA., 2007).

Conclusion

In conclusion, Regenerative agriculture presents a promising paradigm for Bhutan's sustainable agricultural transformation. Anchored in the country's deep-rooted cultural values of environmental harmony and guided by forward-looking policies, Bhutan is well-positioned to lead in climate-smart and biodiversity-enhancing farming systems. However, realizing this potential requires concerted action-addressing systemic constraints, improving market and institutional linkages, and fostering inclusive innovation. With strategic investments in research, capacity-building, and farmer-led initiatives, Regenerative agriculture can serve as a resilient and holistic pathway for food security, rural prosperity, and ecological stewardship in Bhutan

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Chapter - 4

Regenerative Agriculture practices in Nepal: Status, Constraints and Way Forward

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Summary

Regenerative agriculture is a holistic approach that aims to restore soil health, enhance agro-biodiversity, and improve water use efficiency. In Nepal, although farmers have independently implemented Regenerative practices such as use of composting, vermicomposting, biochar, and Jholmal as alternatives to chemical fertilizers, however, still significant policy gaps exist in supporting these initiatives. Furthermore, promising outcomes of techniques like Zero-tillage and Minimum tillage have been recorded in rice and wheat cultivation, however, adoption of these technologies remain low due to limited awareness and shortage of trained manpower for operating seed drills. Moreover, Direct-Seeded Rice (DSR) is an innovative approach that could be promoted to reduce production costs and carbon emissions, addressing both water use concerns and farming efficiency. The incorporation of legumes in cropping systems such as soybean with maize, rice-lentil, and wheat-mungbean rotations has shown improved productivity and soil health benefits. Additionally, Regenerative agriculture practices like Alternate Wetting and Drying (AWD) in rice cultivation optimise water usage without compromising yields, and rainwater harvesting during the monsoon season provide a valuable resource for dry-season irrigation. In conclusion, Regenerative agriculture offers significant potential to conserve soil, water, and energy, contributing to sustainable farming practices in the face of a changing climate.

Key words: Composting, Cropping system, Jholmal, Regenerative agriculture

Background

Regenerative agriculture resonates as an alternative farming practice that considers the minimum soil disturbance, enriches diversity, waste management, water efficiency and fosters agroforestry (Schreefel, Schulte, De Boer, Schrijver, & Van Zanten., 2020). In Nepal, majority of the farmers rely on synthetic fertilisers and pesticides for their farming; consequently, the soil health is deteriorating, which directly impacts crop production. Regenerative practices such as crop diversification, cover cropping, organic manure application, agroforestry, and minimal tillage help to restore soil fertility, improve water retention, and enhance resilience against climate variability (Giller, Hijbeek, Andersson, & Sumberg.,2021).These practices not only increase yields sustainably but also reduce dependency on chemical fertiliser, pesticide and water demand, ultimately helping to increase the system productivity (Musto, Swanepoel, & Strauss., 2023).

Beyond improving productivity, RA contributes to soil restoration, maintains the diversity and climate change mitigation (Ghosh, Saha, Kumar, & Pathania., 2024). Moreover, enhancing soil organic carbon, these practices help in carbon sequestration and reduce the greenhouse gas emissions (Giller et al., 2021; Khangura, Ferris, Wagg, & Bowyer., 2023). RA practices create a suitable environment for farming systems that provide habitat for microbes, support pollinators, and preserve native plant diversity (Schreefel et al., 2020). In a country with fragile mountain ecosystems prone to erosion and landslides, regenerative methods strengthen soil structure and reduce land degradation (Giller et al., 2021). This holistic approach aligns with Nepal's Agriculture Development Strategy (ADS) goals of agricultural development, climate adaptation, and long-term food sovereignty, making it a resilient strategy for the country's agricultural advancement (Khanal et al., 2020).

At the policy and farmers' level, there are associated gaps that affect the adoption of regenerative practices. Regenerative agriculture Agriculture is widely discussed at the policy level; however, less implemented at the farmer's level. This might be due to the cost of adoption and lack of sensitisation (Khanal et al., 2020). Agriculture development strategy aims to achieve soil organic matter by 4.0% by 2035, however, soil health is compromised by low level of organic matter, study shows more 50% of Nepalese farm land has medium to low organic matter content (Gairhe, Khanal, & Thapa., 2021). The depletion of organic matter is due to over-reliance on chemical fertilisers, maximum tillage, low level of organic input used in crop production and lack of crop rotation (H. L. Shrestha, Bajracharya, & Sitaula.,2023). Agrobiodiversity is threatened as traditional varieties and local landraces are replaced by homogeneous, high-yielding cultivars. Modern farming practices are focused on market-driven monocultures, with little emphasis on preserving diversity. It is reported that Nepal is in 49th position in the biodiversity, 40th in agrobiodiversity, 40% of agricultural biodiversity has been lost (Joshi & Gauchan, 2022; Tiwari & Dhakal., 2024).

Management of crop residues is often inadequate: residues are frequently burned rather than recycled through mulching, composting or soil incorporation. The burning of crop residues and wastes biomass exacerbates air pollution and nutrient loss (Bajracharya, Mishra, & Maharjan, 2021; Bhujel, Mathema, Neupane, & Byanju., 2023). Irrigation and water use efficiency is important for Regenerative agriculture, irrigation is only available for about 50% of cropping land in Nepal (Table 1).

Table 1. Availability of irrigation in Nepal

Land type	Land in (Ha)	Irrigation facilities ha	Irrigation facilities ha (%)
Total irrigable land	1,760,000	1557600 ha	88.5
Cultivable land	2,640,000	1557600 ha	59

Source: Economic survey of Nepal 2023-24

Groundwater extraction added more pressure on Regenerative agriculture because, due to over extraction water table is going down every year. Meanwhile, conservation practices such as rainwater harvesting, and watershed-level, soil water retention measures and alternate waiting and drying (AWD) are underemployed, leaving systems vulnerable to seasonal water crisis (S. Dhakal, Subedi, Kandel, & Shrestha., 2024).

At the policy level, these challenges are compounded by poor institutional backup, low financial incentives for RA practitioners, and weak extension. Furthermore, the lack of market linkages and innovative research on RA practices in Nepal's diverse agroecological zones is a pertinent issue. Addressing these gaps requires integrated, context-specific interventions that combine on-farm practices, value chain improvement, capacity building and policy alignment frameworks that reward soil- and biodiversity-positive outcomes.

Various regenerative agricultural practices in Nepal

Production and use of organic and bio-fertiliser

Composting

Compost adds carbon to the soil, which supplies mineral nutrients to plants that enhance the soil's physical, chemical and biological properties. Heap and peat methods of compost preparation are widely used in Nepal. Farmers are facing loss of nutrients from compost due to lack of awareness in preparation and use. Study shows Goat manure contained the highest nitrogen, potassium, and pH levels, while buffalo manure had the lowest nitrogen and potassium contents but the highest organic matter. Vermi-compost contained the highest phosphorus but the lowest organic matter compared to compost that had the lowest phosphorus with a moderate pH (Sharma, Kandel, Khadka, & Chaudhary., 2022). In order to improve the quality of compost, the Government of Nepal implemented the cowshed improvement program at the local and provincial levels. In this program urine collection tank is established near the shed, and collected urine is utilised for compost preparation or sprayed as fertilizer or bio-pesticide (S. C. Dhakal., 2022).

Vermicomposting

Vermicompost has emerged as an effective organic amendment for enhancing crop productivity and sustaining soil health in Nepal. It is rich in essential nutrients, beneficial microorganisms, and humic substances, which improve soil structure, aeration, and water-holding capacity while enhancing nutrient availability for plants (Walia & Kaur., 2024). Studies in Nepal have shown that the application of vermicompost significantly increases crop yield, particularly in vegetables and cereals, by promoting root growth and improving nutrient uptake efficiency (S. R. Shrestha et al., 2025). Study shows vermicompost application in Chitwan district of Nepal significantly enhanced radish growth and yield parameters, with the highest values recorded at 15 t/ha, including maximum root length (29.60 cm), root diameter (36.27 mm), and yield (47.9 t/ha) (Dulal, Baral, Poudel, Kafle, & Shrestha., 2021). Furthermore, vermicomposting use reduces the dependency on chemical fertilizers, thereby mitigating soil degradation and maintaining long-term soil fertility. Its role in improving microbial activity and organic matter content contributes to the restoration of degraded soils, making it a sustainable practice for Nepal's smallholder farmers (Jamkatel, Khatri, Bista, & Ghimire., 2020).

Biochar

Biochar application is an effective soil amendment for enhancing crop productivity. Its incorporation into soil improves key chemical properties, including pH, organic carbon (OC), cation exchange capacity (CEC), and concentrations of base cations, while also increasing the availability of essential nutrients such as phosphorus (P) and potassium (K). Furthermore, Biochar treatment has demonstrated significantly higher crop yields compared to those without Biochar, with the greatest yield improvements observed when biochar was fortified with cattle urine (Vista & Pandit, 2023). Furthermore, application of Biochar in rainfed potato farming in Nepal shows greater yield and less infestation from red ant (Upadhyay, Dhami, Sharma, Neupane, & Shrestha., 2020). In cucurbits, Biochar helps to reduce the water stress and increased yield (Ali, Elshaikh, Hussien, Abdallah, & Hassan., 2020). Having the several benefits of Biochar, it is less widely adopted by farmers due to lack of awareness and difficulty in preparation.

Jholmal

Jholmal is a locally prepared Bio-fertiliser and Bio-pesticide that enhances crop health and boosts yields while minimising production costs and reducing the use of harmful chemicals. It is made by fermenting a mixture of locally available ingredients such as water, cow or buffalo urine and dung, beneficial microorganisms, and specific plant parts in a set proportion (Bhusal & Udas., 2020).

There are three types of Jholmal:

- **Jholmal -1** supplies essential nutrients necessary for plant growth and development.
- **Jholmal - 2** and **Jholmal - 3** help control insect and pest infestations while protecting crops from fungal infections and vector-borne diseases.

Table 1. List of plants used to make Jholmal-3

Scientific name	Common name (English)	Parts used
Artemisia vulgaris	Mugwort	Leaves and stem
Justicia adhatoda	Malabar nut	Leaves
Urtica dioica	Stinging nettle	Leaves and stem
Melia azedarach	Persian lilac	Leaves and fruits
Azadirachta indica	Indian lilac	Leaves and fruits
Agave americana	Century plant	Stem and leaves
Chromolaena odorata	Siam weed	Leaves and stem
Lantana camara	Wild sage	Leaves and flower
Prunus persica	Peach	Leaves
Zanthoxylum simulans	Sichuan pepper	Fruit
Tagetes patula	Marigold	Leaves and stem
Sapium insigne	Tallow tree	Leaves
Zingiber officinale	Ginger	Underground rhizome
Allium cepa	Onion	Bulbs
Capsicum annuum	Chilli	Fruit
Allium sativum	Garlic	Bulbs
Carica papaya	Papaya	Leaves
Sambucus javanica	Elderberry	Leaves
Acorus calamus	Sweet flag	Leaves and rhizome

Source: ICIMOD, 2020

Preparation of Jholmal

The ingredients of Jholmal are jeevatu, unine, cowdung and plants leaves. Jeevatu is a microbial consortium comprising diverse beneficial microorganisms, including lactic acid bacteria, *Azotobacter* species, *Trichoderma* species, phosphate-solubilizing bacteria, potassium-solubilizing bacteria, photosynthetic bacteria, and yeast. These organisms collectively enhance soil fertility, promote plant growth, and improve nutrient availability through various biological processes. Details of the Jholmal preparation is given in Figure 1.

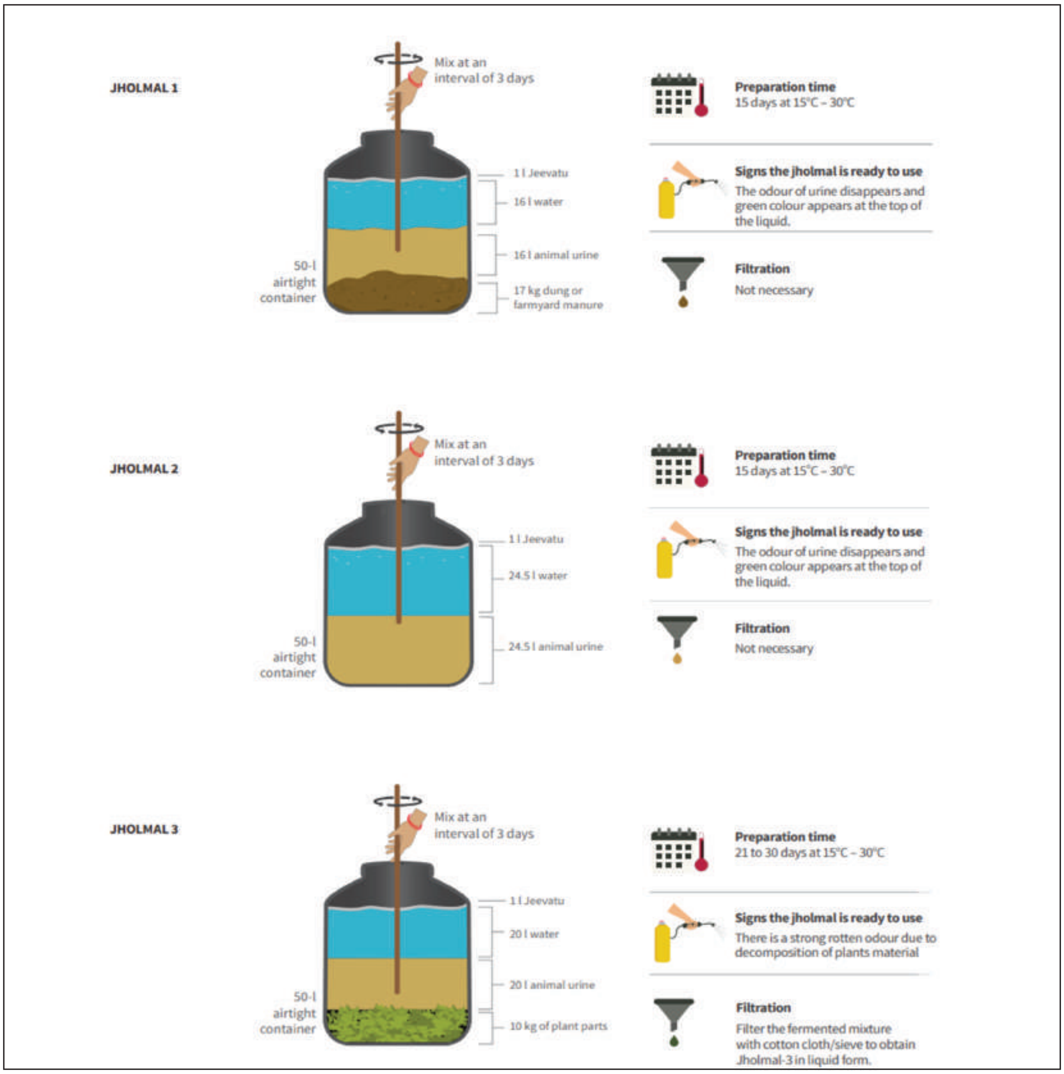

Figure 1: Jholmal preparation methods. Source: ICIMOD, 2020

Application of Jholmal

Jholmal is a liquid formulation serving as both a Bio-fertilizer and a Bio-pesticide. Jholmal-1 is applied by mixing it with water in a 1:3 ratio and applied in every two weeks, while Jholmal - 2 and Jholmal - 3 are diluted with water in the same ratio but applied weekly (Figure 2).

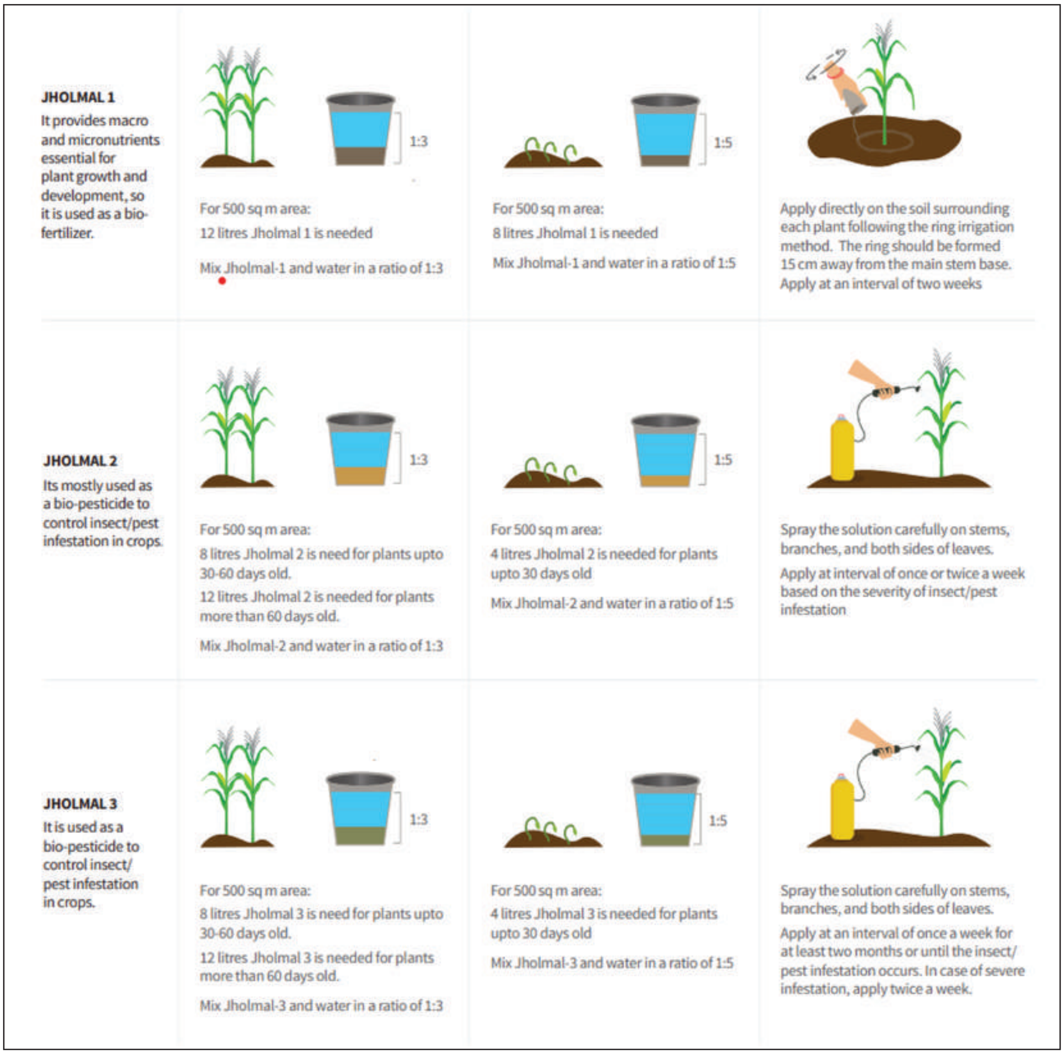

Figure 2: Jholmal application process.

Source: ICIMOD, 2020

Zero tillage/Minimum tillage

Zero-tillage is a farming practice that minimises soil disturbance to sowing and traffic operations, relying on chemical weed control, while maintaining crop residues on the surface to protect against erosion. It influences soil conditions by increasing topsoil moisture, reducing aeration, moderating temperature fluctuations, altering nutrient distribution, and has shown practical value in various cropping systems, including sloping lands, double cropping, pasture renovation, humid temperate areas, and dryland farming (Baeumer & Bakermans., 1974). A field experiment on wheat crop with two tillage practices (Zero and Conventional) and four nitrogen levels (50, 75, 100, and 125 kg N ha^{-1}) showed that tillage had no significant effect on most yield attributes, except that zero tillage produced the highest effective tillers m^{-2} (254) and grain yield (3.3 t ha^{-1}). Nitrogen at 125 kg ha^{-1} significantly increased plant height, yield components, and grain yield (3.6 t ha^{-1}), with the highest yield (3.9 t ha^{-1}) achieved under Zero tillage combined with 125 kg N ha^{-1} (Bartaula et al., 2020). Study shows No-tillage with residue retention and maize - soybean intercropping followed by wheat produced the highest system yield, along with earlier tasseling, lower lodging, and slightly higher test weight compared to Conventional tillage. The findings suggest that farmers in the Terai and inner Terai can benefit from adopting No-tillage, residue retention, and crop rotation in maize - wheat systems (Karki, Gadal, & Shrestha., 2014). Zero tillage/Minimum tillage is a cost-effective technology, though its adoption rate is low because of less trained manpower to operate.

Direct Seeded Rice technology

The dry direct-seeded rice (DDSR) and wet direct-seeded rice (WDSR) are commonly practised in Nepal. Farmers perceived DDSR as a cost-effective and water-saving alternative to transplanted rice, though it has challenges such as severe weed infestation, poor crop establishment, and lower yields. Despite these issues, its higher B:C ratio is comparable for reducing cultivation costs, if weed management is improved (M. Dhakal, Sah, McDonald, & Regmi., 2015). Wet direct-seeded spring rice (Hardinath-1) at, Jhapa district, post-emergence application of Bispyribac sodium significantly reduced weed density, increased effective tillers and grains per panicle, and achieved the highest grain yield (6.97 t ha^{-1}), straw yield, and harvest index. Economic analysis revealed that Bispyribac sodium was the most profitable weed management practice, while uncontrolled weeds resulted in a 67.9% yield reduction compared to weed-free conditions (Bista., 2018). Direct-Seeded Rice (DSR) faces challenges such as the need for precise field levelling, efficient irrigation management, and proper calibration of sowing equipment to ensure uniform crop establishment. Additionally, factors like previous crop harvesting techniques and weather dependency can significantly affect germination and yield.

Incorporation of legumes in the cropping system

Integrating grain legumes such as mung bean and chickpea into rice-based cropping systems significantly improves soil physical quality, aggregation, and organic carbon pools in tropical rice-wheat growing regions. rice-wheat-mung bean and rice-chickpea rotations outperform traditional rice - wheat systems on water use efficiency, methane emission, and carbon stabilization. Combined with integrated nutrient management, legumes rotations offer a sustainable strategy for restoring soil health and productivity in rice agro-ecosystems (Nath et al., 2019). A study of Nepal shows rotating maize with legumes, especially field pea and chickpea, significantly increased maize yield compared to the fallow-maize system. The highest maize yield gains were achieved with recommended fertilizer doses, followed by a combination of fertilizer and farmyard manure, highlighting that legume rotation and integrated nutrient management can enhance productivity and promote agricultural sustainability (Rawal, Khatri, Khadka, & Paneru., 2023). In the Hill and Terai regions of Nepal, the estimated total nitrogen fixation (including roots) by legumes per hectare is 59 kg N for soybean (Glycine max), 28 kg N for mash bean (Vigna mungo), 153 kg N for groundnut (Arachis hypogea), 72 kg N for lentil (Lens culinaris), 84 kg N for chickpea (Cicer arietinum), 412 kg N for pigeon pea (Cajanus cajan), and 80 kg N for grass pea (Lathyrus spp.) and faba bean (Vicia faba) (Maskey, Bhattarai, Peoples, & Herridge., 2001). Meanwhile in Nepal rice-lentil, wheat-mung bean, lentil mixed with field pea, rice - lentil relay, lentil mixed with mustard, maize, soybean mixed are the common legumes incorporation practices.

Water - efficient technologies used in farming

Mulching is a widely adopted water-conservation practice in agriculture, where materials such as plant leaves, straw, or plastic sheets are applied to the soil surface to reduce evaporation and retain moisture. In Nepal, farmers commonly use plant leaves as mulch, particularly in ginger and turmeric cultivation, to maintain soil moisture and suppress weeds. In fruit orchards, mulching is used to minimise water loss and improve soil conditions. In rice nursery beds, leaves of Justicia adhatoda are often applied, not only to conserve water but also to enhance soil organic matter. Additionally, some farmers practice alternate wetting and drying (AWD) techniques in rice fields to optimize water use efficiency without compromising yields. Rainwater harvesting during the monsoon season, followed by its utilisation in the dry season, is another prevalent strategy among Nepalese farmers to cope with water scarcity and ensure sustained crop production. Furthermore, government of Nepal registered and promoted drought-tolerant rice varieties such as Sukkah Dhan 1, Sukkah Dhan 2, Sukkah Dhan 3, Sukkah Dhan 4, Sukkah Dhan 5 and Sukkah Dhan 6 for drought-prone areas. On top of that, investing in solar irrigation can help reduce the country's reliance on fossil fuels, especially as the Government of Nepal is encouraging the adoption of solar irrigation systems through all three tiers of government.

Agro-biodiversity conservation and promotion

Nepal, a global biodiversity hotspot, ranked 49th worldwide, harbors about 24,300 species, of which 28% are agricultural genetic resources (AGRs) across altitudes from 60–5,000 masl. Despite an estimated 40% loss, with some areas reporting complete species loss, conservation efforts since 1986 have been applied ex-situ, on-farm, in-situ, and breeding strategies. Twelve agroecosystems support 1026 species under crop component, 510 under forage, 35 under livestock, 250 under the aquatic animal, 17 under aquatic plant, 3,500 under insect and 800 under microorganism (Joshi et al., 2020). The Government of Nepal has promoted agro-biodiversity through various organisations. Under the centre for Crop Development and Agro-biodiversity Conservation (CCDABC) *Local Crops Promotion Program is implemented* in 72 local levels. Similarly, under the same organisation, Agrobiodiversity Conservation and Community Seed Bank Improvement Program is implemented at 40 Local levels. These programs mainly focused on conserving local crops such as millets, barley, sorghum, tubers and other landraces.

Policy initiatives in Regenerative Agriculture in Nepal

Nepal has undertaken a series of policy measures to promote Regenerative agriculture, focusing on organic farming, sustainable crop production, and biodiversity conservation. The government has established RBPR laboratories in seven major wholesale markets to strengthen residue monitoring, promote safe food and encourage organic production. Key programs such as the Local Crop Promotion Program and Agro-biodiversity Conservation Program are being implemented through the Centre for Crop Development and Agrobiodiversity Conservation, the National Potato, Vegetable, and Spice Crop Centre, provincial agricultural ministries, and local governments. Policy frameworks, including the Organic Agriculture Promotion Guideline 2018 and the Promotion and Conservation of Local Landraces Guideline 2019, provide a legal and strategic foundation. In addition, Karnali Province has prioritized organic farming through a separate provincial act, while the revised Pesticide Management Act, 2075 expands the definition of pesticides, introduces bio-pesticide registration, strengthens residue testing requirements for agro-importers, and enforces strict penalties for misuse. The Agriculture Development Strategy (2015 - 2035) sets a target of achieving 4% organic matter in soils by 2035, aligning with Nepal's Food System Transformations Pathway adopted in 2021.

For soil health improvement, the government has initiated the National Mission for Digital Soil Mapping and drafted a National Soil Action Plan to guide sustainable soil management. Financial incentives, such as subsidies on organic fertilizers, aim to encourage farmers to adopt eco-friendly inputs. Complementary initiatives include promoting cowshed improvements to enhance manure quality, encouraging green manuring practices, and expanding the cultivation of legumes to improve soil fertility through biological nitrogen fixation. These interventions address both the immediate needs of soil restoration and the long-term sustainability of agricultural production.

Nepal's agrobiodiversity conservation and utilization is guided by the Agrobiodiversity Policy (2007, revised 2014) and supported by related national strategies and international commitments such as the Convention on Biological Diversity (CBD) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). The policy emphasizes the conservation, sustainable use, and equitable benefit-sharing of agricultural genetic resources (AGRs), recognizing their role in food security, climate resilience, and rural livelihoods. It promotes on-farm, in-situ, and ex-situ conservation of local landraces, traditional crop varieties, and indigenous livestock breeds, while encouraging participatory plant breeding, community seed banks, and farmers' rights. The framework also integrates agrobiodiversity into agricultural development plans, fosters research and documentation of genetic resources, and ensures that access and benefit-sharing mechanisms are in line with national sovereignty over genetic resources. Through these measures, Nepal aims to balance biodiversity conservation with agricultural modernisation, safeguarding genetic diversity for current and future generations. Efforts are also being made to raise public awareness about the nutritional and cultural value of local foods, while easing the varietal registration process for local landraces to encourage their wider adoption. The near-finalisation of the National Agroecological Roadmap is expected to finalize in 2026 that would potentially promote Regenerative agriculture. Together, these measures illustrate Nepal's multi-pronged approach to building a Regenerative agricultural system.

Various organizations and their role in Regenerative agriculture

Three tiers of government, INGOs, NGOs, cooperatives and the private sector are involved in the promotion of RA in Nepal. Government mainly supports conservation, marketing and utilisation of products. The private sector is mainly involved in branding and marketing of products produced from regenerative practices (Table 2).

Table 2. Organizations and their role in Regenerative agriculture

Organization	Type of Organization	Role
Federal and provincial Agri-ministries	Government	Regenerative polices and budget allocation
Local level	Government	Implement the regenerative practices
National Agriculture Genetic Resource Centre (gene bank, NARC)	Government	Conservation of landraces
National soil research division (NARC)	Government	Digital Soil Mapping, technology recommendation
Crop Development and Agro-biodiversity Conservation Centre	Government	Promotion of local crops and value addition
Libird	NGO	Research and advocacy for conservation of local landraces
Private sectors, community seed banks and cooperatives (eg. Raithane agri-products, Muna Krishi, Kodali Venture)	Pvt.	Advocacy for production, branding and marketing of local products produced from regenerative practices

Recommendations

To promote sustainable and resilient agricultural systems, it is essential to integrate Regenerative agriculture Agriculture into national policies. Governments should mainstream regenerative practices by offering targeted subsidies, financial incentives, and support programs that encourage farmers to adopt eco-friendly farming methods. These policies must be aligned with nationwide soil health restoration initiatives, including composting, green manuring, cover cropping, and conservation tillage, which are fundamental to rebuilding soil fertility and enhancing long-term productivity.

Investing in capacity building through comprehensive training programs, farmers field schools, and field demonstrations should be conducted in diverse ecological zones, considering the farmers' demands. Promoting indigenous crops such as millets and legumes, alongside traditional farmer's knowledge, can help to promote Regenerative agriculture. Research and Development should focus on breeding drought and flood tolerant, disease resistant varieties and fostering cropping systems that integrate cereals and legumes, improving overall system productivity and ecological balance.

Furthermore, enhancing market linkages through certification, branding, and marketing of regenerative products will provide better price realisation for farmers. Efficient water and nutrient management, through techniques like mulching, rainwater harvesting, and AWD must be promoted to ensure resource sustainability. Finally, community engagement is crucial; empowering women and youth through entrepreneurship and cooperatives will drive grassroots-level adoption and ensure inclusive growth in the Regenerative agricultural movement.

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Chapter - 5

Regenerative Agriculture Practices (RAPs) Pilot with Wheat: A Case Study from Pakistan

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Summary

Regenerative Agriculture (RA) is a farming practice that follows the natural processes to improve and protect soil health through biological activity, while increasing farm profitability. This study investigates the impact of Regenerative Agriculture Practices (RAPs) compared with the conventional system on wheat yield at various agro-ecological locations in Pakistan. RAPs technology, which is developed by the Agricultural Engineering Institute (AEI), National Agricultural Research Centre (NARC) under the supervision of Ministry of National Food Security and Research (MNFS&R), Government of Pakistan implemented on the principle of minimum tillage, permanent raised beds, precision planting, organic mulching, and less seed and water input. The field trials of 2022-2023 and 2024-2025 demonstrated that initial yields of RAPs trials were lower than conventional farming, but will improve over the period, which means that the soil health will be gradually recovering with the efficient use of resources. Initially, RAPs present a good yield with application of 90% less seed (5 kg per acre) than conventional (50 kg per acre), and significantly reduced the amount of irrigation up to 60 % with zero input of artificial fertilizers and pesticides. These findings indicate that RAPs is still in the R&D phase and has a demanding potential to improve sustainability, soil resilience, and climate-smart productivity for the wheat crop.

Keywords: Organic mulching, Permanent raised beds, Precision planting, Soil health, Regenerative Agriculture Practices (RAPs).

Introduction

Agriculture is the key of the national economy, ensuring national food security through the production of staple crops such as wheat, rice, and maize (FAO., 2021). Pakistan's agriculture contributes 23.5 % in the national Gross Domestic Product (GDP), 37.4% to employment generation, and about 63% rural population depends on this sector for their livelihood to ensure food security (Pakistan Economic Survey., 2025). This sector is characterized by two major cropping seasons, "Kharif" and "Rabi", with dominant crop rotation such as rice-wheat, cotton-wheat, and maize-based systems. However, the sector faces indicated challenges, including water scarcity, soil degradation, conventional farming practices, climate change impacts, and low productivity (Siyal et al., 2023). In most irrigated regions of South Asia, including Pakistan, conventional and commercial agriculture have been practiced an intensive tillage, excessive seed, high input of agrochemicals (fertilizer and pesticide), and flood irrigation to get maximum crop yield. Although these practices have contributed to short-term wheat yield gains, but simultaneously degraded soil health, disturbed the soil structure, caused excessive use of groundwater resources, reduced soil organic matter, decreased soil biological activity, and increased production costs (Lal, 2020; Pretty et al., 2018). The conventional practices claim the decline of productivity and failure of environmental sustainability (Sadiq et al., 2025).

To overcome these challenges, Climate Smart Agriculture (CSA) contributes as a possible solution by the research scientists (Khangura et al., 2023; Musto et al., 2023; Patil, Perumal, et al., 2025). The umbrella of CSA covers conservation agriculture (CA), which includes machinery such as zero tillage drills, Happy Seeder, and Super/Pak Seeders (Javaid et al., 2023). The CA systems reduce the land preparation operations, save irrigation and tilling time, low emissions through minimum tillage, and gradually increase the soil organic matter by mulching and incorporating crop residues in the soil. In Pakistan, currently more than 2,000 units of Super/Pak Seeders have been adopted in the rice–wheat cropping areas for direct sowing of wheat after incorporating rice residues into the soil in a single pass. This technology effectively minimizes the issues for open-field burning of rice residues, which reduces the SMOG formation and mitigate environmental pollution (Latif et al., 2024). These are the prominent technologies to manage the on-field crop residue, besides the use of external inputs and flood irrigations are applied to get maximum yield (Qin et al., 2024).

Nowadays, the Regenerative Agriculture Practices (RAPs) is a sustainable farming approach which develops to restore ecological balance, improves soil health, and optimizes resource efficiency (Rempelos et al., 2023). RAPs aim to restore the soil to its natural condition through different interventions. The RAPs model, based on permanent raised beds, integrates soil disturbance, over-surface residue mulching, and crop diversification to recycle the biological nutrients into the soil (World Bank, 2021). Permanent raised beds formation is a one-time operation for all crops and is reused for the subsequent crops just after reshaping the beds. Furthermore, field traffic is restricted to furrow bottoms to reduce soil compaction. This practice highlights the improved seed efficiency with optimized plant spacing of the wheat crop. This system dislikes the flood irrigation, synthetic fertilizers and pesticides, and relies on natural soil processes, such as decomposition and microbial nutrient cycle with crop mulch (Schreefel et al., 2020).

RAPs have been practiced in the country on thousands of acres under the self-motivational theme, and farmers are interested in getting rid of using costly fertilizers and chemicals. A large number of farmers are determined and are doing RA practices on small areas in different parts of the country. Conservation agriculture (CA) has become very popular among farming communities as a sustainable approach to crop production. It is considered one of the Regenerative Agriculture Practices (RAPs) by many farmers practicing CA because of its dependence on minimum disturbance to soil, zero external inputs, effective water management, and a better potential for crop yield enhancement. In Pakistan, the World Wide Fund (WWF- Pakistan) has led the way in promoting RAPs in cotton-based production schemes in Pakistan with projects like Better Cotton, Regen-Cotton, and Organic Cotton programmes. These initiatives are introduced to reduce greenhouse emissions through minimizing the number of tillage operations, water requirement for irrigation, as well as the application of fertilizers. Furthermore, in Pakistan, the collaborative efforts, such as the Regenerative Production Landscape Collaborative (RPLC) and the collaboration with other organizations, like Regenagri, are continued to strengthen the adaptation of regenerative practices on various agricultural lands. Among these programmes, WWF-Pakistan has been undertaking capacity building of the farmers on soil health improvement, pest management through less use of pesticides, and various crop rotations. Moreover, the organization helps to make linkages among brands, the Government, and policy stakeholders to form supporting supply chains and overcome challenges faced by smallholder farmers.

The present study aims to investigate the comparative performance of wheat yield under Regenerative Agricultural Practices (RAPs) and conventional farming systems under diverse agro-ecological zones of Pakistan. This assessment shows the improvements in soil health, emission reduction potential, and stability in yield. The research outcomes will lead to knowledge on how regenerative management can be used to increase soil organic carbon, mitigate agricultural greenhouse gas emissions, and enhance climate resilience. Ultimately, the focus of the study is related to the regional and global sustainability frameworks supporting climate-smart and resource-efficient agricultural development within the context of South Asia.

Materials and Methods

The present study on the Regenerative Agriculture Practices (RAPs) for wheat crop was conducted through a collaborative initiative between the Agricultural Engineering Institute (AEI), PARC-National Agricultural Research Centre (NARC), under the supervision of the Ministry of National Food Security and Research (MNFSR), Government of Pakistan. The AEI, NARC designed and developed the RAPs specific machinery, such as multi-crop raised bed planter and residue management equipment, as shown in Figure 1. The permanent raised beds made after breaking the soil hardpan by using a chisel plough. This is to pulverise root-zone soil for better penetration of soil, enhance microbial activity, and improve soil structure development. The conventional raised-bed making method involves considerable primary and secondary tillage operations. This machine enables precision planting, leading to minimum soil disturbance and efficient crop growth under organic conditions. Experiment sites were selected according to the potential agro-ecological zone for the wheat crop all over the Punjab. Field trials were conducted at six experimental locations, AZRI Bhakkar, Kot Islam, AARI Faisalabad, Kala Shah Kaku, Lahore, and NARC Islamabad, which have diverse soil and climatic zones.

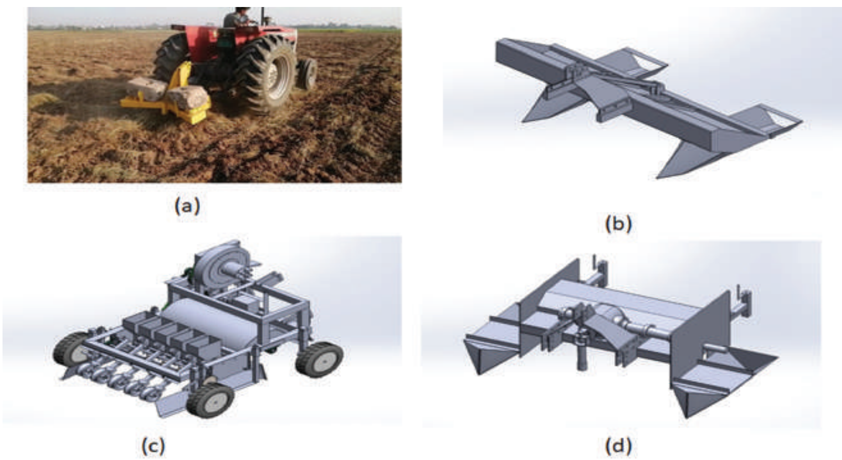

Fig. 1. Regenerative Agriculture Practices (RAPs) machinery used in the study.

RAPs Implementation Recipe

Different implementation models of Regenerative Agriculture (RA) are common in the world. The RAPs protocols implemented in Pakistan are based on the recommendations of senior agricultural scientists, policy makers and field experts including minimum tillage, permanent raised beds, precision seed placement, reduced seed rate (5-6 kg acre^{-1} compared with 50 kg acre^{-1} in conventional practice), and the application of organic mulch on the bed surface to conserve the soil moisture and prevent soil toping and promote microbial activity as illustrated in the Figure 2. Flood irrigation is completely avoided in this practice to prevent soil saturation, and controlled irrigation was applied to maintain an ideal soil moisture level and aeration of the root zone. Moreover, crop rotation was practiced by intercropping to enhance the agrobiodiversity and natural nutrient cycle for soil health. Conversely, at the conventional plots, maximum tillage was applied, external inputs (fertilizer and pesticide), and flood irrigation following the standard farmer practices. The main focus of these experiments was to compare wheat yield performance under RAPs and conventional systems. However, in the conventional practice, each plant has 3-5 tillers/plant, and RAPs dominate with 8-10 tillers /plant as shown in Figure 2 (f). Yield data were recorded at the stage of maturity across all sites, and a simple statistical analysis was performed using descriptive measures, such as means and averages, to assess differences in productivity between the two production systems.

Fig. 2. Depiction of field experiment for wheat sowing and yield analysis under Regenerative Agriculture Practices (RAPs)

Results and Discussion

The comparative yield analysis between the Regenerative Agriculture Practices (RAPs) and the Conventional farming system is presented in Figures 1&2, which show the clear differences across all locations. Overall, conventional plots produced higher wheat yields across all sites during the wheat season of 2022-2023 and 2024-2025, whereas RAPs yield shows an upward trend over the years indicating that the system improves as soil biological and structural recovery. During 2022 - 2023, RAPs yields ranged from 25.28 to 48.08 maunds per acre compared to 40.81 to 54.62 manuds per acre under conventional farming. Notably, at Arid Zone Research Institute (AZRI) Bhakkar, RAPs achieved a highest yield (48.08 maunds per acre) than the conventional system (44.67 maunds per acre), indicating that this practice performs relatively better under arid and coarse-textured soils where water conservation and soil aeration are under observation, While less in Kot Islam due to initial trails. In 2024-2025, RAPs yields rose further to 27.32 - 50.08 maunds per acre, reflecting the soil organic carbon, microbial activity and root growth improved by continuous regenerative practices. Scientific studies (Lal.,2020; Schreefel et al.,2020) confirm that regenerative systems require multiple crop rotations to restore soil structure and enhance the nutrient cycle for yield improvement. The raised - bed design, mulching, and controlled irrigation in RAPS contributed to better water use efficiency, root aeration, and stabilization of soil carbon (Du et al., 2024; Qin et al., 2015).

However, the conventional farming systems show higher absolute yields because of more fertilizer inputs; the Regenerative agricultural practices (RAPs) have been verified to have significantly better resource use efficiency. Under the RAPs, wheat was grown with about 90% less seed (5-6 kg/acre), no agrochemicals, and significantly reduced irrigation requirement (World Bank., 2021). These efficiencies make a major contribution to climate-resilient agriculture by reducing the costs of production, reducing soil degradation, and mitigating GHGs emissions. Overall, the RAPs trials yield slightly below the conventional system, but their long term benefits to improve soil health, restore organic matter through mulching, and sustainability indicate strong potential for achieving yield enhancement through continued refinement and soil regeneration. Similar patterns of long term yield improvement in regenerative management are also verified in field experiments by (Giller et al., 2021; Patil, Choudhari, et al., 2025). Through refinement in machinery design, particularly in precision seed metering and residue management, RAPs can potentially achieve uniformity in yield with conventional farming while delivering substantial ecological advantages. Table1 shows a comparative analysis for wheat growth and yield parameters under RAPs and conventional control treatments in six research sites in Pakistan, depicting the variations in plant height, yield components, and productivity under varying agro-ecological conditions.

Table1. Comparative effects of RAPS treatment and control on growth, yield components, and productivity of wheat across multiple experimental sites in Pakistan

Site	Trails	Plant Height (cm)	Spike Length (cm)	No. of Tillers/m^2	Biol. Yield (g)/m^2 (Grain Yield (g)+Straw Yield (g))	Grain Yield (g)/m^2 (Grain Weight (g)*10000/m^2)	1000 Grain Wt. (g)	Yield (M/ha)
AZRI, Bhakkar	RAPS*	96.33	12.43	261	2018	475.07	51.39	118.77
	Control	98.89	9.33	280	1205.33	441.33	44.03	110.33
Kot Islam, Multan	RAPS	93.13	11.61	250	958	249.73	39.33	62.43
	Control	97.89	10.35	325	1493.33	397	41.75	99.52
AARI, Faisalabad	RAPS	95.79	12.24	240	1450.78	410.67	42.97	102.67
	Control	99.83	10.33	367	1436	539.67	46.57	134.92
Kala Shah Kaku	RAPS	92.22	11.39	230	1437.89	352.07	42.74	88.02
	Control	88.28	10.39	299	1424.67	448	43.41	112.25
PAMCO, Lahore	RAPS	92.2	12.92	300	2013.6	400.93	43.47	100.23
	Control	88.06	9.97	320	1579.67	447.67	38.99	111.92
NARC, Islamabad	RAPS	93.15	12.87	235	1209.92	270.05	48.33	67.51
	Control	98.94	10.79	315	1636.33	422.56	45.67	105.65

*RAPS stands for Regenerative Agriculture Practices

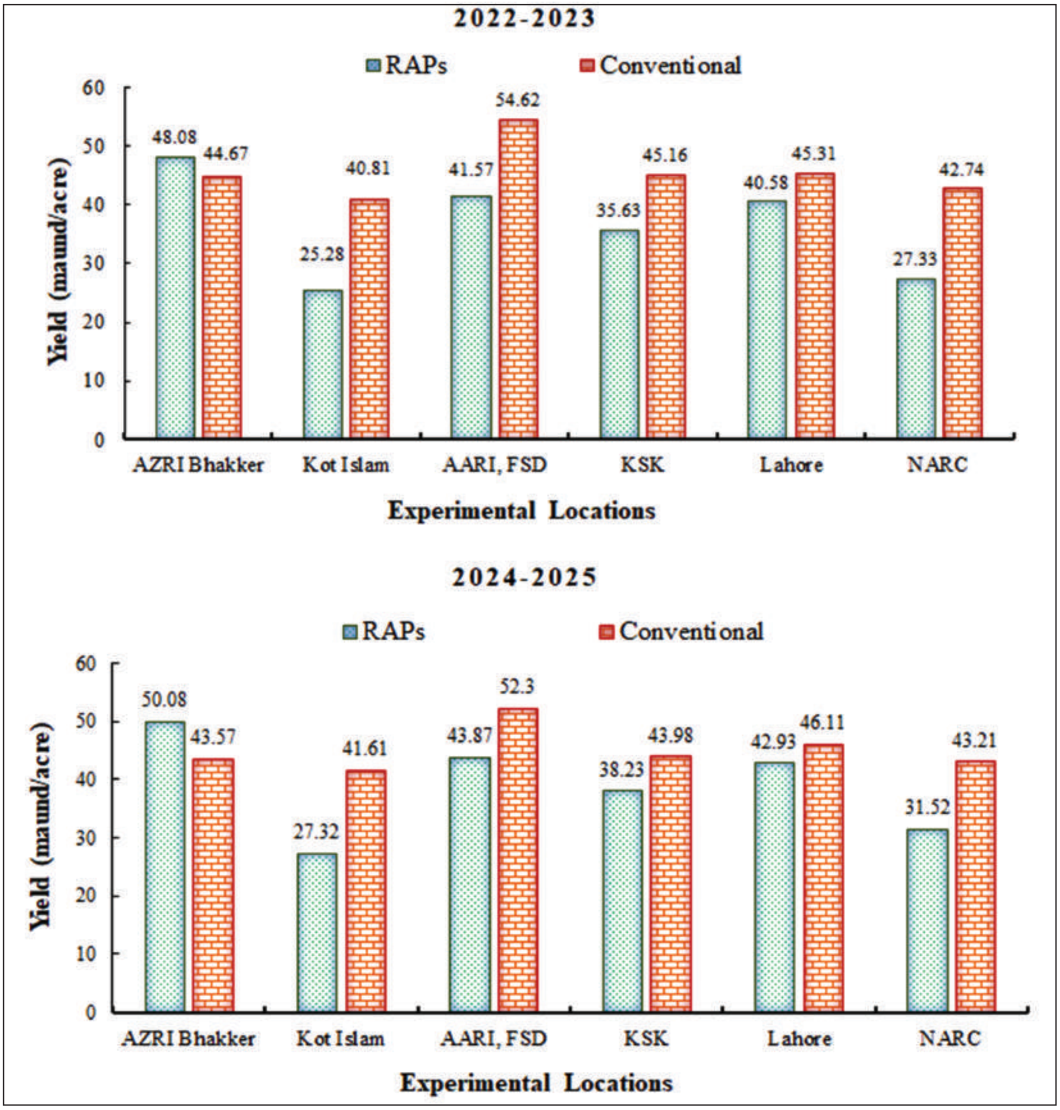

Fig. 3. Graphical presentation of RAPs vs. Conventional wheat yield at different sites

Constraints for RAPs Adoption

The study faced several challenges due to the developmental nature of the Regenerative Agriculture Practices (RAPs). Key barriers, including insufficient financial and technical capacity within government departments, which limit effective extension services. The main constraint is the limited availability of specialized machinery for sowing and harvesting of the crops planted on permanent raised beds. The precision seed metering mechanism required for low seed rates (5-6 kg per acre) are still under development, which affects the sowing uniformity. Adopting intercropping for agricultural biodiversity was also difficult due to the lack of compatible equipment and field management complications. Moreover, less farmer adoption because the technology is still in the research and development phase and not yet commercially available. These constraints highlight the need for continued refinement and extensive technological support for the successful scaling of RAPs.

Way Forward to Scaling Up the RAPs

Regenerative Agriculture Practices (RAPs) is scientifically validated in research and on farms and are now spreading gradually in Punjab and Sindh. To accelerate impact, a fully funded donor program must support the cluster-based scaling. Government and research institutions support RAPs through policy support. The National Program for Enhancing Productivity (NAPEP), Kissan Package, initiated by MNFS&R, provides a strategic platform to mainstream RAPs by integrating advanced technologies with climate-smart practices. In parallel, the SIFC/Green agri-modernization scheme catalyzes public-private partnerships, residue-friendly mechanization, smart irrigation, bio-inputs, and digital Measurement, Reporting, and Verification (MRV) to uplift the RAPs. A targeted policy package with tax incentives is also introduced for mechanization subsidies to scale up precision/residue-friendly seeders & planters via discounts, leasing, and service hubs to enable RAPs.

Conclusion

The Regenerative Agriculture Practices (RAPs) show promising potential as a sustainable alternative to conventional wheat farming. Despite lower initial yields, RAPs improved soil health indicators and yield stability over consecutive periods. RAPs have a low-input nature, minimal tillage, organic mulching, and reduced water up to 60% and 90% less seed (5 kg per acre) offering a tangible way to climate-resilient and low-emission agriculture. Continuous improvement of RAPs machinery, along with farmer training and policy support, will be essential to achieve large-scale adoption and long-term productivity of the wheat crop.

Acknowledgement

The authors thankful to the Public Sector Development Program (PSDP) for providing financial support for the Project "Productivity Enhancement of Wheat".

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Chapter - 6

Promotion of Regenerative Agriculture in Sri Lanka

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Introduction

The Democratic Socialist Republic of Sri Lanka is an island, located in the Indian Ocean, positioned between latitudes 5°55' and 9°50' N and longitudes 74°42' and 81°03' E. The island covers a total land area of 65,610 km², of which approximately 980 km² is occupied by inland water bodies. The population is estimated at around 20 million, with an annual growth rate of 0.9% (AgStat., 2015).

Sri Lanka lies within the tropical climate zone and is divided into three major climatic regions based on annual rainfall: the wet zone, which receives over 2,000 mm of rainfall; the intermediate zone, which receives between 1,000 and 2,000 mm; and the dry zone, which receives less than 1,000 mm annually. Furthermore, based on elevation, these climatic zones are categorized into three regions: low country (0-300 m), mid country (300-900 m), and upcountry (>900 m) (Maraikar et al., 1996). In total, Sri Lanka comprises of 46 distinct agro-climatic zones.

Agriculture contributes approximately 9.9% to Sri Lanka's Gross Domestic Product (GDP), and around 28.5% of the workforce is employed in the agricultural sector (AgStat., 2015). The country's agriculture is broadly divided into two major sectors: the plantation sector and the food crop sector.

The plantation sector includes perennial crops such as tea, rubber, and coconut, along with export-oriented crops like coffee, cardamom, cinnamon, and other spices. The food crop sector comprises rice, the country's staple food, along with fruits, vegetables, legumes, other field crops, and root and tuber crops.

Sri Lanka experiences two main cropping seasons: Maha *and* Yala*,* influenced by two monsoon systems, the Northeast and Southwest monsoons. The Northeast monsoon, occurring from October to January, brings significant rainfall and marks the wet season, while the Southwest monsoon, from April to July, corresponds with the dry season (Pannabokke.,1996). Due to the higher availability of water, the Maha season is considered the primary cropping season in the country.

Agricultural Land Use

Sri Lanka has a total land area of 6,561,000 ha (AgStat., 2015), of which only about 3 million hectares are considered arable (Mapa et al., 2002). Based on the current population, the per capita availability of arable land is approximately 0.14 hectares. In contrast, in 1870, when the total population was only 2.7 million, the per capita land availability was around 2.7 hectares. This significant decline highlights the increasing pressure on land resources available for agriculture. Of the total land area, approximately 22% is occupied by home gardens, 11% by plantation crops, 14% by paddy, and 33.8% by other food crops. Table 1 presents the distribution of cultivable land under different crop types in Sri Lanka.

Table 1. Cultivable extents of different crops in Sri Lanka in 2014

Crop	Extent (ha)
Paddy	922,151
Tea	229,262
Rubber	207,628
Coconut	295,552
Vegetables	90,518
Sugarcane	12,107
Field crops e.g., Chilli, onion, pulses, other grains	216,741
Fruits	134,011
Cinnamon, Cardamom, Clove, pepper etc.	106,356
Potato	4929*

Department of Agriculture, AgStat 2015 *Department of Census and Statistics

Soils

The dominant soil orders in Sri Lanka are Alfisols, Ultisols, and Entisols. Alfisols are particularly prevalent in the dry zone, where most agricultural activities take place. A total of thirteen great soil groups have been identified in Sri Lanka, namely: Rhodustalfs, Tropaqualfs, Haplustalfs, Haplustox, Tropaquents, Natraqualfs, Ustipsamments, Quartzipsamments, Pellusterts, Eutropepts, Rhodults, Tropepts, and Tropohemists (Panabokke., 1996).

Livestock

As of 2023, the livestock sector contributes approximately 1.4% to Sri Lanka's total Gross Domestic Product (GDP). According to the latest data, the cattle population declined by 1.6%, while the buffalo population decreased by 1.5% compared to 2022. In contrast, chicken meat production increased by 3.5%, resulting in a 3.6% rise in per capita availability. The availability of broiler day-old chicks increased by 3%, and the output of layer day-old chicks recorded a significant growth of nearly 43% in 2023.

Goat farming remains a traditional livestock activity, particularly in the dry zone. Out of a total goat population of 754,518, the majority are found in the dry and intermediate zones. The highest concentration i.e., 274,647 goats was reported in the Eastern Province. Notably, 63% of the national goat population is located in the Eastern and Northern provinces. Mutton, the main product of the goat industry, amounted to approximately 2.75 thousand metric tons ('000 MT), translating to a per capita consumption of 0.12 kg in 2023. Beef production slightly declined to 27.28 '000 MT, with per capita availability estimated at 1.23 kg for the year. The total pig population showed a slight increase in 2023. Of the 170,409 pigs recorded, 68% were reared in the Western and North Western provinces.

Livestock Manure

Manure is a valuable byproduct of the livestock industry in Sri Lanka, with potential uses in agriculture and bioenergy production, and the government is actively promoting its production and utilization for organic fertilizer. Efforts are underway to encourage farmers and entrepreneurs in cattle, poultry, goat, and sheep rearing to produce organic manure.

Table 2. Availability of livestock manure in Sri Lanka

Sl.No	Type of Livestock	Total Daily Manure Production (kg)
1.	Poultry	4,197,000
2.	Cattle	36,647,347
3.	Buffalo	11,189,610
4.	Swine	806,947

Source: Ali et al., 2020; Chastain et al., 1999; DAPH, 2020; Manogaran et al., 2022

The main sources of irrigation in Sri Lanka include surface irrigation from large-scale reservoir-based systems (tanks and anicuts), particularly for rice cultivation, and groundwater sources like agro-wells, especially in the dry zone.

In Sri Lanka, the water requirement for rice cultivation is met through rainfall or irrigation. When rainfall is sufficient during the cropping season, rice is cultivated entirely under rainfed conditions. In such cases, crops receive water directly from rainfall or indirectly through runoff and seepage from adjacent areas. There are no irrigation channels involved, and water is retained within the fields using dykes, which also help prevent leakage. In regions where rainfall is unreliable or insufficient, supplementary irrigation is provided through a network of distributary channels sourced from tanks and anicuts.

Major Sources of Irrigation

- **Reservoir / Tank-based systems**: Over 85% of Sri Lanka's irrigation depends on stored rainwater in thousands of tanks, with many interconnected in ancient *tank cascade systems* supporting dryzone agriculture
- **Major and medium irrigation schemes**: Managed by the Irrigation Department and Mahaweli Authority, including large reservoirs and trans-basin canals (e.g., Gal Oya, Mahaweli systems) supplying >100,000 ha of irrigated land.
- **Minor irrigation systems**: These cover fields under 80 ha, usually tank- or anicut-fed, managed locally, suited for smallholder rice cultivation.
- **Hydropower-linked irrigation**: Projects like the Uma Oya complex (functional as of April 2024) integrate surface water storage for both irrigation and hydroelectric generation

Cropping systems and crop rotation

In Sri Lanka, rice-based cropping systems dominate agriculture, particularly during the Maha and Yala seasons. To maximize resource use and improve productivity, farmers widely practice crop rotation and intercropping. Rice is often rotated with high - value non - rice crops, including pulses, oilseeds, and vegetables, as well as sugarcane or bananas, especially in irrigated regions, particularly during the water-scarce Yala season. Intercropping is also common, where traditional farming practices integrate crops such as banana with ginger, turmeric, or pineapple beneath mature coconut plantations.

Rice-Based Systems:

Rice is the primary crop, cultivated in two main seasons: Maha (October to February) and Yala (March to September).

Rice-Rice: Practiced in areas with sufficient water resources.

Crop Rotation:

To maximize returns from land and water, economically valuable non-rice crops are rotated with rice, particularly in the Yala season. Examples include:

Rice - Other Field Crops (OFC) or Rice - Vegetables: Cultivating crops like chilli, onion, potato, cowpea, soybean, black gram, or various vegetables alongside rice or in rotation with rice.

Rice - Fallow: A system where land is left fallow after rice cultivation.

Intercropping:

Involves cultivating multiple crops simultaneously in the same field. This is seen in:

Paddy fields: Indigenous methods include cultivating crops like banana, coffee, black pepper, ginger, turmeric, or pineapple within or around the paddy area.

Coconut lands: Growing coffee, banana, ginger, turmeric, pineapple, or papaya under mature coconut trees.

Regional Specialization:

Certain regions are specialized in OFC cultivation, such as the North Western Province (Kurunegala and Puttalam districts), which produces green gram, cowpea, sesame, groundnut, and chilli.

Traditional Practices:

Traditional agriculture in Sri Lanka also includes practices like "Chena cultivation," a shifting cultivation method that has historically been managed to minimize environmental impact.

Climate Resilience:

Crop management options, including crop rotation and nutrient management, are being explored to enhance the climate resilience of cropping systems in Sri Lanka, addressing challenges like increased temperatures and erratic rainfall.

Policies and Institutional supports for Regenerative agriculture in the country:

National Agriculture Policy (2021)

Sets an overall direction toward sustainable productivity, food security, and climate resilience - it creates space for agroecological approaches but does not contain a single, fully-formed "Regenerative agriculture" program (Ministry of Agriculture).

Government institutions

Ministry of Agriculture (MOA), Department of Agriculture (DoA), Sri Lanka Council for Agricultural Research Policy (SCARP), Provincial/Divisional Agriculture Offices, and the

Agrarian Development / Services Departments-They provide research, extension, input regulation, and farmer outreach (Ministry of Agriculture). Additionally, DOA promotes the Good Agricultural Practices.

Rapid National Organic Push (2021)

It showed that sudden, large-scale bans of fertilizer/agrochemical access without phased support severely damaged yields and livelihoods, underlining that regenerative.

Development partners and NGOs

They are active with pilot projects, GAP/Good Agricultural Practices, training, and climate-smart/soil health initiatives. These actors are important for technical support, capacity building, and financing pilots.

Finance & market mechanisms (partial)

Some public credit schemes and development finance instruments exist, but targeted finance for regenerative investments (cover - crop seeds, composting infrastructure, agroforestry establishment) is limited and unevenly accessible.

Moreover, several Acts, such as Fertilizer Act (MOA), Plant Protection Act, Pesticide Act, Seed Act, and Soil Conservation Act, are regulated by the DOA and MOA.

Major Issues and Threats to Soil in Sri Lanka

Soil degradation is a significant problem in the country, especially on agricultural lands. In Sri Lanka, it is primarily caused by the conversion of forests to other land uses and improper land management. The primary causes include the loss of arable land due to urban expansion, overgrazing, unsustainable farming practices, and long-term climate change. Specific issues include soil erosion, compaction, biodiversity loss, salinization (including inland salinity buildup in the low country dry zone), soil acidification in the wet zone, low CEC, depletion of nutrients and organic matter in the low country dry zone, nutrient buildup in upland vegetable soils, and acid sulfate soils in southwestern coastal areas (about 10,000 hectares of paddy fields abandoned). An additional 45,000 hectares have become less productive (yielding 1-2 tons per hectare), posing major challenges for Sri Lankan soils.

Soil erosion is the major factor responsible for land degradation in Sri Lanka. More than 33% of the land is exposed to erosion (Nayakekorala., 1998). Severe erosion has taken place in the hill country on sloping lands under vegetables and potatoes, tobacco, poorly managed seedling tea, and Chena cultivation. Soil erosion is also considered a threat to agricultural production in the rain-fed farming areas in the dry zone. Soil erosion is a serious threat to agricultural production Low soil fertility and soil compaction due to soil erosion are treated with the application of inorganic fertilizer and tillage, respectively.

Table 3. Measured soil erosion rates under different land uses without any soil conservation measures in Agro Ecological Zones in Sri Lanka (Ref)

AEZ	Land Use	Soil Loss (t/ha/yr)
Mid Country Wet Zone	Seedling Tea Mixed home garden	40 0.05
Mid Country Intermediate Zone	Tobacco vegetables	70 18.4
Low Country Dry Zone	Sorghum/Pigen Pea Cotton	21 22

Depletion of soil organic matter

Soil organic matter content is one of the key parameters influencing soil fertility. Most of the soils in many parts of the country are low in organic matter. Therefore, cation exchange capacity and nutrient retention in the soil are low. Due to the prevailing high temperature of the country, the increase of organic matter in the soil is very difficult. Therefore, it is necessary to apply organic manure in every season.

Table 4. Soil Organic Matter content in different cropping systems

Cropping System	AEZ	Organic matter content %
Rice	LCDZ	1.8
Rice	LCWZ	4.0
Rice	LCIZ	1.0
Rice-Veg Rice-Rice	UCIZ	2.7 1.8
Vegetable	UCWZ	7.7
Rice - Veg	MCWZ	1.7
Rice - Veg	MCIZ	3.5

DOA Unpublished Data 2016, 2017

Table 5. Soil characteristics of the different cropping systems in the country

Characteristic	Uncultivated soil	Rice	Rice-Vegetable	Intensive Vegetable Cultivation	Rice-OFC/Vege-OFC
pH	6.4	5.9	5.4	5.5	6.4
EC	0.07	0.07	0.164	0.144	0.09
P	12.5	6.6	55.8	69.8	10.9
K	160	64.9	181.6	315.1	145.7

DOA Unpublished Data, 2012

Soil Management Practices in the Country

Soil Fertility Management System

Inorganic fertilizers were introduced to Sri Lankan agriculture in the early 1950s. Since then, their use has played a major role in meeting the nutrient requirements of commercially cultivated crops. However, a small number of farmers continue to cultivate crops without using inorganic fertilizers, instead relying on organic sources to manage crop nutrition. The current promotion of organic agriculture further supports and encourages such growers.

Traditionally, subsistence farmers engaged in *chena* cultivation did not use inorganic fertilizers. Their burn-and-fallow system allowed crops to be grown on newly cleared land with relative ease for about 2-3 years. Afterwards, farmers would shift to new areas, leaving the previously used land to regenerate. Today, however, the practice of slash-and-burn has largely disappeared due to land scarcity and the demand for higher productivity to ensure economic viability. With the introduction of inorganic fertilizers and improved crop varieties, new fertilizer recommendations have been developed for different crop types. However, the

Department of Agriculture (DOA) recommends the application of organic manure at a rate of 10 t ha^{-1} in combination with inorganic fertilizers.

Integrated plant nutrient management (IPNM) practices enhance the availability of applied nutrients as well as native soil nutrients and provide balanced nutrition to crops, match the nutrient demand of the crop with nutrient supply from nature and applied sources, improve and sustain the chemical, biological, and physical properties of the soil, minimize the deterioration of the soil, water, and ecosystem by promoting C sequestration, reducing nutrient losses, and increasing the fertilizer use efficiency. IPNM systems help the balanced use of fertilizer for crop production. Also, when adding fertilizer to a crop, it is essential to consider assessing the contribution from different sources, such as soil, water, organic manure, rain, etc., to the nutrient pool.

Major practices of IPNM are cropping pattern with green manure, mix cropping, crop rotation, and in situ green manuring, correction of pH with liming, and practicing of different agronomic practices such as mulching, contour planting, etc. (helps to conserve moisture, improves soil fertility, and reduces weed growth). In Sri Lanka, many soil conservation methods, such as contour planting in vegetable farms on hill slopes, are used. In 1993, DOA initiated the soil test-based fertilizer recommendation programme for the food crop sector. It minimizes the heavy use of fertilizers and reduces nutrient accumulation in the soil, ultimately mitigating environmental pollution.

Regenerative technologies used/promoted in Sri Lanka for water conservation, soil-moisture retention, and soil-health improvement:

Regenerative Agricultural practices in Sri Lanka are presented in the Table 6.

Table 6. Regenerative agricultural practices in Sri Lanka

Technology / Practice	What it is / How it works	Benefits	Constraints / Challenges
Zero / Minimum Tillage in Paddy	Seeding rice without full ploughing reduced soil disturbance to preserve structure and organic matter.	Reduces labour, fuel, and time costs; helps maintain soil structure; can reduce erosion and loss of soil organic matter.	Requires good weed control (pre-emergent herbicides); possibly higher seed rate; risk of lower establishment in some soils; adoption is low currently.
Cover Cropping, Green Manures, Organic Amendments / Mulching	Growing non-cash or leguminous crops during fallow or between seasons; applying green manures or organic matter; mulching to reduce evaporation.	Improves soil fertility; adds nitrogen (if legumes); improves moisture retention; suppresses weeds; may reduce need for synthetic inputs.	Availability of organic materials; labour for collecting / processing; consistent management needed; sometimes yield risk during the transition period.

Technology / Practice	What it is / How it works	Benefits	Constraints / Challenges
Crop Diversification & Inter-Season Cropping	Instead of monoculture or leaving land fallow, grow alternate or multiple crops; use non-paddy crops during dry seasons or lesser rainfall periods.	Better use of land; income spread over seasons; reduces risk; improves soil health via crop rotation; can reduce pest/disease cycles.	Water constraints; markets/demand for alternate crops; input knowledge; sometimes infrastructure (irrigation, seed supply, etc.).
Soil Fertility Management Technologies	Biofertilizers, eco-friendly substitutes/complements to chemical fertilizers; sensors to monitor soil nutrients; improved fertilizer efficiency.	Reduced chemical input use, lower cost, environmental gain; improved soil health; possible long-term sustainability gains.	New technologies are often costlier initially; there is a need for awareness/training, regulation/quality control, possible variability in performance, and farmers' risk aversion.
Smart Farming / Digital / Geo-Spatial Tools	Use of sensor, climate data, soil moisture, weather forecasting, satellite imagery, digital platforms to inform farm decisions (when to plant, irrigate, apply inputs etc.)	Helps optimize input use (water, fertilizer, pesticide), reduce waste; helps mitigate climate risk; better decision timing; possibly improves yield & resource efficiency.	Access (digital literacy, connectivity); trust in data/advice; cost of sensors/infrastructure; ensuring local calibration of models; occasional mismatch with traditional knowledge/practices.
Agroforestry & Traditional Mixed Systems	Integrating trees, shade, polyculture systems, and multi-layered cropping (fruit, timber, food crops together) rather than monocultures.	Boosts biodiversity; shade moderates microclimate; diversifies income; carbon sequestration; improves soil and ecosystem functions.	May require a longer time to mature income from trees; complexities in management; possibly need better technical support; land tenure/ownership issues; seedlings supply, etc.
Water Management & Traditional Systems	Conservation of water (rainwater harvesting, rehabilitation of tanks, bund improvements, etc.), making use of traditional irrigation infrastructure; managing bunds, spillways, etc.	Helps ensure water availability; reduces risk of crop failure in dry spells; enhances resilience; supports multiple crops / seasons.	Cost of rehabilitation, maintenance, community coordination, competing water uses, and climate change affecting rainfall patterns.
Regenerative Practices in Plantation (Tea, Coconut, etc.)	Reducing chemical inputs, shade tree integration, soil carbon measurement,	Helps meet export / sustainability market demands; potential	Costs of certification; need to monitor and measure results; managing tradeoffs

Technology / Practice	What it is / How it works	Benefits	Constraints / Challenges
	better pest/disease eco-management, possibly reagent uses etc.	premium; improves long-term soil health; possible carbon credit opportunities.	(e.g., yield vs input reductions, pests without synthetic chemicals); scaling smallholder involvement.

Machinery use in Regenerative Agriculture in Sri Lanka

Minimum Tillage Planters: Machines (seed drills, planters) that sow seeds without doing full ploughing; they often create slots/furrows, deposit seed, and cover seed with minimal soil disturbance. Preserves soil structure; reduces erosion; retains soil moisture; preserves soil organisms; reduces fuel, labour & input costs.

Rotary Tillers/Cultivators/Roto-Slasher: Implements that break up soil, mix residues, level seedbeds, etc. It can be used for shallow tillage and residue incorporation. Allows incorporation of crop residues, mixing organic matter; can prepare seedbeds more cleanly; used in reduced tillage systems when deeper tillage is needed occasionally.

Compost/Organic Material Processing Machinery: Machines to shred / chop organic residues, tree branches; compost making machines & compost sieving; compost turners, etc. It helps accelerate compost formation; improves the quality of compost, allows scaling of organic amendments; better incorporation of high volumes of biomass residues; and reduces reliance on synthetic fertilizers.

Degree of use of organic matter in the country

- Most commonly generated organic manure in the rice-rice cropping system is rice straw. Straw could replace nearly 1/3 of the N, and the total supply of K .
- Use of animal wastes and green manures for rice cultivation is very limited.
- Intensive vegetable growing areas in the country use cattle and poultry manure with chemical fertilizers.
- Animal wastes as presently available in the country cannot make a major contribution towards meeting the plant nutrient requirements of farming systems.

Challenges or Barriers to the use of machinery in Regenerative agriculture in Sri Lanka

- **Access & affordability:** Many farmers (especially smallholders) may not be able to afford machines or the associated operational costs (fuel, maintenance, spare parts).
- **Scale mismatch:** Small holdings may not need or be able to use large machines; shared machinery access (custom hiring centres or cooperatives) may be required.
- **Technical training & knowledge:** Even with machinery, using them properly for regenerative goals (e.g., depth of tillage, seed placement, residue retention) requires training/extension support.
- **Power / Fuel / Energy:** Many machines require diesel or electricity; fuel costs fluctuate; electricity is not always reliable in remote areas.
- **Repair, maintenance, and parts availability:** Local service networks and spare parts must exist; otherwise, breakdowns reduce utility.

- **Appropriateness of machines:** Soil types, terrain (steep, wet, hilly) may limit what machines can be used. For instance, heavy tractors are difficult in wet, muddy paddy fields or sloped land.
- **Integration with policy & incentives:** Without subsidies, incentives, access to credit/cost sharing, adoption remains limited.

Contribution of Regenerative agriculture practices on the improvement of rural livelihood, environmental functions, C sequestration, climate change adaptation and mitigation, soil fertility improvement, and biodiversity conservation in Sri Lanka

Regenerative agricultural practices in Sri Lanka have shown multiple benefits across soil, water, climate, and livelihoods. Watershed management projects, particularly in the Upper Mahaweli and dry zone catchments, have demonstrated that soil and water conservation measures such as terraces, bunds, and riparian buffers reduce runoff and sedimentation, improving irrigation reliability and community livelihoods (World Bank., 2021). Climate-smart agriculture assessments highlight practices such as alternate wetting and drying (AWD) in paddy systems, agroforestry, mulching, and composting, which provide both adaptation and mitigation benefits by stabilizing yields, reducing water use, and lowering methane emissions (FAO., 2019; Weerasekara et al., 2016). Empirical trials with cover crops like Mucuna in coconut and rubber systems have improved soil organic carbon (SOC), reduced runoff, and enhanced nutrient cycling, thereby strengthening soil fertility and hydro-physical properties (Jayakody et al., 2014). National soil fertility assessments also confirm that integrating compost and organic amendments enhances nutrient availability and reduces over-reliance on synthetic fertilizers (Department of Agriculture (DOA & HARTI., 2020). Agroforestry interventions in the dry zone have been particularly effective, increasing aboveground carbon stocks while diversifying household incomes through fruit and fuelwood production (Gunathilake et al., 2018). Furthermore, biodiversity conservation reports emphasize that practices such as agroforestry, buffer strips, and organic farming contribute to on-farm biodiversity and ecosystem services, supporting pollinators and habitat connectivity (Central Environmental Authority (CEA., 2020). Together, these findings suggest that Regenerative agriculture in Sri Lanka not only enhances soil fertility and environmental functions but also strengthens rural livelihoods, contributes to carbon sequestration, and supports climate adaptation and biodiversity conservation.

Research and Development work

DOA Initiatives - Integrated Plant Nutrient Management Practices

Integrated nutrient supply and management (INM) through the combined use of organic and inorganic fertilizers has been shown to enhance crop productivity while sustaining soil fertility. This approach improves fertilizer use efficiency, contributes to long-term soil health, and increases the benefit–cost ratio, making it a viable strategy for sustainable agriculture in Sri Lanka (Wijewardena & Yapa., 1999). Across diverse cropping systems in Sri Lanka, integrated nutrient management through the sensible combination of organic and inorganic sources has proven effective in sustaining crop yields and improving soil fertility. Rice straw and legume residues play vital roles in rice-based systems, poultry manure offers substantial benefits in both rice–maize and vegetable systems, and green manure legumes enhance nutrient cycling. Collectively, these findings reinforce INM as a cornerstone for sustainable intensification in Sri Lankan agriculture.

The rice - rice system is the most widely practiced cropping system in Sri Lanka, with rice straw serving as the most common organic amendment. Amarasiri and Wickramasinghe (1988), reported that rice straw contains 0.66 - 0.84% nitrogen (N) and 1.30 - 2.03% potassium (K). Their findings indicated that straw incorporation could substitute nearly one-third of the N requirement and fully replace the K supplied by inorganic fertilizers. However, they cautioned that the substitution potential for N is highly dependent on soil and environmental conditions. While straw recycling did not impair soil K status or crop yields, it also did not significantly improve soil organic matter content.

Further evidence highlights the role of other organic inputs in rice-based systems. Weerasinghe et al. (2001), demonstrated that applying different organic manures enhanced soil fertility in sandy soils under rice - rice cultivation. Similarly, Weerasinghe and Lathiff (1999), showed that incorporating groundnut residues could save nearly one-third of the N fertilizer requirement of the subsequent rice crop. In addition, De Silva et al., (2005) found that in rice - maize rotations on sandy soils, poultry manure combined with inorganic fertilizer resulted in the greatest improvements in soil fertility, followed by cattle manure, while straw provided the lowest response.

Research on up-country intensive cropping (UCIC) systems has also demonstrated the potential of organic manures to reduce dependency on inorganic fertilizers. Wijewardhana (1999) reported that poultry manure applied at 10 t ha^{-1} could substitute up to 50% of the recommended inorganic phosphorus (P) and potassium (K) fertilizers in a two-year rotation of cabbage, tomato, and pole bean. This underscores the role of animal manures in maintaining soil fertility in high-input vegetable systems.

Legume integration has proven to be particularly effective in enhancing nutrient availability. Nijamudeen et al., (2003) showed that incorporating black gram as an in situ green manure in maize cultivation significantly increased soil available P and exchangeable K compared to non-legume systems. Such practices not only improve soil fertility but also reduce dependence on external inputs. Furthermore, a long-term study conducted by the DOA for rice and vegetables clearly showed that the integrated use of recommended NPK fertilizer with 10 t/ha compost applied treatment gave the highest yield and improved the soil health compared to the NPK alone treatment.

Organic Agriculture

DOA initiated research on organic agriculture in Sri Lanka in 2000, especially in vegetables. Recommendations were established in 2005 for organic vegetable production, with rates of cattle manure of 20 - 30 t/ha, poultry manure of 15-20 t/ha, and compost of 40 t/ha as a basal application (DOA., 2010). Additionally, these recommendations were reduced via the split application (basal + top dress) of organic manure sources. Accordingly, cattle manure could be reduced to 15 t/ha, poultry manure to 12 t/ha, and compost to 25 t/ha. Furthermore, DOA developed technologies to prepare the vermi-compost, a rapid method for quality compost preparation, liquid organic fertilizer, etc. (DOA annual reports)

Use of Biofertilizers

Use of biofertilizers is limited. More research efforts are needed to explore the feasibility of their use at the field level. Presently, DOA is researching phosphorus - solubilizing bacteria and N - fixing bacteria for rice and vegetable cultivation.

Use of Biochar

DOA research includes the use of mulching materials for soil moisture conservation, and recommends the partially burnt rice husk (biochar) for moisture conservation and nutrient retention in agricultural lands. These fall squarely under Regenerative agriculture, focusing on improving soil health, moisture, and sustaining productivity.

Grain Legume & Oil Crops Research & Development Centre (GLORDC), Angunakolapelessa

This R&D institution works on grain legumes and oil crops, and undertakes work on improved varieties, agronomy, soil & water management, and conservation methods in dry zones. Their research is relevant for Regenerative agriculture (improving sustainable productivity, reducing input dependence, and maintaining soil health) (doa.gov.lk).

Development Projects & Other Initiatives in Regenerative Agriculture in Sri Lanka

Gliricidia-based Agroforestry Systems

A recent review (Atapattu., 2023) has evaluated *Gliricidia sepium* in agroforestry systems, finding strong potential for improving soil fertility, increasing soil moisture retention, supporting livestock feed, and providing bioenergy.

Smallholder Agribusiness and Resilience Project (SARP)

This is a large ongoing project (2021-2027) involving IFAD and the Sri Lankan government, aiming to build climate resilience among 40,000 rural households in six districts across three river basins. Components include capacity building, inclusive value chains, last-mile infrastructure, and likely Regenerative practices (water conservation, sustainable agronomy) among its interventions.

Agroforestry in Tea and Coconut Plantations (IUCN Project)

An ongoing project (June 2021 - June 2025) focused on implementing agroforestry in tea and coconut plantations. This is relevant for Regenerative agriculture in terms of integrating trees with crops, diversifying production, enhancing ecosystem services, and carbon benefits.

Research and Extension

Research on soil fertility management in Sri Lanka is primarily carried out by the respective crop research institutes. These institutes develop plant nutrient management strategies and options aimed at achieving optimum crop yields. Fertilizer requirements are periodically assessed for different crops across diverse agro-ecological regions. Alongside studies on fertilizer responses for new crop varieties, research is also conducted on nutrient flows within various agro-ecosystems. On-farm trials are used to evaluate field-level fertilizer responses, with consideration given to the indigenous nutrient supply of soils. In recent years, growing environmental and health concerns have prompted greater emphasis on recommending nutrient sources that minimize adverse impacts. Consequently, the quality of imported fertilizer materials is now subject to strict monitoring. Agricultural extension activities are largely managed by technical officers within the Department of Agriculture, which facilitates effective communication between research and extension. These officers play a key role in technology transfer through field demonstrations, farmer training sessions, and other capacity-building programs, thereby ensuring that scientific findings reach farming communities efficiently.

Constraints of the Regenerative Agriculture in Sri Lanka

The promotion of Regenerative agriculture in Sri Lanka faces several constraints that limit its widespread adoption. A major barrier is the low level of awareness and technical knowledge among farmers, many of whom continue to believe that crop yield and quality are directly proportional to the amount of fertilizer applied (Wickramasinghe et al., 2019). Weak extension services also exacerbate the issue, as grassroots officers often lack the capacity to effectively communicate Regenerative practices, while market forces in the fertilizer industry promote over-application through simplified interpretations of Liebig's "law of the minimum" (Bandara & Weerasinghe., 2020). Policy and institutional gaps remain significant, with government initiatives historically prioritizing short-term yield improvements over long-term soil health and ecosystem sustainability (FAO., 2017). Moreover, research and technology development in integrated plant nutrient systems (IPNS) and soil biology are insufficient, leading to a lack of context-specific solutions suited to diverse agro-ecological zones (Weerasinghe et al., 2001). Economic constraints also discourage adoption, as many regenerative practices such as mulching, composting, and agroforestry require higher labor inputs and lack adequate financial incentives or subsidies (Maraikar & Nambuge., 2001). In addition, poor integration between crop and livestock sectors reduces the potential for nutrient recycling and organic matter management, which are critical for sustainable soil fertility enhancement (Gunapala & Amarasiri., 1989). Socio-cultural barriers, including farmer risk aversion and reluctance to move away from conventional practices, further hinder adoption. Collectively, these constraints underscore the need for stronger policy support, enhanced extension systems, targeted farmer education, economic incentives, and locally adapted research to accelerate the transition towards Regenerative agriculture in Sri Lanka.

Way Forward for Regenerative Agriculture in Sri Lanka

Policy and Institutional Support

- Establish regulatory frameworks to monitor fertilizer quality and control excessive use.
- Integrate Regenerative agriculture into national agricultural policies and climate-smart strategies.
- Promote inter-agency coordination between crop, livestock, water, and forestry sectors for holistic resource management.
- Introduce incentives and subsidies for adopting biofertilizers, composting, agroforestry, and cover cropping.

Research and Development:

- Develop location-specific IPNS (Integrated Plant Nutrient System) technologies tailored to different agro-ecological zones.
- Strengthen research on soil microbial processes, nutrient cycling, and biomass recycling.
- Explore untapped nutrient sources such as organic wastes, green manures, and crop residues.
- Encourage collaborative research between universities, crop research institutes, and private sector innovators.

Farmer Education and Extension:

- Strengthen farmer training programs, field schools, and demonstrations on regenerative practices.
- Enhance the capacity of Extension officers through continuous professional training.
- Develop educational campaigns to correct misconceptions (e.g., "more fertilizer = higher yield").
- Use ICT tools and smart farming platforms (e.g., GeoGoviya) to reach farmers efficiently.

Economic and Market Incentives:

- Provide financial incentives, subsidies, and credit schemes to support the transition.
- Encourage value addition and premium markets for sustainably produced crops.
- Foster public–private partnerships to invest in compost production, organic fertilizer processing, and regenerative technologies.
- Establish carbon credit schemes for farmers who adopt regenerative practices that enhance soil organic carbon.

Crop-Livestock Integration:

- Promote mixed farming systems to recycle organic matter and nutrients.
- Support infrastructure for manure collection, composting, and utilization.
- Develop model farms showcasing synergies between livestock and crop production.

Environmental and Climate Adaptation:

- Scale up soil and water conservation measures (mulching, contour bunds, tank cascade systems).
- Encourage agroforestry and home garden systems (e.g., Kandyan gardens) to restore biodiversity.
- Position Regenerative agriculture as a tool for achieving SDGs and climate commitments.

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Chapter - 7

Regenerative Agriculture: Restoring Earth's Balance Through Soil, Science, and Stewardship

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Summary

Regenerative agriculture (RA) is a systems approach to farming that aims to restore soil functions, strengthen ecosystem services, and sustain farm livelihoods while producing food, feed, and fibre. Interest in RA is rising because conventional intensification has often increased yields at the cost of soil organic carbon losses, biodiversity decline, water stress, and rising climate risks. However, RA is not a single technology or a universal package; definitions vary across science, policy, and markets. This chapter synthesizes the evidence base and proposes a practical way to frame RA for research and implementation: (i) define the local problem and the 'regeneration target' (soil, water, biodiversity, livelihoods), (ii) apply a small set of core principles (minimise disturbance, keep soil covered, diversify, maintain living roots, and integrate livestock/trees where appropriate), and (iii) verify progress using measurable outcomes (soil health, productivity, profitability, and climate/biodiversity indicators). We highlight proven practice options (cover crops, residue retention, diversified rotations, reduced tillage, agroforestry, improved grazing, and organic amendments including biochar) and discuss key trade-offs (transition costs, yield variability, context specificity, and risks of 'greenwashing'). Finally, we outline a discovery-to-delivery pathway for scaling RA in South Asia, including extension systems, enabling policy, and robust monitoring, reporting, and verification (MRV).

Keywords: Agroecology; Climate resilience; Conservation agriculture; MRV; Soil health; Smallholders; South Asia.

Introduction

Agriculture faces a convergence of pressures - land and soil degradation, water scarcity, biodiversity loss, and climate change. Up to 40% of the global land is estimated to be degraded, affecting billions of people and undermining ecosystem services and food security (UNCCD, 2025; UNEP, 2024). Climate change is already slowing long-term impact in agricultural productivity, with stronger footprints in warmer regions (Ortiz-Bobea et al., 2021). At the same time, two-thirds of the global population experiences severe water scarcity for at least part of the year, with large shares in South and East Asia (Mekonnen & Hoekstra, 2016).

These trends expose the limits of business-as-usual intensification that relies heavily on external inputs and simplified cropping systems. Sustainable agriculture aims to reduce negative impacts, but many stakeholders now ask for approaches that *move beyond 'do no harm' to actively restore soil and ecosystem functions*. Regenerative agriculture has emerged as a prominent umbrella term for this ambition. Yet its rapid uptake also raises a question;. How can RA remain scientifically grounded and locally actionable while avoiding vague claims and fragmented interpretations?

What is Regenerative Agriculture?

Regenerative agriculture is commonly referred to a farming system that *improves the condition of the land over time*, especially soil structure, organic matter, biological activity, and water regulation, while maintaining or improving farm productivity and profitability. Across the scientific literature, RA is best understood as a set of aims and guiding principles rather than a fixed list of practices (Schreefel et al., 2020; Newton et al., 2020; Khangura et al., 2023).

RA lacks a single agreed definition, and different actors emphasise different outcomes (Schreefel et al., 2020). Some narratives focus on soil carbon and climate mitigation, others on biodiversity and landscape restoration, and others on farm economics or food sovereignty (Gordon et al., 2023). Critiques note that broad claims can overstate what specific practices can deliver in all contexts, especially for soil carbon sequestration (Amundson, 2022; Powlson et al., 2014; Giller et al., 2021).

For practical use in research and policy, this chapter frames RA through three linked components:

(1) Purpose: What problem is RA expected to solve in a given place (e.g., erosion, low infiltration, declining yields, high input costs)?

(2) Principles: What design rules guide system redesign (Section 3)? and

(3) Outcomes: What measurable indicators show progress (soil, water, biodiversity, productivity, and livelihoods), supported by MRV (Section 5)?

Principles and design rules

Most RA frameworks converge on a small set of soil- and ecosystem-centred principles. These principles are broadly consistent with conservation agriculture and agroecology, but RA typically communicates them as outcome-driven 'regeneration' goals (EASAC, 2022; FAO, 2019; Schreefel et al., 2020). The principles below are widely applicable, but their implementation should be adapted to climate, soils, farming systems, and socio-economic constraints:

1. **Minimise soil disturbance:** Reduce the intensity and frequency of tillage and avoid practices that degrade soil structure and aggregation, or accelerate organic matter loss. Where full zero tillage is not feasible, reduced/partial tillage and controlled machinery can still reduce compaction and erosion risks.

2. **Keep the soil covered:** Maintain residues or living cover to protect soil from erosion, temperature extremes, and evaporative losses.

3. **Maintain living roots for more of the year:** Extend the period of photosynthesis and root activity using cover crops, relay crops, or perennials to feed soil biota and improve nutrient cycling.

4. **Diversify plant communities:** Use diverse rotations, intercropping, and habitat diversification to strengthen pest regulation, nutrient cycling, and resilience.

5. **Integrate livestock and trees where appropriate:** Well-managed grazing and agroforestry can close nutrient loops, diversify income, and enhance landscape functions. However, it requires careful design to avoid overgrazing and competition for water.

6. **Reduce reliance on external inputs by optimising ecological processes:** Increase nutrient-use efficiency, recycle on-farm biomass, and apply inputs strategically (e.g., precision nutrient and water management).

7. **Focus on people and place:** Adoption depends on profitability, labour requirements, risk, knowledge, and local institutions. RA must be co-designed with farmers and aligned with equity goals.

What can RA deliver and where are the limits?

RA can deliver meaningful benefits, but outcomes are not guaranteed and often take several seasons to emerge. Evidence is strongest for improvements in soil cover, reduced erosion, better infiltration, and enhanced biological activity when principles are consistently applied. Reported benefits commonly include improved aggregation, infiltration, and nutrient cycling (soil function), higher plant-available water and reduced runoff (water resilience), increased habitat complexity and beneficial organisms (biodiversity), and reduced risk and input dependency, sometimes with improved profitability (farm performance).

At the same time, three cautions are central for a science-based RA narrative (Fig. 1). First, soil C changes are complex. Soil C is essential for soil function, but its response depends on baseline C, climate, depth, and management history. Short-term gains at the surface may not translate into large whole-profile stock gains, and permanence can be threatened by drought, fire, or re-tillage (Amundson, 2022; Powlson et al., 2014). Second, yield responses are context specific. No-till or reduced tillage can reduce yields in some environments if residue, weed control, and nutrient management are not adapted (Jat et al., 2022; Pittelkow et al., 2015). Therefore, RA should prioritise locally tested bundles rather than single practices. Third, claims must be verified. Because RA is increasingly linked to markets (e.g., carbon credits), robust MRV is needed to avoid greenwashing and to protect farmers from unrealistic expectations (Newton et al., 2020; EASAC, 2022; Gordon et al., 2023).

Scaling regenerative agriculture: a discovery-to-delivery pathway

Scaling RA requires more than promoting practices; it requires aligning incentives, knowledge systems, and evidence. In South Asia, where smallholder constraints, labour dynamics, and climatic risks are strong, *'one-size-fits-all' recommendations rarely work*. Key building blocks for scaling include (Fig. 2):

- **Co-design and local validation:** Define the local regeneration goal with farmers and test context-specific practice bundles through on-farm trials and participatory learning.
- **Transition support and risk management:** Provide short-term finance or incentives to cover transition costs (equipment, cover crop seed, learning time) and to buffer early yield risks. Insurance and credit products can be redesigned to reward verified risk-reducing practices.
- **Extension and learning networks:** Strengthen advisory systems and farmer-to-farmer learning, supported by digital tools that are easy to use and locally relevant.
- **Markets and MRV:** If RA is linked to premiums or C payments, MRV systems must be transparent, low-cost, and conservative in claims. At least the programs should report both productivity and environmental indicators, not C alone.
- **Policy coherence:** Align RA initiatives with national priorities (food security, water, climate adaptation, livelihoods) and avoid conflicting subsidies that promote soil-degrading practices.

Priority applications and niches (illustrative South Asia cases)

RA tends to deliver the fastest gains when it targets a binding constraint (erosion, poor infiltration, nutrient losses, high irrigation energy, or high input costs) and when there is enough biomass to keep soil covered. The best early wins are low-risk packages that reduce a visible loss (runoff, ponding, lodging, fertilizer waste) while keeping yield risk low. In South Asia, residues and manure often have competing uses (fodder, fuel). Priority niches, therefore, pair soil-cover goals with realistic biomass strategies (partial retention, cover crops/legumes, or agroforestry litter) rather than assuming residues will be available (Table 1).

1. Rainfed, erosion-prone uplands (hills and undulating plateaus): Focus on stopping monsoon runoff and conserving moisture. Entry packages combine contour farming/graded bunds or strip cropping, reduced soil disturbance, legumes (intercrops or short cover crops), and targeted residue mulch; small agroforestry hedgerows can add biomass and stabilize slopes. These interventions reduce soil loss, improve infiltration, and stabilize yields under rainfall variability. Track ground cover, infiltration after first rains, visible sediment movement (e.g., silt in drains), and yield stability across wet and dry years.

2. Irrigated, water-stressed systems (e.g., NW Indo-Gangetic Plains): Priorities are precision irrigation (laser levelling, scheduling, drip or subsurface drip where feasible) plus split fertigation, residue retention, and diversified rotations (including pulses/oilseeds where markets exist). Raised beds, mulch, and better scheduling reduce evaporation and deep percolation while improving timeliness of operations. Benefits include lower pumping cost and higher water productivity, not just soil health. Core pilot metrics should include irrigation savings, nitrogen-use efficiency, and net margin.

3. Rice-based systems (irrigated and lowland rainfed): Combine alternate wetting and drying (AWD) or mid-season drainage with improved straw management (retention/composting/timed incorporation) and, where feasible, legume breaks or non-rice crops in parts of the landscape. These packages address water scarcity and residue burning while improving soil structure and root function over time. Severe over-drying (yield risk) must be avoided and nitrogen timing should be adjusted to limit potential N_2O trade-offs. Water use, crop duration, lodging incidence, yield, and simple flooding proxies (days flooded, water-table depth) should be tracked.

4. Degraded rangelands and mixed crop–livestock systems: Aim to rebuild ground cover and reduce compaction. Start with stocking-rate adjustment, planned/rotational grazing with rest periods, strategic water points to spread grazing pressure, fodder banks, and manure collection/composting for targeted recycling to fields. In mixed systems, the RA benefit often comes from closing nutrient loops (better manure handling and targeted return to soil) and reducing bare ground. Track basal cover, biomass, infiltration, erosion symptoms, and livestock output per hectare.

5. Peri-urban horticulture: Address pollution risk and soil fatigue in intensive production. Priority packages combine quality composting and safe recycling of organic wastes, year-round soil cover (mulches/living covers), drip fertigation, protected cultivation where appropriate, and integrated pest management (IPM) to cut pesticide loads while maintaining quality. Because markets penalize cosmetic defects, RA must be presented as a "quality and safety" strategy as much as a sustainability strategy. Track water productivity, nitrate/salinity trends, pesticide-use records, and produce rejection rates.

These niches are practical starting points for pilots because benefits can be observed quickly and measured credibly. A niche-first strategy also helps design incentives that farmers value (lower pumping costs, less fertilizer waste, reliable fodder) while building an evidence base for scaling. For each niche, we must define a small MRV set (2-3 agronomic, 2-3 environmental, 1-2 economic indicators) and align extension, inputs, and finance accordingly (Table 2).

Global and regional initiatives

RA has moved rapidly from grassroots innovation to mainstream policy and corporate programmes. Examples illustrate both opportunity and the need for scientific guardrails.

(a) **Europe:** The European Academies' Science Advisory Council (EASAC) reviewed RA claims and concluded that many proposed 'regenerative' measures overlap with established sustainable farming approaches, and that policy should prioritise outcomes, trade-offs, and evidence rather than labels (EASAC, 2022).

(b) **United States:** The United States has a growing landscape of private and public RA programs. In December 2025, USDA announced a Regenerative Pilot Program intended to support farmers in adopting soil- and water-improving practices (USDA, 2025). Such programs highlight the need for clear definitions and MRV to ensure public value.

(c) **India:** In India, RA is increasingly discussed alongside natural farming, conservation agriculture, and climate-smart agriculture. National dialogues emphasise soil health, water efficiency, and farmer profitability, with calls for eco-region-specific approaches and institutional support (TAAS, 2021). International research programs in the region also frame RA as a pathway to rebuild soil biology, diversify systems, and improve resilience (CIMMYT, 2022).

(d) **South Asia and SAARC:** A regional agenda can help harmonise approaches, share evidence, and build capacity. At the SAARC Agriculture Centre consultation in Dhaka (August 2025), participants proposed a 'SAARC Mission on Regenerative Agriculture' focused on policy coherence, inclusive governance, and scaling agroecological elements suited to local contexts (SAARC Agriculture Centre, 2025).

Challenges and safeguards for credibility

Eight recurring challenges must be addressed for RA to deliver durable impact:

1. **Definition drift and greenwashing:** Without outcome-based standards, almost any practice can be labelled 'regenerative'. Programs should specify principles, baseline conditions, and measurable outcomes.

2. **Transition costs and equity:** RA can require new machinery, knowledge, and labour. Smallholders may need targeted support to avoid exclusion.

3. **Biophysical limits:** In arid or cold regions, biomass production may limit cover crops. In heavy soils, no-till can raise waterlogging risk. Therefore, adaptation is essential.

4. **Time lags:** Soil organic matter and biodiversity gains often take years; short projects may miss long-term benefits.

5. **Measurement uncertainty:** SOC and GHG estimates carry uncertainty. Conservative accounting and transparent uncertainty reporting are non-negotiable.

6. **Trade-offs:** Poorly managed residue retention can increase pest pressure, while livestock integration can increase methane emissions if productivity does not improve.

7. **Institutional alignment:** Input subsidies, price policies, and extension messages can conflict with RA principles.

8. **Knowledge systems:** RA requires integration of agronomy, soil science, ecology, economics, and social science. Investment in interdisciplinary research and 'science of delivery' is critical.

Conclusions

Regenerative agriculture Agriculture has become a powerful narrative for shifting agriculture from extractive to restorative pathways. To be credible and useful, RA must be framed as an outcome-verified, context-adapted redesign of farming systems. This must not be a brand label or a single practice. Evidence supports many RA-aligned practices for improving soil cover, e.g., infiltration, and resilience, but climate mitigation claims, especially for soil carbon, require careful, conservative accounting. For South Asia, scaling will depend on locally tested practice bundles, transition finance, strong advisory systems, and low-cost MRV that reports both farm and environmental outcomes. A SAARC-level mission could accelerate shared learning, harmonise standards, and mobilise investments toward food security, livelihoods, and ecosystem restoration.

Table 1. Priority regenerative agriculture niches in South Asia, with binding constraints, entry management packages, and minimum indicators for monitoring

Priority niche	Binding constraint(s)	Entry package (illustrative)	Minimum indicators (examples)
Rainfed, erosion-prone uplands	Runoff, soil loss; low infiltration; high yield variability	Contour/strip farming; residue/stone mulch; legume intercrops/cover; agroforestry hedgerows	Ground cover (%); infiltration (simple test); visible sediment loss; yield stability (multi-year)
Irrigated, water-stressed systems	High pumping cost; low water productivity; nutrient losses / low NUE	Laser leveling; irrigation scheduling/drip; split N / fertigation; residue retention; rotation diversification	Irrigation volume & energy; water productivity; NUE proxy (yield/N applied); net margin
Rice-based systems	CH_4 intensity; water scarcity; residue burning; soil structure decline	Alternate wetting & drying (AWD); smart straw management; balanced & split N; legume break/rotation (where feasible)	Days flooded / AWD adoption; water use; yield; CH_4 intensity proxy (practice-based)
Degraded rangelands & mixed systems	Bare ground; compaction; low fodder; weak nutrient cycling	Planned grazing + rest; stocking alignment; fodder banks/legumes; manure composting; targeted recycling to fields	Basal cover / biomass; infiltration; erosion symptoms; livestock output per ha
Peri-urban horticulture	Nutrient & pesticide pollution; salinity risk; soil fatigue; quality penalties	Quality compost + safe waste recycling; mulch/living cover; drip fertigation; IPM; protected cultivation (as needed)	EC / salinity trend; input records (pesticide, N); water productivity; rejection rate / quality grade

Table 2. A practical minimum indicator set for regenerative agriculture monitoring, reporting and verification (MRV)

Domain	Indicators (field scale)	Remarks
Soil health	Soil organic carbon (SOC) stock; bulk density; aggregate stability; infiltration; soil biological activity (e.g., microbial biomass)	SOC stock (not only concentrations) is preferable; Equivalent soil mass to be used when bulk density changes.
Water	Soil moisture and plant-available water; irrigation water productivity; runoff/erosion indicators	Remote sensing can complement field monitoring; interpret with rainfall variability.

Domain	Indicators (field scale)	Remarks
Biodiversity & ecosystem services	Ground cover; plant diversity; beneficial insects; pollinator habitat; tree/shrub cover (where relevant)	Selection of indicators must be relevant to the target service and landscape context.
Productivity & economics	Yield (or livestock output); yield stability; input costs; gross margin/net returns	Transition years to be tracked separately; include labour and machinery costs.
Climate	GHG intensity (where feasible); SOC change over time	Over-claiming sequestration must be avoided; uncertainty and permanence risks for reporting

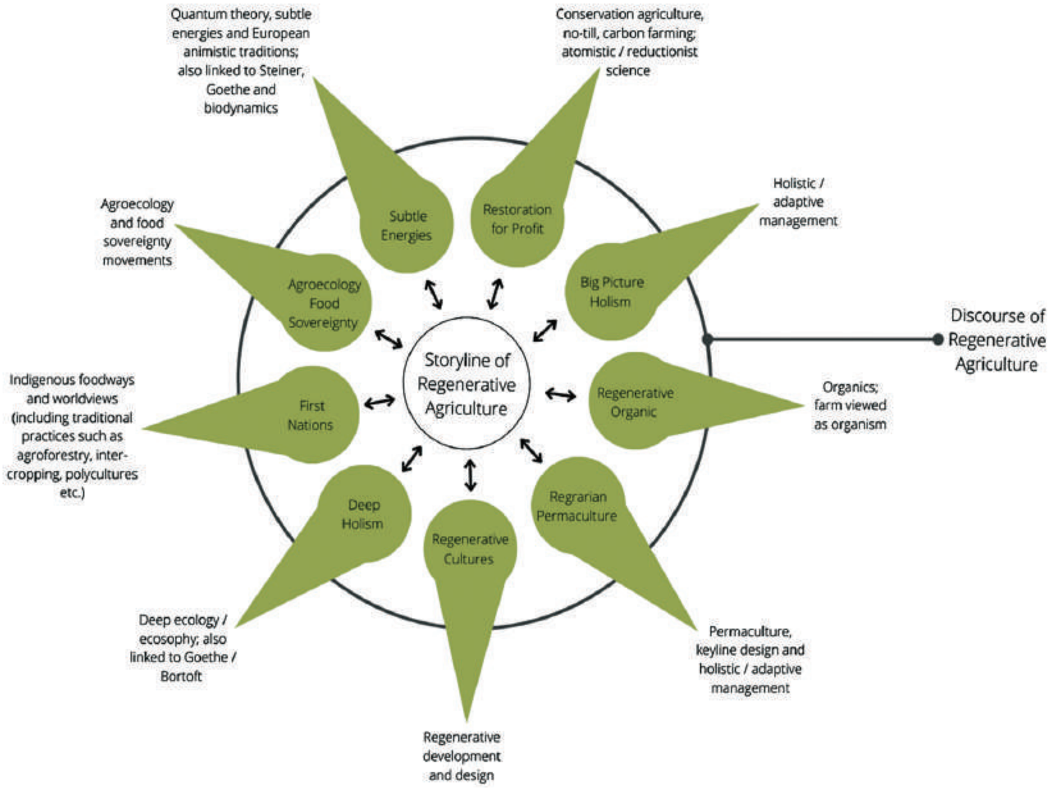

Fig. 1 Multiple discourses associated with Regenerative agriculture and the risk of fragmented meanings (Gordon et al., 2023)

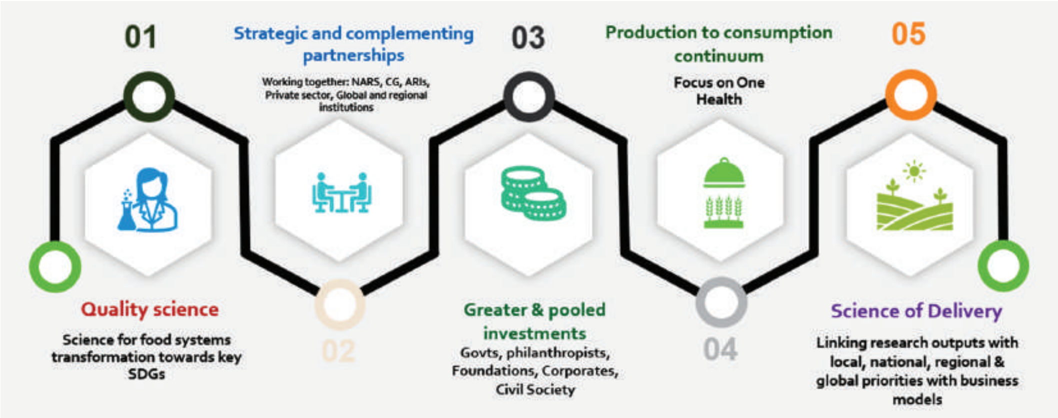

Fig. 2 'Discovery-to-delivery' strategy for scaling Regenerative agriculture (Jat and Shirsath; Personal communication)

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Chapter - 8

Agrobiodiversity and Regenerative Agriculture (REGAGRI)

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Abstract

Regenerative agriculture (REGAGRI) is a nature-positive farming system deeply rooted in traditional agricultural practices. Central to REGAGRI is agrobiodiversity, comprising of six main components and four sub-components, which sustain the ecological balance of farming landscapes. This paper, is prepared through review, observation, survey, and experiential insights (ROSE), explores the principles and practices of Regenerative agriculture aimed at restoring and revitalizing productive and ecological capacities. A truly regenerative system relies on eight key components that are locally sourced, nature-positive, and self-regenerating. It emphasizes circular and integrated farming, aligns with the ten principles of agroecology, and delivers high ecological yield and superior food health. Key practices include cultivar and species mixtures, mulching, integrated farming, composting, water harvesting, and crop rotation. Critical to REGAGRI are participatory research, site-specific technologies, evolutionary breeding, product diversification, ecological pest management, and conservation through use. In Nepal, 27 landraces across 11 crops have been formally registered with communities managing seed selection, storage, and renewal through community gene banks-a model effective for promoting REGAGRI. Additionally, Regenerative agriculture supports securing Geographical Indication tags and depends on reliable marketing channels like farmers' markets. The concept of deep Regenerative agriculture Agriculture integrates cultural, social, spiritual, and astrological traditions to enhance sustainability. REGAGRI contributes to food, nutrition, health, business, and environmental security, highlighting the urgent need for investment in research and development to promote and expand these practices.

Keywords: agroecology, conservation, eco-friend, ecological yield, nature positive practice.

Introduction

Agriculture across the world has evolved through diverse types and models, ranging from highly industrialized, chemical - intensive systems to more sustainable, nature-positive approaches. Broadly, these can be classified as nature-positive (such as regenerative agriculture and ecological farming) and non-nature-positive (such as conventional chemical-based agriculture). While conventional, monoculture-dominated systems have contributed significantly to food production, they have also caused adverse effects on the environment, biodiversity, and human health (Joshi et al.,2020, Altieri.,1999). In response, alternative systems that work in harmony with nature have gained prominence, with regenerative agriculture emerging as a leading approach (Jayasinghe et al., 2023; Newton et al., 2020).

At the heart of any agricultural system, whether modern or traditional, agrobiodiversity plays a decisive role in ensuring productivity, resilience, and sustainability (Joshi., 2025b). Agrobiodiversity encompasses six major components, summarized as CALFIM: Crops, Aquatic agricultural genetic resources, Livestock, Forages, Agro-insects, and Agro-microbes, along with four subcomponents: domesticated species, semi-domesticated species, wild relatives, and wild edible species (Figure 1) (Joshi et al., 2020). This diversity, coupled with traditional knowledge, forms the foundation for food, nutrition, health, business, and environmental security (Joshi et al., 2024).

When agrobiodiversity is integrated into regenerative agricultural practices, the outcomes are exceptional-producing food that is pure, high in quality, tasty, healthy, and rich in nutrients. Furthermore, agrobiodiversity serves as the basis for generating various agricultural inputs, making it a central pillar in building resilient agro-ecosystems. Recognizing this, the Nepal Genebank has been actively working on regenerative agriculture with agrobiodiversity as its core focus. Its working philosophy rests on the principles that genetic diversity underpins climate-resilient farming systems, that local biodiversity should be the first resource considered when addressing agricultural problems, and that a localized seed system combined with a globalized product system ensures zero environmental shock and the development of evolving crop populations.

Nepal's rich agricultural landscape spans three major agroecozones-High Hill, Mid Hill, and Terai-and 15 distinct agroecosystems, each harboring unique agricultural genetic resources (Joshi et al., 2024). However, the influx of exotic genotypes and the spread of monoculture have led to the erosion and endangerment of many local varieties. Safeguarding and promoting localized diversity, along with preserving the associated traditional knowledge, is therefore critical. This paper aims to highlight the key working modalities, guiding principles, and selected success stories that demonstrate how agrobiodiversity can be harnessed to strengthen regenerative agriculture in Nepal and beyond.

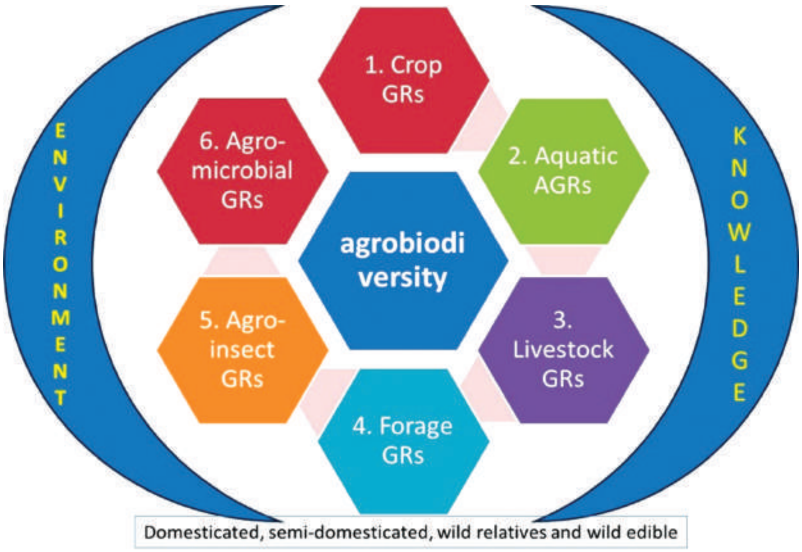


Figure 1. Components and subcomponents of agrobiodiversity

Methodology

This paper draws upon over two decades of experience and research conducted by the Nepal Genebank in the conservation and utilization of agricultural genetic resources through nature-positive practices. Since 2000, the Genebank has carried out on-farm action research aimed at promoting native and localized germplasm and technologies, adding value to these resources, and exploring their potential through nature-based solutions. The study is grounded in the authors' ROSE approach-Review, Observation, Survey, and Experiences-which integrates multiple sources and methods of data collection:

- Review-Relevant scientific literature, project reports, and online resources were examined to understand the broader context of agrobiodiversity and regenerative agriculture.

- Observation-Field visits were undertaken to various research sites and farming communities, with direct observation of farming practices, crop diversity, and resource management.
- Survey-Structured and semi-structured surveys were conducted with farmers and key informants to gather primary data on the use, management, and perceptions of local genetic resources.
- Experiences-Insights were drawn from the authors' long-term involvement in fieldwork, participation in interaction meetings, and collaborative discussions with farming communities.

In addition, the methodology incorporates findings from national and international projects implemented by the Genebank, including the recent Deep Regenerative Agriculture Project in the High Hill region supported by WWF Nepal. These initiatives provided valuable opportunities for testing, validating, and scaling nature-positive solutions in diverse agroecological settings. By combining literature review, empirical field research, stakeholder engagement, and experiential knowledge, this study presents a comprehensive synthesis of how agrobiodiversity can be effectively integrated into regenerative agricultural systems in Nepal.

Regenerative Agriculture (REGAGRI)

Regenerative agriculture, or REGAGRI, is an agricultural system designed to regenerate, restore, and revive the productive and ecological capacity of farming landscapes while ensuring nature-positive outcomes (Jayasinghe et al., 2023; Kremen et al., 2012; Newton et al., 2020). It is founded on the principle that agriculture requires eight essential inputs or components-collectively referred to as Octaculture (Figure 2). When all these components are locally available, nature-positive, and capable of regenerating themselves, the agricultural system qualifies as regenerative. The term REGAGRI itself blends the English prefix RE with the Nepali word GAGRI-meaning "clay pot"-symbolizing the act of refilling, restoring, or replenishing.

REGAGRI promotes circular agriculture (Figure 3) and integrated farming systems, where resources are recycled within the farm and interlinked enterprises support each other. It also incorporates the 10 Keys of Agroecology (Figure 4), ensuring that production is aligned with ecological principles. Two of its defining indicators are the ecological yield and the food health index (Figure 5). Ecological yield measures the total contribution of each genotype to human well-being, livestock nutrition, and ecological health-considering benefits to air, soil, water, microbes, insects, and overall environmental quality. The food health index evaluates the nutritional and medicinal value of a food item relative to others, recognizing that regenerative farming products often have higher scores on both metrics.

A distinctive feature of REGAGRI is its emphasis on eco-friends-species and genotypes that support each other's growth, development, and reproduction during agricultural practices. In rice cultivation, for example, more than 100 species and numerous landraces function as eco-friends. These include aquatic plants like azolla and duckweed; animals such as ducks, fish, and water birds; legumes like soybean, black gram, and pigeon pea; aquatic vegetables like watercress; and a wide range of beneficial microorganisms such as endophytes, saprophytes, mycorrhizae, Bacillus, Trichoderma, Aspergillus, Penicillium, Clostridium, Azotobacter, as well as phytoplankton and zooplankton. Beneficial insects such as lady beetles, ground beetles, assassin bugs, green lacewings, minute pirate bugs, and spiders, along with earthworms, further contribute to the system's productivity and balance.

By valuing ecological relationships, closing nutrient loops, and prioritizing local and renewable inputs, REGAGRI creates resilient agroecosystems that enhance biodiversity, restore soil fertility (Schreefel et al., 2020; Khangura et al., 2023), and produce nutrient rich, health promoting food.

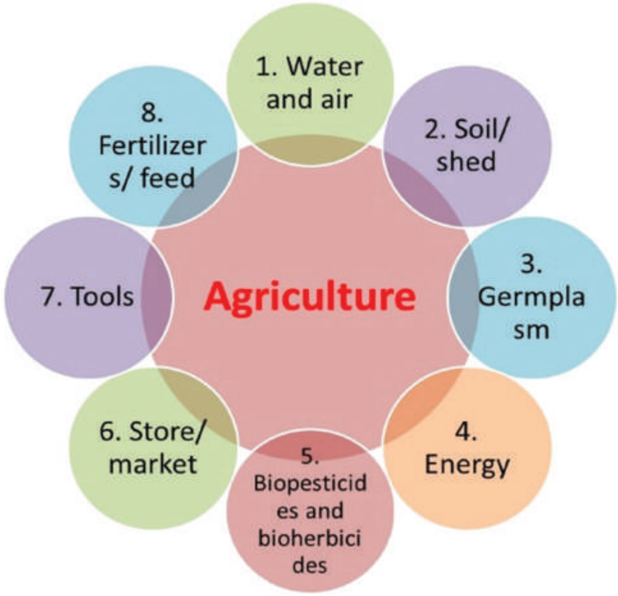
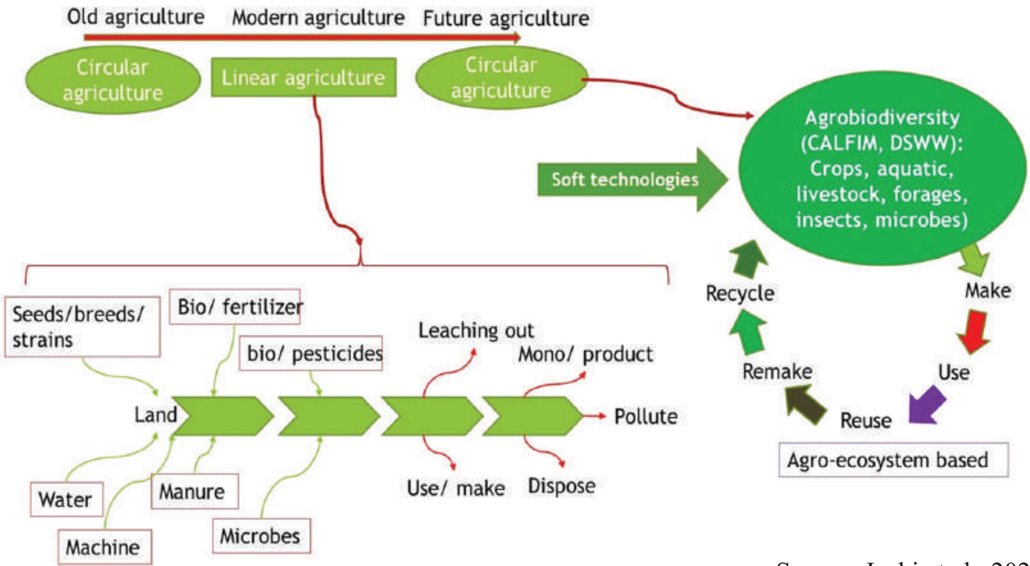


Figure 2. Eight inputs required for agricultural practices (octaculture)



Source: Joshi et al., 2023

Figure 3. Circular and linear agriculture

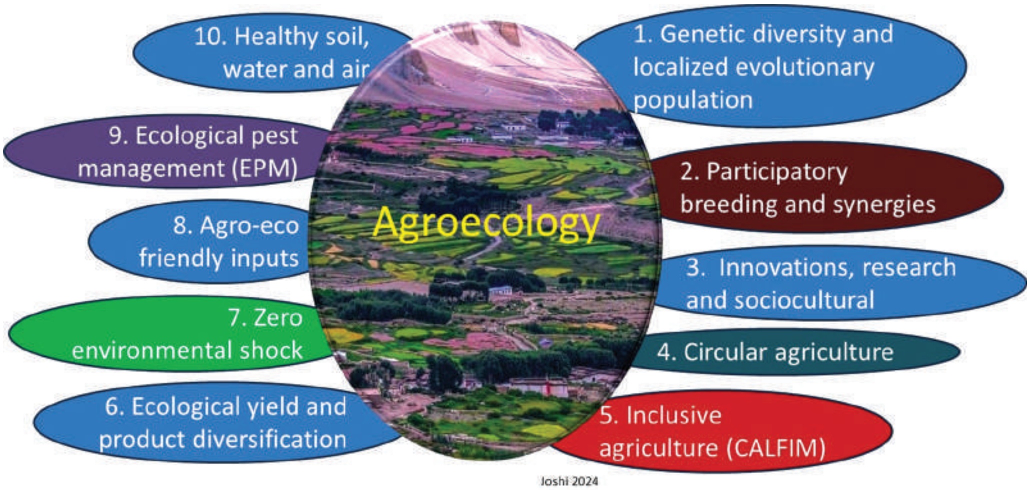


Figure 4. 10 keys of agroecology (agrobiodiversity and breeding perspectives)

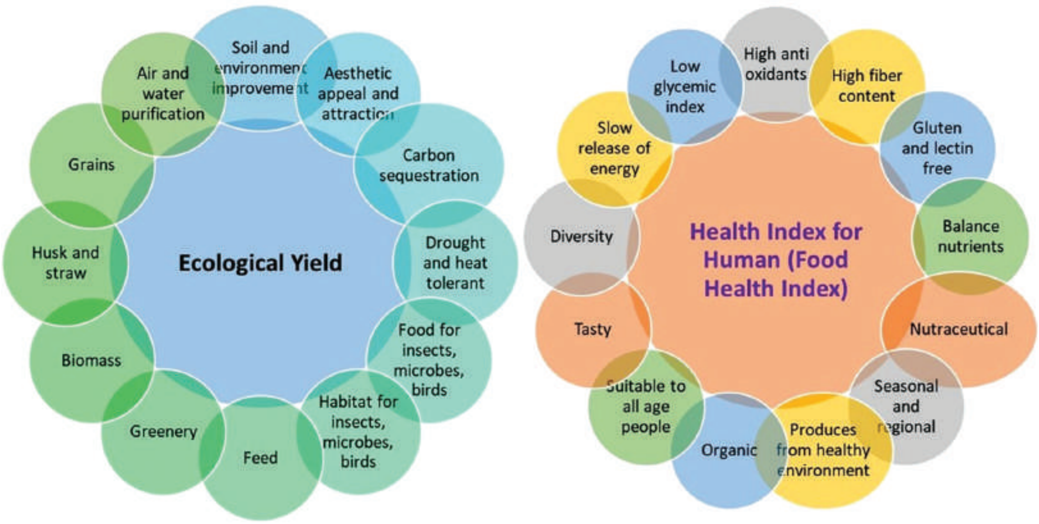


Figure 5. List of components in ecological yield and food health index

Source: Joshi 2025a

Regenerative agriculture -based species level features: Rice as an example

When cultivated under a Regenerative agriculture system, rice can develop and sustain a unique set of adaptive and productive traits that ensure long-term resilience and ecosystem harmony. One of its remarkable features is the ability to complete its full seed cycle within the same area, allowing farmers to save and replant seeds continuously. Such populations have been grown for more than 60 generations at the same site, demonstrating strong local adaptation and zero environmental shock. Such stability not only maintains productivity but also supports high ecological yields and promotes rich associated biodiversity. The grains produced retain a balanced nutrient profile, contributing to both food and nutritional security.

Regenerative rice populations exhibit high phenological flexibility, with the capacity to adjust their maturity period according to seasonal and environmental variations. They possess a high buffering capacity against both biotic and abiotic stresses, supported by rich genetic variation. This diversity allows for the production of meiotic variants, giving rise to evolving populations that adapt naturally over time. Morphological traits such as leaf rolling capacity, straight and narrow leaves, varied leaf textures, and optimal stomatal density and size contribute to efficient photosynthesis, water management, and stress tolerance.

Plant architecture in regenerative rice further enhances its performance. Dense tillering combined with variation in plant and tiller height improves canopy structure and light interception. The root system is equally robust, characterized by long and deep roots, variation in root length, prolific root production, and the continuous ability to generate new roots and shoots. These root traits enhance nutrient and water uptake, improve soil structure, and strengthen resilience to drought and flooding. Collectively, these features demonstrate how rice, under Regenerative agriculture, becomes a dynamic, self-evolving, and ecologically balanced crop capable of sustaining both productivity and environmental health.

Farmer's practices that promote REGAGRI

Farmers play a central role in advancing and generating Regenerative agricultural practices that enhance biodiversity, restore soil health, and build resilient farming systems (Joshi.,2025b). One of the most impactful approaches is cultivating diversity-growing mixtures at both the species and landrace levels-which strengthens ecological interactions and reduces vulnerability to pests, diseases, and climate extremes. Crop diversification and crop rotation further enrich soil fertility, break pest and disease cycles, and optimize the use of available resources. Many farmers also practice mulching, which conserves soil moisture, regulates temperature, and suppresses weeds, while relying more on compost and farmyard manure (FYM) to replenish organic matter and maintain soil biological activity.

Water management is another cornerstone of regenerative farming. Through water harvesting, farmers capture and store rainwater for use during dry periods, ensuring crop growth while reducing pressure on natural water sources. The own seed cycle-saving, selecting, and replanting seeds each season-helps maintain locally adapted genetic resources and strengthens seed sovereignty. Farmers also integrate nature-positive practices in both production and storage, such as using botanical protectants and low-energy preservation methods to safeguard quality and reduce waste.

Many regenerative farmers operate within integrated farming systems and circular agriculture, where crops, livestock, and other enterprises are interconnected, ensuring that outputs from one activity become inputs for another. This contributes to a self-reliant agricultural system, reducing dependence on external inputs and enhancing farm sustainability. Underpinning all these practices is the wealth of traditional knowledge and skills that farmers have developed over generations-knowledge that guides decisions, fosters innovation, and ensures that agriculture remains both productive and harmonious with the surrounding ecosystem.

A Case of Australian Pines in Chitlang Goat Farm, Makwanpur

In the early 1990s, large areas of Chitlang in Makwanpur were planted exclusively with exotic Australian pines. While the initiative may have been intended for reforestation, within a few years several negative impacts became evident. Water scarcity emerged as a pressing issue, affecting both drinking water and irrigation supply. The pines' dense canopy and needle litter inhibited the growth of forages and grasses, depriving goats and other livestock of essential feed. The absence of broadleaf species also meant no leaf litter for compost production or livestock bedding, no firewood for household energy needs, and limited opportunities for plant diversity to flourish. Over time, the ecosystem was reduced to a very narrow range of species, resulting in a significant loss of biodiversity.

Recognizing these impacts, the Goat Development Farm and the local community held discussions and collectively appealed to the concerned authorities for the removal of the pines. After about five years of active removal, the agroecological system began to rebuild, revive, and restore itself. Natural water sources replenished, providing sufficient supply not only for the farm but also for two surrounding villages. Fodder availability improved dramatically, with large quantities of grasses and a variety of diversified fodder species emerging. Biodiversity levels increased, and the overall environmental quality of the area improved significantly.

This case demonstrates how replacing ecologically incompatible exotic species with more diverse, native, and regenerative vegetation can restore ecosystem services, enhance biodiversity, and improve livelihoods for both farmers and surrounding communities.

Keys of REGAGRI

The success of Regenerative agriculture (REGAGRI) depends on a set of core principles and strategies that integrate biodiversity, farmer participation, and ecosystem health (Rhodes., 2017). One of the fundamental keys is participatory research combined with site-specific technology development. This approach ensures that agricultural genetic resources (AGRs) and related technologies are made competent for local conditions, and that landraces-spanning crops, livestock, aquatic species, forages, and beneficial microbes- are genetically enhanced for improved resilience and productivity. Value addition through breeding is emphasized, alongside the establishment of diversity blocks, segregating lines, and genotype mixtures tailored to household needs. Cultivar mixtures are designed with eco-friends in mind, ensuring that coexisting species and varieties benefit each other.

Evolutionary breeding forms another pillar of REGAGRI. This involves site-specific breeding with a broad genetic base, often mixing and cultivating more than 10 landraces together. Such populations evolve under local environmental pressures, becoming increasingly climate-resilient and adapted to farmers' needs. Seed systems remain farmer-managed, ensuring that seed quality and diversity are maintained. Over time, evolutionary breeding leads to higher ecological yields, enhanced nutritional value, and stronger overall performance each season.

Ecological Pest Management (EPM) is also integral to REGAGRI. Instead of relying on chemical controls, EPM strengthens the farm ecosystem to manage pests naturally. This involves attracting, feeding, hosting, and nesting beneficial organisms; diversifying habitats; applying push-pull strategies; and maintaining healthy, biologically active soils. A strong and diverse farm ecosystem is more capable of suppressing pest outbreaks while supporting beneficial species.

Conservation through use is another key principle, recognizing that sustainable utilization is the best way to preserve local diversity. Successful actions under this approach include genetic enhancement and promotion of proso millet in Humla, foxtail millet in Lamjung, and beans in Dolakha through participatory plant breeding. Initiatives such as the development and distribution of Chino Kutak, identification and distribution of more than 50 elite lines, repatriation of over 500 accessions, diversification of products, and mechanization of harvesting systems demonstrate how conservation and utilization can work hand in hand.

Registration of native landraces by communities

In Nepal, the majority of farming communities have long practiced Regenerative agriculture, sustaining crop diversity through traditional and nature-positive methods. Many native landraces continue to be cultivated under these systems, maintained and improved by farmers themselves. A notable milestone in this process is the formal registration of 27 landraces belonging to 11 crop species across 18 districts, all led by the farming communities.

These landraces are generally produced following Regenerative agriculture principles, with communities taking full responsibility for seed selection, storage, and renewal. All activities-from planting to harvesting, seed saving to distribution-are owned and managed locally, ensuring that the genetic integrity and adaptive traits of each landrace are preserved. This community-led registration not only safeguards agricultural biodiversity but also strengthens local seed sovereignty, cultural heritage, and resilience in the face of climate and market challenges.

Community Genebank: An effective approach for promoting Regenerative agriculture:

A community genebank is a broad-spectrum system designed to conserve and utilize all six components of agrobiodiversity, making it a powerful tool for advancing Regenerative agriculture. It goes beyond a traditional seed repository to encompass multiple conservation units, including a seed bank, field genebank, agro-insect field genebank, agro-microbial field genebank, aqua pond genebank, livestock farm genebank, forage field genebank, school field genebank, and even agro gene sanctuaries that preserve entire ecosystems. Together, these components ensure that crops, aquatic resources, livestock, forages, beneficial insects, and beneficial microbes are conserved in living and functional forms.

Community genebanks are essentially networks, formed through the collective contribution of many household genebanks, each maintaining a portion of the local genetic heritage. By pooling these resources, communities safeguard diversity, ensure the availability of locally adapted genetic materials, and promote knowledge sharing.

Since agrobiodiversity is a cornerstone of Regenerative agriculture, community genebanks play a pivotal role in sustaining and expanding it. They provide farmers with a steady supply of diverse, resilient, and regenerative planting materials and other agricultural genetic resources, enabling production systems that are self-renewing, ecologically balanced, and resilient to environmental changes. In this way, community genebanks serve not only as biodiversity reservoirs but also as active engines for promoting and scaling Regenerative agriculture.

REGAGRI to ensure the Geographical Indication Tag

Geographical Indication (GI) is a crucial system that guarantees the quality and authenticity of products while providing significant monetary benefits to the producers and regional economy. To sustain the GI status of particular products, it is essential that these products are cultivated using Regenerative agriculture practices.

Products derived from exotic genotypes or grown with reliance on chemical inputs do not qualify for GI certification. Therefore, the adoption of REGAGRI-Regenerative agriculture-is mandatory to uphold the integrity and eligibility of products seeking or maintaining the GI tag. By ensuring that GI- tagged products are produced through sustainable and regenerative farming methods, we protect both the unique identity of the product and the long-term health of the environment.

Farmers' market to promote the products of Regenerative agriculture

Ensuring a reliable market for each product is essential for the success of Regenerative agricultureAgriculture. Farmers' markets serve as an effective strategy to secure direct access to consumers, establishing a strong link between primary producers and buyers. This direct connection not only promotes awareness and demand for products grown through regenerative practices but also helps farmers receive better prices by eliminating intermediaries. Ultimately, farmers' markets play a vital role in supporting and expanding Regenerative agriculture Agriculture by creating sustainable and profitable opportunities for producers.

Deep Regenerative agriculture

Regenerative agriculture is fundamentally farming in harmony with nature. Traditionally, agricultural practices have encompassed not only the biological and physical aspects of farming but also cultural, social, spiritual, and even astrological dimensions. However, with the advancement of modern agricultural science, many of these traditional practices have been largely overlooked.

Deep Regenerative agriculture seeks to blend traditional wisdom with contemporary scientific knowledge to sustainably enhance productivity (Figure 6). This holistic approach recognizes that farming practices vary significantly depending on local conditions-differing from site to site, caste to caste, and religion to religion. To fully realize the potential of deep Regenerative agricultureAgriculture, further scientific research and study are essential. Emphasizing and strengthening localized practices and technologies, rather than replacing them with exotic alternatives, is key to achieving sustainable, resilient, and high-yield farming systems.

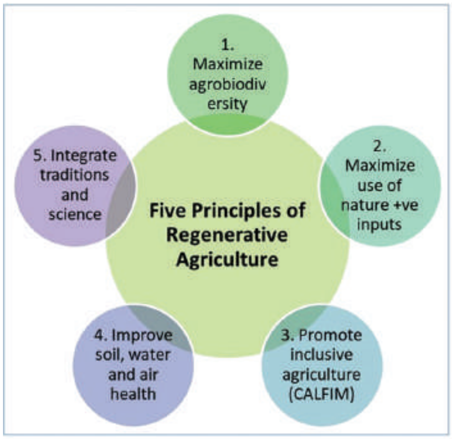


Figure 6. Principles of regenerative agriculture and components of deep regenerative agriculture

Challenges

One of the key challenges in Regenerative agriculture is the widespread use of storage and packing systems that are not nature-positive. Traditionally, living beings or their parts-such as seeds-were stored and preserved using natural materials like wood, clay, soil, bamboo, leaves, bark, and natural fibers. These materials supported the health and vitality of the stored items by maintaining a positive connection with nature.

Today, however, plastic-based storage and packing materials have largely replaced these natural alternatives. This shift has led to the near disappearance of eco-friendly storage practices and materials that are vital for sustaining the regenerative cycle. To overcome this challenge, there is a pressing need to revive and promote the use of natural storage and packing materials. Additionally, even ancillary items such as ropes and threads should be made from nature-positive sources to fully support sustainable, regenerative agricultural systems.

Conclusion

Building self-dependent farming households is key to creating resilient agricultural systems. Strengthening local systems and supporting localized innovations will empower communities to farm in harmony with nature-transforming fields, farms, and research areas into habitats that are friendly to agro-insects, agro-microbes, and birds. Promoting and utilizing site-specific genetic diversity allows farmers to harvest multiple products sustainably, ensuring both ecological balance and economic stability. By embracing these principles, we can make agriculture truly nature-positive. Let us commit to going local: working with local resources, respecting local traditions, and globalizing local knowledge. Avoiding mono genotype agriculture which is crucial to preserving biodiversity and preventing conditions that lead to pandemics. Together, we can foster a sustainable, diverse, and healthy future for agriculture and the planet.

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Chapter- 9

Regenerative Agroforestry: Pathways for Productivity, Resilience, and Sustainability

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Abstract

Agriculture faces the dual challenge of ensuring food security for nearly 10 billion people by 2050, while restoring degraded ecosystems and mitigating climate change. Regenerative agroforestry (RAF) represents a promising pathway by embedding Regenerative agriculture principles-minimal soil disturbance, organic amendments, continuous cover, diversification, and integration of perennials - into multifunctional tree - crop - livestock systems. This review synthesizes global and regional evidence on RAF, integrating meta-analyses, long-term trials, and institutional case studies. Results demonstrate consistent ecological and economic benefits: land equivalent ratios averaging 1.6 (up to 2.1 in degraded soils), soil organic carbon sequestration of 0.3 - 1.1 Mg C ha^{-1} yr^{-1}, biodiversity gains of 20–30%, runoff reductions of 50–70%, and net present values 2-3 times greater than cereals in fragile soils. Long-term studies confirm sustained carbon sinks, enhanced yields in Faidherbia parklands and Cacao agroforests, and resilience under climate stress. However, adoption remains constrained by tenure insecurity, gender inequities, high transaction costs, restrictive timber regulations, and elite capture of incentives. Scaling requires nested pathways: farm-level credit and tenure security; community-level FPOs and nurseries; policy reforms integrating agroforestry across sectors; market incentives through PES, carbon credits, and certification; and alignment with global frameworks such as the SDGs, Paris Agreement, and UN Decade on Ecosystem Restoration. Emerging frontiers include soil-microbe-carbon interactions, digital monitoring systems for payments, integrative modelling, and participatory valuation of ecosystem services. It can be concluded that RAF is a cornerstone nature-based solution that can simultaneously enhance productivity, regenerate ecosystems, and strengthen resilience, provided institutional and equity barriers are systematically addressed.

Keywords: ecosystem services; nature-based solutions; Regenerative agroforestry; scaling pathways; socio-economic barriers; sustainability transitions.

Introduction

Agriculture stands at a decisive crossroads. On one hand, it must produce sufficient food for a projected global population of 9.7 billion by 2050, while on the other, it faces escalating soil degradation, biodiversity loss, and climate instability (Lal 2006; FAO 2018).Conventional intensification, epitomized by the Green Revolution, delivered yield gains but at high ecological and social costs-nutrient mining, declining water tables, reduced agrobiodiversity, and growing greenhouse gas emissions (Davis et al., 2019). These crises are particularly acute in fragile agroecosystems such as the red and lateritic soils of South Asia, but they are symptomatic of global land-use transitions.

In response, Regenerative Agriculture (RA) has emerged as a paradigm that seeks not merely to sustain, but to actively restore ecological processes in production landscapes (Schreefel et al. 2020; Schulte et al. 2022; Prairie et al. 2023). Its guiding principles include minimal soil disturbance, organic amendments, continuous cover, diversification, and integration of perennials or livestock (Hajji-Hedfi et al., 2025). Unlike conventional agroforestry, which primarily focuses on productivity, regenerative agroforestry (RAF) is about regeneration (Azhar et al., 2024). Instead of working against nature, the farmer worked with it, integrating trees, crops, and livestock in a way that mimicked natural ecosystems. It helps rebuild soil, increase biodiversity, and even fight climate change. Recent evidence challenges the notion that agroforestry's benefits are anecdotal or context-specific. Meta-analyses demonstrate statistically robust outcomes: maize yields increase by 7% globally under agroforestry, with up to 60% gains where nitrogen-fixing species are included (Baier et al. 2023). In European alley-cropping, cereal yields decline by ~2.6% per year after canopy closure, but total system productivity remains positive when carbon and timber are included (Kay et al. 2019). A global review found SOC gains of 0.3–1.1 Mg C ha^{-1} yr^{-1} across systems (De Stefano & Jacobson, 2018; Kiran et al., 2023; Mayer et al., 2022). These results provide a quantitative foundation for RAF as a nature-based solution.

This review synthesizes global and regional evidence on RAF, moving beyond descriptive documentation. Specifically, it:

1. Develops a conceptual framework linking regenerative principles, ecological processes, and socio-economic outcomes.
2. Classifies RAF systems in multifunctional terms.
3. Synthesizes meta-analytical and long-term empirical evidence of ecological and economic outcomes.
4. Analyses socio-economic and institutional barriers, highlighting gender and tenure dynamics.
5. Identifies scaling pathways and policy integration models.
6. Outlines research frontiers and methodological innovations.

By combining quantitative synthesis, mechanistic insight, and institutional analysis, this review situates RAF as a cornerstone for reconciling productivity, regeneration, and resilience.

Conceptual Framework of Regenerative Agroforestry

RAF operationalizes these principles by embedding trees and shrubs within farming systems, delivering ecological services such as carbon sequestration, nutrient cycling, and biodiversity support alongside diversified livelihoods (Elevitch et al., 2018). Through intentional design, trees interact with crops and livestock to deliver ecological processes (carbon sequestration, nutrient cycling, biodiversity habitat, water regulation), which in turn underpin socio-economic outcomes (yield stability, income diversification, resilience, and food–nutrition security).

Canopy cover reduces soil temperature by 2–3°C and increases humidity by 5–10%, buffering crops against climate stress (Torralba et al. 2016). Tree litter inputs contribute 1–3 t C ha^{-1} yr^{-1} to soils, driving SOC accumulation (Montagnini & Nair, 2004). Root exudates and microbial interactions increase microbial biomass carbon by 20–35% (Barrios, 2007). Multi-layered home gardens diversify diets, raising dietary diversity scores by 30–40% (R. Jamnadass et al., 2013).The framework (Figure 1) positions RAF as a bridge between ecological processes and livelihood outcomes.

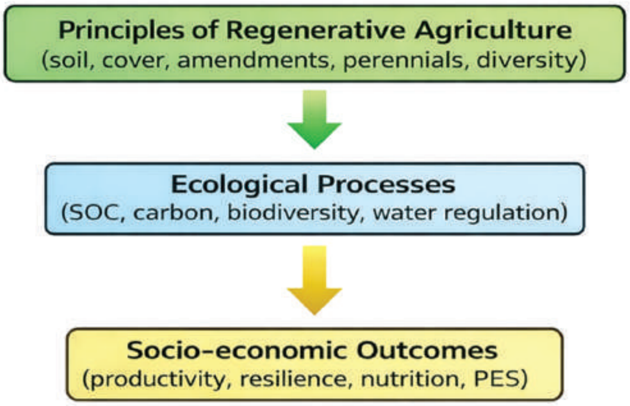

Figure 1. Conceptual framework of RAF

Classification Of Agroforestry Systems

Agroforestry systems are highly diverse. Traditional classifications (Nair, 2014)focused on structure. A regenerative lens instead emphasizes multifunctionality across ecological and socio-economic dimensions. Major types include:

- Agrisilviculture (crops + timber/fuel trees): improves soil fertility, controls erosion, and delivers long-term timber income (Bijalwan et al., 2009; Kumar et al., 2024).
- Agri-silvi-horticulture (crops + fruits + timber): buffers microclimates, enhances SOC, and provides staggered incomes (Biswas et al. 2022, 2026).
- Silvi-/horti-pasture (trees/orchards + fodder grasses + livestock): increases livestock productivity and SOC (Greene et al. 2023).
- Alley cropping (crops between leguminous hedgerows): increases maize yields by 30–50% and reduces fertiliser use (Abunyewa et al., 2004; Danso & Morgan, 1993).
- Boundary/contour planting: reduces erosion by 50–70% (Nasir Ahmad et al., 2020).
- Block plantations: accumulate biomass and carbon, with sequestration rates of 0.3–0.6 Mg C ha^{-1} yr^{-1} (Prabha & Surya, 2022).
- Energy plantations: deliver biofuel while sequestering 2–3 t C ha^{-1} yr^{-1} (Kay et al. 2019).
- Homegardens: multilayered systems that enhance biodiversity and nutrition (R. Jamnadass et al., 2013).

Table 1 presents the classification of Regenerative Agroforestry (RAF) systems based on their dominant ecological functions and socio-economic outcomes. The systems range from agrisilviculture and agri-silvi-horticulture to homegardens and energy plantations, reflecting structural and functional diversity. Ecological benefits include nutrient cycling, soil organic carbon (SOC) enhancement, erosion control, biodiversity conservation, and carbon sequestration. Socio-economic outcomes span timber and fruit income, diversified harvests, improved livestock productivity, stable cereal yields, renewable energy production, and Payment for Ecosystem Services (PES). Overall, the table highlights how RAF systems integrate ecological restoration with livelihood enhancement, supporting productivity, resilience, and sustainability.

Table 1. Classification of RAF systems

System Type	Ecological Functions	Socio-economic Outcomes
Agrisilviculture	Nutrient cycling, erosion control	Timber income
Agri-silvi-horticulture	SOC, microclimate buffering	Diversified harvests
Silvi-/horti-pasture	Fodder supply, biodiversity	Improved livestock productivity
Alley cropping	N fixation, erosion control	Stable cereal yields
Boundary planting	Soil & water conservation	Fruit, fodder, timber
Block plantations	Carbon sink, biomass	Timber/PES income
Energy plantations	Renewable energy	Biofuel markets
Homegardens	High biodiversity, nutrient cycling	Food, nutrition, cultural values

Evidence Synthesis: Ecological And Economic Outcomes

Productivity and land-use efficiency

Meta-analyses show RAF consistently increases productivity per unit land. The global average Land Equivalent Ratio (LER) is 1.6, with values above 2.0 in degraded soils (Martin-Guay et al., 2018). Indian long-term trials in lateritic soils reported LER > 2.1 with timber–fruit–legume combinations (Biswas et al., 2022, 2026). By contrast, in European alley cropping, cereal yields declined ~2.6% annually post-tree establishment, requiring canopy management to sustain complementarity (Kay et al. 2019).

Soil organic carbon and fertility

SOC sequestration is one of the most consistent benefits. Global reviews show accumulation of 0.3–1.1 Mg C ha^{-1} yr^{-1}, with larger gains in tropical systems and degraded soils (Cardinael et al., 2019; Sharma et al., 2022). SOC gains extend below 30 cm depth, especially under broadleaved species, which enhance subsoil carbon more effectively than conifers (Kay et al., 2019).

Water regulation and erosion control

RAF improves infiltration by 30–50% and reduces surface runoff by 50–70% in contour-based systems (Kugedera et al., 2025). This enhances water-use efficiency, especially in semi-arid zones where shading and mulching reduce evaporative losses.

Biodiversity and ecosystem services

Agroforests increase pollinator and bird species richness by 20–30%, maintaining ecological functions essential for production (Torralba et al. 2016). In Latin America, shaded coffee and cacao agroforests maintain biodiversity levels comparable to secondary forests (Montagnini & Nair, 2004).

Economic outcomes

RAF provides diversified income streams:

- Short-term: annual crops supply cash and food.
- Medium-term: fruits and fodder add resilience.
- Long-term: timber and PES generate asset value.

In West Africa, Faidherbia parklands boosted maize yields 40–100%, lowering fertiliser costs (ICRAF, 2020). Silvopastoral PES in Latin America delivered USD 50–150 ha^{-1} yr^{-1} in carbon income.

Trade-offs and synergies

While trees may compete for light and water, evidence shows trade-offs can be converted into synergies through:

- Temporal complementarity (annuals provide food security until trees mature) (Biswas et al. 2022).
- Species selection (N-fixers increase maize yields by 60%: Baier et al. 2023).).
- Pruning regimes (increase maize by 0.5 Mg ha^{-1}: Baier et al. 2023).
- Optimal tree canopy thresholds (~15–30%) for balancing yield and services (Torralba et al., 2016).

Long-term Empirical Evidence

Short-term studies often exaggerate or underestimate RAF benefits due to establishment lags or initial management intensity. Long-term experiments provide more robust insights into cumulative effects on soil, productivity, and livelihoods. Table **2** highlights long-term RAF studies across regions, demonstrating sustained ecological and economic gains. In Jhargram (India), SOC doubled with higher LER and NPV. Sahel parklands boosted maize yields, Latin American agroforests conserved biodiversity with stable income, and European alley cropping enhanced carbon sinks despite slight unmanaged yield declines.

Table 2. Selected long-term RAF studies

Region	System	Duration	Outcomes
India (Jhargram)	Timber–fruit–legume	10 yrs	SOC doubled; LER 2.1; NPV 2–3× cereals
Africa (Sahel)	Faidherbia parklands	Multi-decadal	40–100% ↑ maize yields
Latin America	Cacao/Coffee agroforests	Multi-decadal	Biodiversity ≈ secondary forests; stable income
Europe	Alley cropping	>15 yrs	Carbon sinks; cereal yield ↓ 2.6% yr^{-1} (unmanaged)

In India's red and lateritic soils, >10-year experiments with timber–fruit–legume systems showed SOC doubled (0.35% → 0.7%) and LER exceeded 2.0, while net present value (NPV) was 2–3× higher than monocropped cereals (Biswas et al., 2022). Boundary plantations reduced erosion by 60%, stabilising fragile uplands.

In sub-Saharan Africa, Faidherbia albida parklands improved maize yields by 40–100% after canopy leaf fall provided seasonal fertilisation, cutting fertiliser needs by 25–50% (Baier et al., 2023; ICRAF, 2020). Across the Sahel, multi-decadal regeneration of on-farm trees enhanced drought resilience and food security (Bayala et al., 2020).

In Latin America, shaded cacao and coffee agroforests maintained biodiversity levels comparable to secondary forests while providing stable incomes. Long-term monitoring in Costa Rica showed carbon sequestration of 2–4 Mg C ha^{-1} yr^{-1} and significant pollination services (Greene et al., 2023; Montagnini & Nair, 2004).

In Europe, alley cropping trials (>15 years) revealed consistent carbon gains but yield declines of 2.6% yr^{-1} in cereals when canopy was unmanaged. Yet, when timber, carbon, and biodiversity were accounted for, system multifunctionality remained positive (Kay et al., 2019; Torralba et al., 2016).

These cross-regional cases show RAF outcomes are context-dependent but consistently beneficial when long-term ecological processes and diversified income streams are considered. Table 3 synthesizes global meta-analytical evidence showing that RAF systems outperform monocultures ecologically and economically. Average LER is 1.6, SOC sequestration ranges from 0.3–1.1 Mg C ha^{-1} yr^{-1}, biodiversity increases by 20–30%, runoff declines by 50–70%, and net present value (NPV) is 2–3 times higher in degraded soils.

Table 3. Meta-analytical evidence of ecological and economic outcomes

Indicator	Global Evidence
Land Equivalent Ratio (LER)	1.6 avg (up to 2.0 in degraded soils)
SOC sequestration	0.3–1.1 Mg C ha^{-1} yr^{-1}
Biodiversity richness	20–30% ↑ vs. monocultures
Runoff reduction	50–70% ↓ runoff
NPV	2–3× ↑ vs. cereals in degraded soils

Ecosystem services from raf: framework and critical gaps

Multifunctionality through ecosystem services

RAF provides provisioning (food, fodder, timber), regulating (carbon, erosion control, microclimate), supporting (nutrient cycling, pollination), and cultural (spiritual, dietary diversity, traditional knowledge) services (Millennium Ecosystem Assessment, 2005). Its added value lies in bundled services, where one practice delivers multiple benefits. Figure 2 shows that RAF delivers strong ecological gains across regions. India and Latin America exhibit higher yield (LER) and biodiversity improvements, while Africa shows moderate gains. Europe records comparatively lower values. SOC sequestration remains consistent across regions, highlighting RAF's global potential for enhancing productivity, carbon storage, and biodiversity.

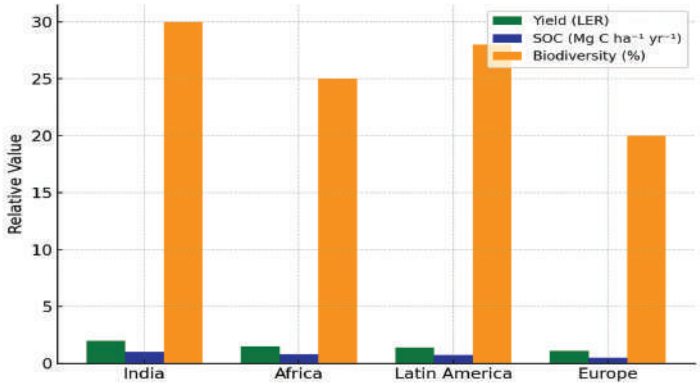

Figure 2. Global evidence: RAF impacts by region

Quantitative valuation

- Carbon: sequestration ranges 0.3–1.1 Mg C ha^{-1} yr^{-1} (Cardinael et al., 2019; Sharma et al., 2022).
- Soil fertility: SOC increases 0.3–0.5% per decade under RAF (Biswas et al., 2026).
- Water regulation: 30–50% higher infiltration; 50–70% lower runoff (Kuyah et al., 2019).
- Biodiversity: 20–30% higher species richness (Torralba et al., 2016).
- Nutrition: homegardens raise household dietary diversity by 30–40% (R. H. Jamnadass et al., 2011).

Economic valuation of services

Provisioning services dominate cost–benefit analyses, but regulating and cultural services remain undervalued. Emerging valuation methods include:

- Carbon credits: silvopastoral systems yield USD 50–150 ha^{-1} yr^{-1} (Raj et al., 2025).
- Watershed PES: schemes in Costa Rica and Kenya show strong willingness-to-pay (Cremaschi et al., 2012).
- Participatory valuation: useful for cultural services (Catacutan & Naz, 2015).

Gaps

1. Non-market services (erosion, biodiversity) rarely monetised.
2. Trade-offs poorly modelled—few dynamic tools capture service interactions.
3. PES equity risks—up to 58% of benefits captured by elites (Singh et al., 2025).
4. Lack of standardised indicators hampers national integration into NDCs and SDGs.

Socio-economic and institutional barriers

RAF adoption depends more on institutions and equity than on biophysical feasibility (Singh et al., 2025).

- Land tenure: 24% of households cite tenure insecurity as a barrier; women face restrictions in tree planting under customary systems (Doss & Meinzen-Dick, 2020).
- Labour and gender: establishment labour is high; women's participation raises adoption by 20% but they remain excluded from markets (R. H. Jamnadass et al., 2011).
- Finance: high upfront costs deter smallholders; PES transaction constitute a significant share of total payments (Mayr et al., 2025).
- Policy silos: agroforestry is caught between forestry and agriculture ministries; restrictive timber policies (e.g., sandalwood in India) reduce adoption (Jinger et al., 2023).
- Elite capture: PES and subsidies disproportionately benefit large landholders (58% in Kenya: (Minoia, 2020).

Comparative evidence shows enabling reforms (e.g., liberalising tree harvest in Haryana, India) increase adoption dramatically. The principal socio-economic and institutional barriers to RAF adoption. About 24% of households face tenure insecurity, while women's decision-making increases adoption by 20% (Table 4). High upfront investments, PES transaction costs exceeding 40%, restrictive timber laws, and elite capture (58%) further limit equitable and widespread scaling.

Table 4. Socio-economic and institutional barriers to RAF adoption

Barrier	Quantitative Evidence
Tenure insecurity	24% households cite as barrier
Labour/gender roles	20% ↑ adoption with women's decision-making
Financial constraints	High upfront costs; PES transaction costs >40%
Policy silos	Restrictive timber laws reduce adoption
Elite capture	58% report elite capture of PES

Scaling Pathways and Policy Integration

Table 5 illustrates the multi-level scaling pathways of RAF. At the farm level, credit access, extension support, and tenure security are critical. Community institutions such as FPOs, nurseries, and cooperatives strengthen collective action. Policy reforms, market instruments like carbon credits and PES, and alignment with SDGs, NDCs, and UN Decade frameworks enable broader adoption and impact.

Table 5. Scaling pathways of RAF

Level	Enablers
Farm	Credit, extension, tenure security
Community	FPOs, nurseries, cooperatives
Policy	Timber policy reform, subsidies
Markets/Finance	Carbon markets, PES, certification
Global	SDGs, NDCs, UN Decade frameworks

Farm level

Adoption depends on credit, tenure, and extension. Surveys show adoption averages 15–20% of households in Africa, but rises above 30% where enabling policies exist (Miller et al., 2020). In India, adoption increased 5–6× following timber policy reforms (Jinger et al., 2023).

Community level

FPOs and nurseries reduce transaction costs. In Malawi, community nurseries cut seedling costs by 40% (Nyoka et al., 2018). Cooperatives in Latin America linked agroforestry to organic certification, boosting premiums by 20-30%.

Policy and institutional integration

- India's 2014 National Agroforestry Policy created enabling frameworks but faces weak implementation (Jinger et al., 2023).
- Brazil incentivised cacao agroforests through tax and credit (Montagnini & Nair, 2004).
- Rwanda mainstreamed agroforestry into NDCs, linking adoption to climate finance (CPI & FAO, 2025).
- Europe's CAP provides agroforestry subsidies, but uptake is low (~3% of land) due to mechanisation constraints (Kay et al., 2019).

Markets and finance

PES and carbon credits provide tangible incentives. Verified silvopastoral systems generate 3–6 t CO_2 ha^{-1} yr^{-1} tradable credits (Schettini et al., 2021). Certification premiums (organic, fair-trade) raise farmer incomes 20–40% (Ansah et al., 2026). Green bonds and blended finance are emerging in Asia, linking institutional investors to RAF adoption.

Global integration

RAF aligns with SDGs (Zero Hunger, Climate Action, Life on Land), Paris Agreement commitments, and the UN Decade on Ecosystem Restoration. Integration into national accounts and NDCs would formalise RAF as a recognised mitigation and adaptation pathway.

Gaps

1. Lack of national monitoring systems for agroforestry adoption.
2. Inequitable benefit distribution in PES and certification.
3. Persistent policy silos across ministries.
4. Limited use of digital platforms for scaling and MRV.

Research Frontiers and Methodological Innovations

To move from descriptive to predictive and actionable science, RAF research must adopt new methods:

- **Soil–plant–microbe interactions:** isotope tracing (^{13}C,^{15}N), metagenomics, and radiocarbon dating to quantify carbon pools (Freckman et al., 1997).
- **Systems modelling:** ABMs for farmer behaviour, LCAs for system footprints, IAMs for climate integration (Barrios, 2007).
- **Remote sensing & digital tools:** satellites, LiDAR, UAVs, and mobile apps for MRV and PES payments (ICRAF, 2020).

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- **Remote sensing & digital tools:** satellites, LiDAR, UAVs, and mobile apps for MRV and PES payments (ICRAF, 2020).

- **Socio-economic innovations:** participatory valuation, RCTs of tenure and PES interventions (Kiptot et al., 2014).
- **Integrative frameworks:** One Health (linking soil, nutrition, health), food-energy-water nexus (Yupanqui et al., 2025).
- **Critical research questions include:** thresholds for tree density and pruning, microbial mediation of SOC stabilisation, digital MRV for PES, and gendered labour trade-offs.

Land tenure and property rights

RAF requires long-term investment in trees. Insecure tenure discourages farmers, as they risk losing both trees and land. Studies show that 24% of households cite tenure insecurity as their primary barrier. Women, in particular, face restrictions: in sub-Saharan Africa, customary systems often prevent women from planting or harvesting trees (Tantoh et al., 2026). In India, fragmented landholdings and restrictive timber policies (e.g., sandalwood, teak) limit adoption. Conversely, reforms in Haryana and Madhya Pradesh liberalising timber harvest rules led to widespread tree planting.

Labour demand and gendered roles

RAF establishment is labour-intensive. Women typically manage food crops, home gardens, and small livestock, linking RAF to nutrition outcomes (R. H. Jamnadass et al., 2011). Men dominate timber marketing and access to extension services. In Uganda, households where women had decision-making roles had 20% higher adoption rates and improved dietary diversity (Castle et al., 2022).

Financial constraints and market failures

High upfront costs and delayed tree returns deter smallholders. PES schemes are promising but transaction costs may exceed 40% of payments (Sheikh et al., 2025). FPOs and cooperatives reduce costs, yet coverage is uneven. Perishable agroforestry products (fruits, fodder) require cold storage and transport infrastructure, which remain scarce in many rural areas (ICRAF, 2020).

Policy silos

Agroforestry straddles agriculture, forestry, and environment ministries. Fragmentation leads to contradictory regulations-forestry departments restrict harvest, while agriculture departments push yield maximisation (Kay et al., 2019). Comparative cases show streamlined policies boost adoption: Brazil's integration of agroforestry into tax and credit incentives catalysed cacao agroforests (Montagnini & Nair, 2004).

Elite capture and inequity

Without safeguards, RAF scaling risks reinforcing inequalities. In Kenya, 58% of PES adopters reported elite capture, with wealthier farmers dominating benefits (Oduor, 2020). Women, tenants, and smallholders are often excluded.

Implications

RAF barriers are not technical but institutional and equity-driven. Addressing them requires tenure reforms, gender-responsive extension, low-cost finance, and harmonised policies. Table 4 summarises evidence-based barriers.

Conclusions and Way Forward

RAF demonstrates that productivity and ecological regeneration are not mutually exclusive. Evidence shows:

- Productivity gains (LER averages 1.6, up to 2.1 in degraded soils).
- SOC accumulation (0.3–1.1 Mg C ha^{-1} yr^{-1}).
- Biodiversity increases (20–30% vs monocultures).
- Diversified incomes through crops, fruits, timber, PES, and certification.

  The novelty of this review is its integration of quantitative meta-analyses, long-termevidence, mechanistic insights, and institutional dynamics.

The way forward requires:

- Policy integration: harmonise forestry and agriculture, embed RAF in NDCs.
- Equity safeguards: ensure gender, tenure, and smallholder inclusion.
- Monitoring innovation: digital MRV systems for PES and carbon.
- Research expansion: predictive tools, nexus frameworks, participatory approaches.
- Global positioning: treat RAF as a cornerstone of nature-based solutions under SDGs and Paris Agreement.

The challenge is no longer proving RAF's benefits, but designing scalable, equitable, verifiable pathways for global adoption.

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Chapter - 10

Crop-Livestock Integration & Regenerative Agriculture in Pakistan

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Introduction

The Need for Integration and Regeneration

Pakistan has a diversified economic base with the agriculture sector, contributing 24 percent in GDP and 37.4 percent in employment. The agriculture sector in Pakistan witnessed. robust growth in 2023-24, with an overall increase of 6.25 percent. Notably, the crops saw a remarkable growth of 11.03 percent, a significant improvement compared to the previous year. The livestock sub-sector maintained steady growth, increasing by 3.89 percent, slightly higher than its growth in the previous year. This indicates sustained and stable performance in livestock production and underscores the vitality of mixed crop-livestock production systems for livelihoods and food security in the country. The national livestock population has shown an upward trend, with 2024 estimates indicating 57.5 million cattle, 46.3 million buffalo, 32.7 million sheep, and 87 million goat heads. This trend suggests increasing demand for milk and meat, with a predominant of mixed farming smallholder farmers (Ministry of Finance, 2024).

Climate change induced hazards (like the devastating flood in 2022 destroying Kharif crops) are endangering the livelihood and food security of mix farming communities due to vulnerable nature of conventional system of farming (FAO/GIEWS, 2022). Crop livestock integration and regenerative agriculture are ways of good agriculture practices which offers solutions to complicated problems like nutrient recycling (manure → crops and crop residues → livestock) income diversifications, soil health improvement and water harvesting, and heat tolerant, drought resistant and flood resilience. These practices are in line with the guidance of Food and Agriculture Organization's (FAO's) regarding sustainability, food security and livelihood of communities involved in integrated mix farming system (FAO, 2026).

The Case for Integrated Crop–Livestock System (ICLS)

Agronomic and economic complementarities

Preliminary studies in Punjab province involving 360 farming households have shown that integrated crop–livestock farming household make statistically significant higher incomes compared to specialized farmers involved in either in crop only or livestock only farming. The mix crop-livestock farmers earn an additional 791 PKR per household indicating not mere agronomic benefits but also economic impacts. It has been demonstrated that the ICLS on the global as well as local Pakistani context promotes diversity, recycles nutrients, and stabilizes cash flows which are the benefits as highlighted by FAO's Plant Production and Protection Division (Fares et al., 2025; FAO, 2026). Furthermore, institutional elements strengthen these benefits as a paper in Punjab province have reported that extensive extension services, demonstrative trails, access to credits, and land ownership rights positively influenced sustainable land management adoptions for example farmyard manuring, and agroforestry with a noticeable enhancement in soil fertility (Sheikh et al., 2024).

Nutrient Cycling and Manure management

The gap between crop potential and yield in Pakistan is partly due to imbalanced NPK utilization and minimum recycling of bio-supply (manure/excreta). It was found that synthetic fertilizer use combined with low bio-supply recycling resulted in a substantial gap between nutrient supply and P and K crop needs, which would cost 3 billion USD to fill with synthetic fertilizers. If all bio-supply was recycled, it could eliminate K synthetic fertilizer needs and decrease N synthetic fertilizer needs to 43% of what was purchased in 2010. Farm level composting and optimal manure processing and management are practical climate smart techniques and methods to reduce the cost and improve soil organic composition (Nazir, 2022; Akram et al., 2018).

Regenerative Initiatives Globally

Many high-impact projects are promoting practice of Regenerative agriculture globally. In 2025 InterAmerican Institute for Cooperation on Agriculture (IICA) in partnership with Bayers, launched a training initiative that ambitiously want to benefit 100 million smallholder farmers in the Americas, India, and Africa. The training is being delivered in five languages, including Hindi, English, Spanish, Portuguese, and Swahili, on a range of regenerative topics and methods like cover cropping, rotational crop-livestock Integration, and management of soil and environmental health. The main objectives of this initiative are to foster rural communities' resilience, reverse the degradation of soil and environmental health, conserve biodiversity, and promotion of inclusive value chains (Anonymous 2024).

The South American Regenerative Agriculture (SARA) initiative in Latin America is aiming to bring 120,000 hectares of land under regenerative grazing, with a future expansion plan to 500,000 hectares under the Verra carbon methodology. SARA, based in Chile, Argentina, and Paraguay, supports farmers in preventing pasture degradation, fostering water harvesting, improving the carrying capacity of pastures, and creating carbon credits. The initiative aims to fix one million tonnes of carbon annually. Adding to this, Embrapa, which is a Brazilian research organization in cooperation with IICA and Brazilian Cooperation Agency (ABC), is replicating the Brazilian regenerative success model in Africa with a core focus on tropical soil enrichment, promoting agroforestry, and fostering regional resilience through South-South cooperation (Geert, 2024; Emmanuel, 2025).

Regenerative Agriculture (RA) Principles and Evidence in Pakistan

Regenerative agriculture is based on the principle of minimized soil disturbance, permanent cover, diversified crop rotations, input of organic matters, and grazing management to restore soil health, carbon sequestration, and water management improvement (Khetran, 2024).

Pilots and programs

World bank in collaboration of NARC piloted a wheat trial in 20221/22 to compare raised beds with mulching (organic) and precision planting without any synthetic inputs to conventional drill and broadcast system. Regardless of lower seed delivery due to planter error the profit of regenerative plots was more comparable to the conventional plots due to decreased input costs as the yield shortfall stood at just around 15%. Also, WWF project ‘Pakistan Regenerative Production Landscape Collaborative’ is an innovative sectoral model to foster agricultural ecosystems that conserve and enhance natural resources and build community resilience whilst enabling businesses to source responsibly. It is striving to build multi-stakeholder governance and enabling farmers organizations to scale up Regenerative agriculture with benefits for soil health, livestock production, water security and livelihood of farmers (WWF-Pakistan, 2024; World Bank, 2023).

Fodder Integration, Intercropping & Year-Round Forage

Intercropping offers farmers the opportunity to engage nature's principle of diversity on their farms. Intercrops can be more productive than growing pure stands. Many different intercrop systems are being practiced in the country, including mixed intercropping, strip cropping, and traditional intercropping arrangements in the country. For example, landholdings in Pakistan's mountainous Northern Areas are minute, farmers aim to maximize production per unit of area per season. An integrated approach that complements rather than competes with the existing farming system is needed. Forage production and availability have been affected by sole cropping vs. intercropping of forage legumes with cereals. To obtain early and good yields on small holdings under severe winter conditions, compatible fodder crops can be planted in mixtures to produce high fodder yields with good quality. Leguminous dwarf fodders like berseem can be mixed with taller species such as oats, ryegrass, brassicas etc. Lucerne is considered one of the most important leguminous fodder crops in Pakistan's Northern Areas. Important priorities for future research include evaluating the potential for suitable cash cropping, promoting intercropping of potential fodder crops that might provide a more ensured/continuous supply over the winter, and improving the nutritional content of animal diets with, for example, the introduction/evaluation of improved alfalfa and fodder oats (Muhammad and Ates, 2023).

Another study aimed to evaluate the effects of Wheat-Berseem strip intercropping on various soil organic carbon (SOC) pools, soil biochemical properties, plant growth, yield, and nutrient uptake, with a focus on its potential for improving carbon sequestration and land use efficiency and found Wheat-Berseem intercropping as a promising agroecological approach that improves SOC sequestration, nutrient dynamics, and resource use efficiency, supporting long-term soil fertility and sustainable crop production (Iqbal et al., 2025).

Climate Resilience & Risk Management

The 2022 flash floods destroyed millions of acres of crops and livestock assets, stirring an acute food insecurity as approximately 800,000 livestock animals perished which was a critical source of nourishment and livelihoods for rural communities. In addition to that, 2 million acres of crops and orchids was destroyed. The toll the 2022 Floods have taken on Pakistan's economic and food security is definitive now (Laghari & Salman, 2022).

Pakistan is a case of double injustice adding a tiny share of global greenhouse gases, yet it is bearing the effect of global climate change impacts. It places among the top 10 countries vulnerable to climate change. The 2022 IPCC Report underlines the heightened vulnerabilities because of global warming and climate change leading to more floods. As per the Asia-Pacific Disaster Report 2022, Pakistan could lose more than 9 percent of its annual GDP due to climate change. The Notre Dame Gain Matrix2 ranked Pakistan the 5th most impacted country by climate change shocks and is positioned as the 36th least-prepared nation to cope with climate changes. The combination of reduced crop yields, water scarcity, and changing agricultural practices can lead to severe food insecurity and economic challenges for marginalized communities and more importantly, for farmers.

Agriculture sector is the largest contributor to GHG emissions in Pakistan with a share of 41 percent, primarily through livestock rearing and cropland. These two sub-sectors represent 78 percent and 22 percent of total agricultural GHG emission respectively. This makes agriculture sector a priority area for Pakistan in tackling climate change. Considering this background, numerous climate smart agricultural initiatives, such as, changing planting dates, soil conservation practices (zero tillage), water management techniques for example drip and sprinkler irrigation, alternate wetting and drying, crop rotation and diversification, mix farming, promotion of new crop varieties etc. have been employed. Policies and legislation framework are currently under implementation across the country that enable and support adaptation of climate smart activities providing a conducive ground for future actions (Rana & Gill, 2024). Climate-smart practices like diversified rotations, residue cover, agroforestry, improved water management, and early warning need to be advanced and regenerative and integrated approach need to be adopted.

Agroforestry & Silvopasture: Integrating Trees, Forages, and Livestock

Agroforestry presents a sustainable and economically viable solution to Pakistan's pressing agricultural and environmental challenges. By integrating trees with crops and livestock, it enhances soil fertility, conserves water, mitigates climate change, and diversifies rural income sources. With agroforestry already practiced on 19.3 million hectares, scaling up its adoption can significantly contribute to food security, economic stability, and ecological resilience.

Despite its potential, agroforestry remains underutilized due to financial constraints, lack of awareness, and weak market linkages. Addressing these barriers through targeted policies, financial incentives, capacity-building programs, and research investments can unlock its full benefits. Strengthening value chains and facilitating market access for agroforestry products will further enhance rural livelihoods and national economic growth.

A well-structured agroforestry strategy, supported by government initiatives, private sector participation, and community engagement, can drive long-term environmental and economic sustainability. As Pakistan faces increasing climate risks and agricultural challenges, prioritizing agroforestry can ensure a resilient future for its farming communities while fostering sustainable rural development (Abbas,2025). Silvopasture purposely manages trees, forage, and grazing livestock for production and environmental services (shade, microclimate, nutrient cycling, carbon). Scientific studies show silvopasture promote animal performance, quality of forage, and ecosystem services, while involving cautious light and grazing management (Jose & Dollinger, 2019).

Policy Landscape & Emerging Initiatives

The Pakistan Economic Survey 2023-24 highlights agriculture growth (6.25%) and livestock growth (3.89%). Ministry of Finance statistics prove the livestock sector's vitality and growing milk/meat production and demand. Pakistan Agricultural Research Council (PARC) and NARC led technology demonstration pilots and dissemination for crops, natural resources, and animal sciences. Future livestock policy interventions underline improving feed resources, breed improvement, health interventions, extension services, and marketing channels which are grave for ICLS success. Under Special Investment Facilitation Council (SIFC), the Green Corporate Livestock Initiative (GCLI) is revolutionizing breeding (through the IVF labs), launching aquaculture policy, and promoting gender-inclusive digital policies thus creating conducive environment for integrated, climate-smart agriculture. Besides PARC have started laparoscopic Artificial Insemination (AI) for the improvement of small ruminant production which is central to integrative approach (Anonymous, 2025; Ministry of Finance, 2024).

Design & Implementation Framework for Pakistan

Livestock integration

Dairy buffalo and cows are stall-fed using on-farm fodder (like maize berseem, and cowpea cycle), crop residues including wheat straw, and cotton stalks where safe, fodder trees like Acacia, Leucaena in suitable sites, and manure utilization for composting and biogas slurry application (Mohammad & Ates 2023; Onte et al., 2025).

Grazing/trees

Establish pilot silvopasture demonstration sites with density of trees and species of forages adapted to light regime and rotational grazing for animal welfare and tree protection thereby promoting pasture health and environmental protection.

Barriers and Practical Solutions

Residue burning & Zero tillage

Pilot studies have demonstrated that Zero tillage with straw retention improve yield and soil benefits. It is recommended that there should be subsidies/credit targeted for machinery like planters and recyclers etc. which will increase the adoption of these practices (Khan et al., 2022; Niamat et al., 2021).

Fodder deficits

There is a dire need to promote cultivation of cereal–legume intercropping and promotion of fodder species with multi-cuts. Also need to increase the area under berseem in winters and maize-cowpea in summer. There is a need to link the peri-urban dairying to silvopasture (Dost & Ates, 2023; Onte et al., 2025).

Institutional gaps

There is a need to scale up extension services and demonstration plots and improve the land ownership rights and provide financial incentives which is a predictor of adoption of good practices on sustainable basis (Sheikh et al., 2024).

Climate shocks

There is a need for diversification of cropping patterns for climatic shocks and climate smart livestock production. Community level grains and fodder bank and crop mappings is recommended strongly (Mushtaq et al., 2022; Rana & Gill, 2024).

Conclusion

The resilience and profitability of Pakistan agriculture sector is linked to the strengthening crop-livestock integration and widespread dissemination and adoption of regenerative practices. There is increasing evidence as shown by demonstration pilot studies at national and provincial level that ICLS/RA can enhance livelihood of farmers decrease soil degradation and soil restoration and enhances water harvesting and act as a barrier to climate induced hazards. There is a need of concrete coordinated efforts at all levels for the adoption of these nature-based solutions. Livestock is already playing a central role in the agriculture landscape and integrating Regenerative agriculture with the mix systems of integrated crop livestock farming van reap immense benefits not for just people and the economy but also nature and food security (Azad, 2024; WWF-Pakistan, 2024).

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Chapter - 11

Embedding Circularity in Regenerative Agriculture: Evidence, Pathways, and Challenges for Agrifood Transitions in South Asia

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Introduction

Agrifood systems in South Asia are increasingly recognized as operating beyond ecological thresholds, with soil degradation, declining soil organic carbon, nutrient losses and imbalances, groundwater depletion, air pollution, and rising greenhouse gas (GHG) emissions emerging as interlinked systemic challenges rather than isolated externalities (Schreefel et al., 2020; Velasco-Muñoz et al., 2021; Sher et al., 2024; Chakraborty et al. 2025). Long-term syntheses show that productivity gains achieved through post-Green-Revolution intensification have been accompanied by erosion of soil ecosystem services, disruption of nutrient cycles, and reduced system resilience, particularly in smallholder-dominated landscapes characteristic of South Asia (Schreefel et al., 2020).

Policy and technological responses have largely emphasized incremental efficiency improvements, commonly framed within sustainable intensification. While such approaches reduce resource use per unit output, they rarely reverse absolute ecological degradation and often shift environmental burdens across space or time (Velasco-Muñoz et al., 2021). As a result, sustainability gains remain partial and fragile, underscoring the limits of optimization within fundamentally linear agrifood systems.

Within this context, Regenerative agriculture (RA) has gained traction as an approach explicitly oriented toward restoring agroecosystem function. Recent reviews converge on RA as an outcome-oriented paradigm centered on rebuilding soil organic matter, enhancing biological activity, improving hydrological function, and strengthening ecosystem resilience over time (Schreefel et al., 2020; Sher et al., 2024; Garbisu et al., 2025). RA overlaps with, yet differs from, other sustainability paradigms. Compared with sustainable intensification, RA prioritizes regeneration rather than relative efficiency gains. Compared with agroecology, RA selectively draws on ecological principles while remaining institutionally flexible and less explicitly normative (Tittonell et al., 2022). This flexibility has accelerated uptake across policy, corporate, and development arenas, but has also generated definitional ambiguity and uneven implementation.

A critical limitation of Regenerative agriculture, as currently operationalized, is its frequent confinement to field- or farm-scale practices. While regenerative interventions may restore soil processes locally, they do not inherently govern how nutrients, biomass, water, and energy circulate across farms, landscapes, and value chains. Consequently, regenerative gains may remain spatially fragmented or be undermined by leakage elsewhere in the system (Choudhury et al., 2024; Guerrero-Villegas et al., 2025).

In parallel, the circular economy (CE) has emerged as a systems framework aimed at replacing linear resource flows with circular ones by closing material, nutrient, water, and energy loops. In agrifood systems, CE emphasizes residue and waste valorization, nutrient recycling, water reuse, and energy recovery across food and non-food value chains (Morseletto, 2020; Velasco-Muñoz et al., 2021; Rodríguez-Espinosa et al., 2023). However, CE frameworks were largely developed in industrial contexts and, when applied to agriculture without ecological grounding, risk prioritizing recycling efficiency over ecosystem regeneration, potentially increasing emissions or shifting environmental burdens (Morseletto, 2020; Choudhury et al., 2024).

This chapter argues that embedding circularity within Regenerative agriculture is essential to address these limitations, provided that circular economy principles are explicitly adapted to the ecological and socio-institutional realities of agricultural systems. Circular economy principles provide systems logic for governing flows and evaluating system-wide outcomes, while Regenerative agriculture supplies the biophysical engine necessary for restoring soil and ecosystem function. Their integration offers a coherent basis for agrifood transitions that are both regenerative and systemically consistent. Accordingly, the aim of this chapter is to synthesize evidence, identify pathways, and critically assess challenges associated with embedding circular economy principles within Regenerative agriculture in South Asia. The chapter develops a conceptual framework to guide an evidence synthesis of environmental outcomes, and to examine trade-offs, governance constraints, and greenwashing risks shaping circular-regenerative transitions.

Conceptual foundations: RA, CE, and their integration

Regenerative agriculture: definition and conceptual grounding

Across recent peer-reviewed literature, Regenerative agriculture is increasingly defined by processes and outcomes of regeneration, rather than by prescriptive practice lists (Newton et al., 2020). Systematic reviews emphasize soil organic matter restoration as the primary entry point, with cascading benefits for nutrient cycling, water regulation, biodiversity, and climate mitigation (Schreefel et al., 2020; Sher et al., 2024; Rosier et al., 2025). This outcome-based framing aligns RA with soil ecology and Earth-system science, positioning regeneration as a trajectory rather than a static state (Garbisu et al., 2025). Conceptually, RA differs from sustainable intensification by prioritizing absolute ecological recovery, and from agroecology by remaining largely agnostic to political economy and governance questions (Tittonell et al., 2022). This ambiguity has facilitated wide adoption, but also creates space for selective interpretation and greenwashing.

Circular economy: systems logic and conceptual limits

The circular economy conceptualizes sustainability as a challenge of system-wide flow management, aiming to replace linear *extraction–use–disposal* models with closed-loop systems that retain material value and reduce waste (Morseletto, 2020). In agriculture, CE encompasses nutrient recycling, biomass valorization, water reuse, and bioenergy integration across interconnected value chains (Velasco-Muñoz et al., 2021; Guerrero-Villegas et al., 2025). However, CE is not inherently regenerative, as it primarily focuses on managing material and energy flows to reduce waste and resource throughput, rather than actively restoring the ecosystems from which resources are derived. As a result, circularity can be pursued without enhancing biodiversity, rebuilding soil health, or delivering net-positive ecological outcomes unless explicit regenerative objectives are incorporated (Morseletto, 2020; Velenturf & Purnell, 2021; Friant et al., 2023). Circular interventions may also intensify energy use, increase emissions, or shift burdens across scales if ecological thresholds are ignored (Morseletto, 2020; Choudhury et al., 2024). This exposes a conceptual gap between circularity as flow optimization and regeneration as ecosystem recovery.

Conceptual overlaps, synergies, and trade-offs

Regenerative agriculture and circular economy converge in their rejection of linear systems and their emphasis on regeneration of natural capital. Both highlight nutrient cycling, biomass management, and long-term resilience as central objectives (Schreefel et al., 2020; Velasco-Muñoz et al., 2021). These overlaps create synergistic pathways, particularly where circular flows reinforce regenerative processes, such as organic residue recycling that enhances soil carbon and biological activity.

At the same time, theoretical trade-offs are critical. Circularity without regeneration risks becoming extractive in new forms, while regeneration without circularity risks remaining localized and systemically inefficient. Recent conceptual analyses emphasize that not all circular practices are regenerative, and not all regenerative practices are circular, necessitating explicit criteria for integration (Morseletto, 2020; Choudhury et al., 2024).

An integrated circular–regenerative framework

To address these complementarities and tensions, this chapter develops an integrated circular–regenerative environmental management framework (Figure 1). In this framework, the circular economy provides the systems logic governing flows of nutrients, biomass, water, and energy across agrifood value chains, while Regenerative agriculture provides the biophysical engine restoring soil function, biodiversity, and ecosystem resilience.

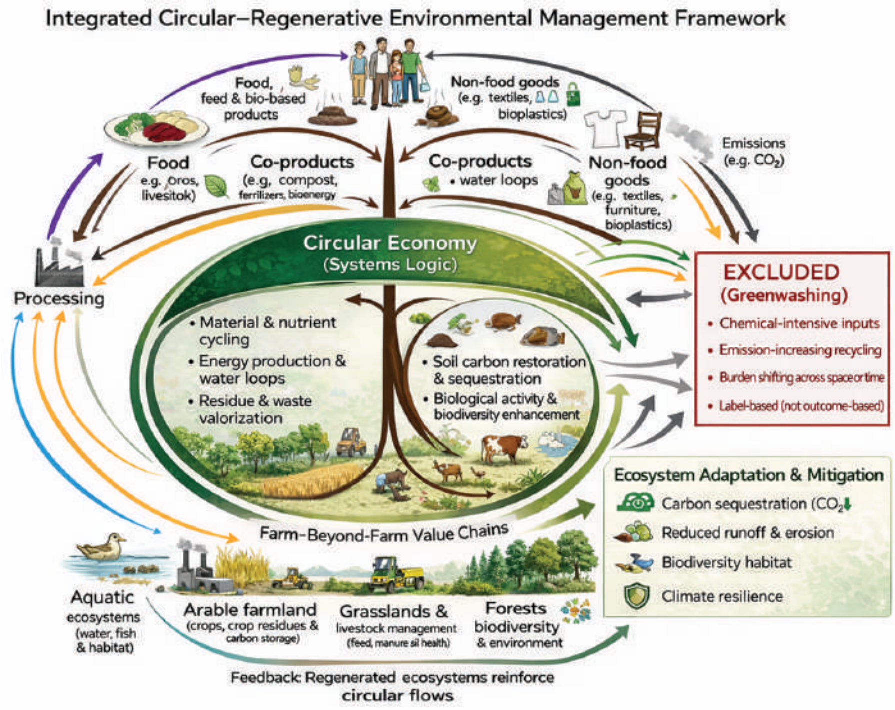
Figure 1. Integrated Circular–Regenerative Environmental Management Framework. The figure illustrates the integration of circular economy (CE) and Regenerative agriculture (RA) in agrifood systems. CE functions as a systems logic governing material, nutrient, energy, and water flows across food and non-food value chains, while RA operates as a biophysical engine restoring soil organic carbon, biodiversity, hydrological function, and yield stability within arable land, grasslands, forests, and aquatic ecosystems. Circular flows reconnect food and bio-based production with co-products and residues, while feedbacks from regenerated ecosystems reinforce circularity. The framework explicitly incorporates climate mitigation and adaptation outcomes and delineates an exclusion zone for greenwashing, excluding chemical-intensive, emission-increasing, burden-shifting, or label-based practices lacking demonstrable environmental benefits.

The framework embeds feedback loops linking regeneration to climate mitigation and adaptation, and defines exclusion zones for chemical-intensive inputs, emission-increasing recycling, burden shifting, and narrative-based sustainability claims without outcome verification. By operationalizing these boundaries, the framework directly addresses greenwashing risks highlighted in recent RA and CE scholarship (Tittonell et al., 2022; Choudhury et al., 2024). Crucially, this framework is analytical rather than prescriptive. It provides the conceptual basis for synthesizing evidence (Section 4), identifying pathways, and interrogating challenges (Section 5) associated with embedding circularity in Regenerative agriculture in South Asia.

Methods: Evidence synthesis and analytical framework

Overall methodological approach

The employed methodology adopts a structured conceptual and evidence-synthesis methodology to examine how Circular Economy (CE) principles can be meaningfully embedded within Regenerative agriculture (RA) to support agrifood transitions in South Asia. The approach is explicitly designed to address three interrelated objectives articulated in Sections 1 and 2: first, to consolidate empirical evidence on environmental outcomes associated with RA- and CE-aligned practices; second, to



interrogate the conceptual and theoretical coherence of CE–RA integration; and third, to identify pathways and safeguards that distinguish substantive system transformation from circularity- or regeneration-oriented greenwashing.

Rather than pursuing a statistical meta-analysis, which would be constrained by heterogeneity in indicators, scales, and system boundaries, the chapter follows an interpretive evidence-synthesis logic commonly applied in sustainability transitions and circular economy research. This approach prioritizes triangulation across empirical findings, conceptual frameworks, and measurement practices, allowing systemic patterns, trade-offs, and boundary conditions to be identified across diverse contexts (Stillitano et al., 2021; Veloso et al., 2025). Such synthesis-oriented designs are increasingly recognized as appropriate for analyzing regenerative and circular transformations that cut across biophysical, technological, and institutional domains (Stathatou et al., 2023; Falcone et al., 2022).

Literature identification and search strategy

The literature corpus was assembled through a multi-stage search strategy combining Web of Science, and Google Scholar, supplemented by backward and forward citation tracking of key review and framework articles. Consensus was used as a core discovery engine due to its semantic search capability, which facilitates identification of conceptually adjacent literature even where terminology differs across RA, agroecology, CE, and sustainability science.

Search queries were iteratively refined to capture four intersecting strands of literature: Regenerative agriculture and soil-ecological outcomes; circular economy applications in agriculture and agri-food systems; measurement frameworks and life-cycle-based assessment of environmental performance; and governance, credibility, and greenwashing risks in sustainability transitions. This iterative querying strategy is consistent with best practices in conceptual synthesis and systematic narrative reviews, particularly in emerging interdisciplinary fields where definitional convergence is still evolving

(Stillitano et al., 2021; Falcone et al., 2022). To align with the chapter's regional focus, studies addressing South Asia were prioritized, while globally situated studies were retained where they offered transferable conceptual frameworks, metrics, or methodological insights relevant to smallholder-dominated agrifood systems. Particular emphasis was placed on literature published within the last 15 years, reflecting the rapid evolution of RA and CE discourse and practice over this period (Stathatou et al., 2023; Veloso et al., 2025).

Analytical inclusion boundaries and anti-greenwashing logic

A defining feature of the methodological design is the explicit operationalization of anti-greenwashing boundaries, consistent with the integrated circular–regenerative framework presented in Figure 1. Inclusion decisions were guided not by labels such as "regenerative" or "circular" alone, but by whether studies reported outcome-based environmental performance aligned with the biophysical regeneration and systemic efficiency criteria articulated in Section 2.

This logic reflects growing recognition that both RA and CE are vulnerable to conceptual dilution when practices emphasize input substitution, recycling, or branding without delivering net environmental gains (Tittonell et al., 2022; Lopes et al., 2023). Studies were therefore critically assessed for evidence of burden shifting across spatial or temporal scales, rebound effects associated with circular technologies, or increases in energy and emissions intensity despite apparent material closure (Falcone et al., 2022; Yu, 2026). This approach mirrors recent methodological advances that call for outcome-oriented assessment of circularity and regeneration rather than narrative compliance (Veloso et al., 2025; Stillitano et al., 2021).

Evidence clustering and typological classification

To move beyond fragmented reporting of individual practices, the assembled literature was analytically clustered into practice–system typologies reflecting how CE–RA interactions manifest across agrifood systems. This clustering was informed by systems ecology and agri-food supply-chain perspectives, which emphasize that environmental outcomes emerge from interactions among disturbance regimes, biomass flows, nutrient cycling, and system integration rather than isolated interventions (Stathatou et al., 2023; Veloso et al., 2025).

Within each cluster, studies were interpreted according to whether their primary logic was biophysical regeneration (e.g. soil carbon restoration and biodiversity enhancement), system-level circularity (e.g. material and energy loop closure), or explicit integration of both. This typological lens enabled comparison between nominally regenerative or circular practices and those demonstrating synergistic outcomes, as well as identification of conceptual mismatches where circular optimization conflicted with regenerative thresholds (Falcone et al., 2022).

Environmental indicators and cross-metric interpretation

Consistent with the integrated framework in Section 2, the synthesis emphasized multi-indicator environmental assessment, recognizing that single metrics can obscure trade-offs and misrepresent system performance. Indicators reported across the literature were interpreted jointly, with particular attention to soil organic carbon dynamics, GHG emission intensity, nutrient losses, hydrological regulation, biodiversity proxies, and life-cycle energy use. This integrative reading reflects advances in circular economy metrics and life-cycle assessment, which increasingly stress the need to align material flow indicators with ecological outcomes and temporal persistence (Stillitano et al., 2021; Falcone et al., 2022). Where studies employed life-cycle or systems-based methodologies, their boundary assumptions and indicator choices were explicitly considered to avoid false equivalence between short-term efficiency gains and long-term regenerative capacity (Veloso et al., 2025).

Context sensitivity and uncertainty management

Given the ecological and institutional heterogeneity of South Asian agrifood systems, findings were interpreted with explicit attention to context dependency. Differences in climate, soil type, farm size, baseline management, and policy environments were treated as explanatory variables rather than sources of analytical noise. Divergent results were retained within the synthesis and examined for underlying causes, consistent with interpretive approaches in sustainability transitions research that emphasize learning from variability rather than suppressing it (Stathatou et al., 2023; Yu, 2026). This approach is particularly important for RA–CE integration, where the same practice may generate regenerative benefits in one context and ecological trade-offs in another, depending on system boundaries and governance arrangements (Tittonell et al., 2022).

Methodological limitations

As an evidence-synthesis study-based chapter, this research does not generate new primary data or estimate pooled effect sizes. Instead, it prioritizes conceptual coherence, cross-study triangulation, and outcome-based interpretation. While this limits causal attribution at fine scales, it strengthens the chapter's ability to address the core research objective articulated in the title: identifying evidence, pathways, and challenges for embedding circularity within Regenerative agriculture at system and transition levels. Such synthesis-oriented methodologies are increasingly recognized as essential complements to experimental and modeling studies in guiding agrifood transformation debates (Stillitano et al., 2021; Veloso et al., 2025).

Results

Soil organic carbon sequestration across Regenerative Agriculture systems

Figure 2A and Table 1 summarize soil organic carbon (SOC) sequestration rates reported for major Regenerative agriculture (RA) system classes relevant to South Asia. Across the reviewed literature, agroforestry systems (AF) consistently exhibit the highest soil-only sequestration rates, with values typically ranging from approximately 0.3 to 2.5 Mg C ha^{-1} yr^{-1}. These rates are well supported by global and regional meta-analyses showing that conversion from annual cropping to tree-based systems enhances carbon inputs through litter fall, root turnover, and microclimate-mediated stabilization, particularly in tropical and subtropical environments (Lorenz & Lal, 2014; Shi et al., 2018; Zomer et al., 2016).

Integrated crop–livestock systems (ICL) display intermediate but robust sequestration outcomes, generally between 0.4 and 1.2 Mg C ha^{-1} yr^{-1} (Figure 2A; Table 1). Evidence indicates that these gains arise from manure recycling, pasture phases, and increased biomass retention, although outcomes vary with stocking rates and grazing management (Herrero et al., 2020; Jat et al., 2022). Importantly, studies from South Asia emphasize that SOC responses in integrated systems are closely linked to broader socio-ecological trajectories and management transitions rather than single practices (Aravindakshan et al., 2020).

Organic amendment–based systems (OA) show moderate SOC sequestration rates, typically ranging from 0.2 to 0.9 Mg C ha^{-1} yr^{-1}. Long-term trials demonstrate that compost, manure, and similar inputs can increase SOC, but that net sequestration rates depend on amendment quality, mineralization dynamics, and synchronization with crop demand (Powlson et al., 2016; Cobo et al., 2018).

Conservation agriculture (CA) and cover crop or diversified rotation systems (CC) exhibit lower median SOC gains, generally between 0.15 and 0.45 Mg C ha^{-1} yr^{-1}, reflecting evidence that reduced tillage alone delivers modest carbon accumulation unless combined with residue retention and diversification (Powlson et al., 2016; Sapkota et al., 2017; Jat et al., 2022).

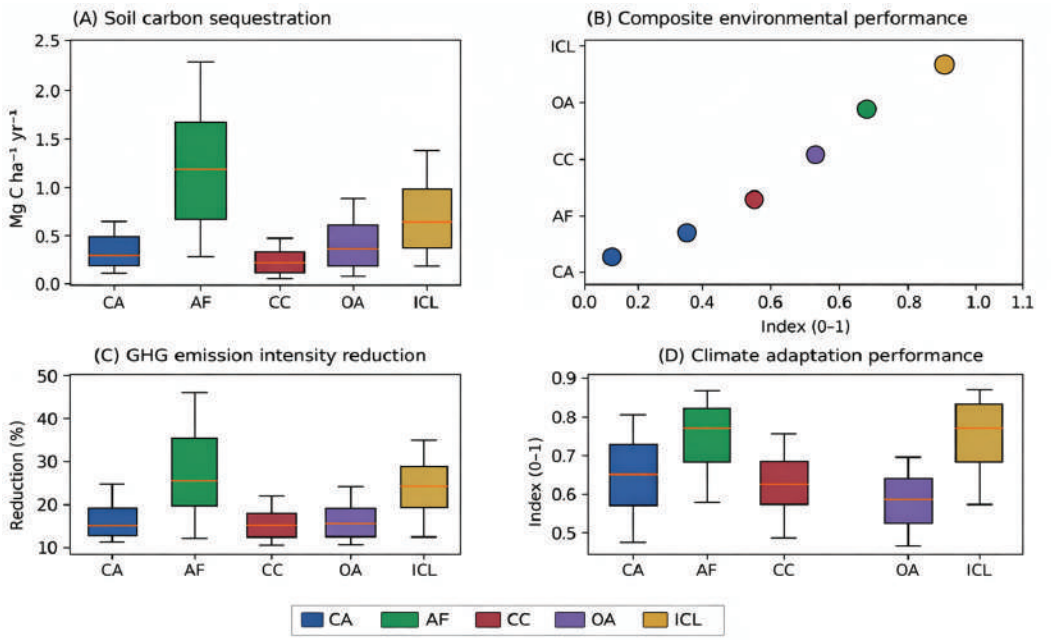


Figure 2. Synthesized environmental performance of Regenerative Agriculture (RA) systems in South Asia.

Panel (A) shows soil organic carbon sequestration rates (Mg C ha^{-1} yr^{-1}) synthesized from meta-analyses and long-term field studies (Lorenz & Lal, 2014; Powlson et al., 2016; Shi et al., 2018; Jat et al., 2022). Panel (B) presents a composite environmental performance index (0–1) derived from normalized literature-reported outcomes across carbon, nutrient cycling, biodiversity, and resource-use efficiency dimensions (Herrero et al., 2020). Panel (C) depicts greenhouse gas emission intensity reduction (%) relative to conventional systems, accounting for energy use, nitrogen efficiency, and life-cycle trade-offs (Powlson et al., 2016; Cobo et al., 2018; Jat et al., 2022). Panel (D) illustrates a climate adaptation performance index (0-1), reflecting resilience-related indicators such as water regulation, yield stability, and livelihood diversification (Dhyani et al., 2021; Herrero et al., 2020; Aravindakshan et al., 2020). Values represent literature-derived ranges and central tendencies rather than single empirical datasets. RA systems include conservation agriculture (CA), agroforestry systems (AF), cover crops/diversified rotations (CC), organic amendments (OA), and integrated crop-livestock systems (ICL).

Table 1. Soil organic carbon sequestration rates under different RA practices in South Asia

RA practice	SOC sequestration rate (Mg C ha^{-1} yr^{-1})	Evidence base
Conservation agriculture (CA)	0.15 – 0.45	Long-term CA trials in Indo-Gangetic Plains show modest but stable SOC gains primarily in surface layers (0–15 cm), constrained by residue availability and partial tillage adoption (Aravindakshan et al., 2015; Jat et al., 2022; Powlson et al., 2016).
Agroforestry systems (AF)	0.3 – 2.5	Meta-analyses and long-term Indian AF studies consistently show higher sequestration due to woody biomass inputs and deep rooting; soil-only sequestration typically ≤2.5 Mg C ha^{-1} yr^{-1} (Lorenz & Lal, 2014; Shi et al., 2018; Dhyani et al., 2021; Bania et al., 2025).
Cover crops / diversified rotations (CC)	0.1 – 0.5	SOC gains are modest and highly context dependent in South Asia due to biomass removal and water constraints (Powlson et al., 2016; Chivenge et al., 2011).
Organic amendments (OA)	0.2 – 0.9	Compost, manure, and biochar increase SOC, but long-term sequestration rates rarely exceed 1 Mg C ha^{-1} yr^{-1} when mineralization is accounted for (Cobo et al., 2018; Lal, 2021).
Integrated crop–livestock systems (ICL)	0.4 – 1.2	SOC gains arise from manure recycling and residue retention, with variability across stocking rates and grazing intensity (Herrero et al., 2020; Aravindakshan et al., 2020).

Composite environmental performance across RA systems

Figure 2B integrates multiple outcome dimensions into a composite environmental performance index, supported by the indicator synthesis in Table 2. Agroforestry and integrated crop-livestock systems consistently achieve the highest composite scores, typically in the range of 0.75-0.85. This reflects their capacity to deliver concurrent benefits across soil carbon, biodiversity, nutrient cycling, and microclimate regulation, aligning regenerative biophysical processes with circular resource flows (Herrero et al., 2020; Zomer et al., 2016).

Table 2. Composite environmental performance index (0-1) across RA systems

RA practice	Composite index (0–1)	Interpretation
CA	0.55 – 0.65	Gains in erosion control and energy efficiency are offset by limited biodiversity and nutrient recycling unless complemented by diversification (Aravindakshan et al., 2015; Jat et al., 2022).
AF	0.75 – 0.85	Strong multifunctionality across carbon, biodiversity, microclimate, and nutrient cycling dimensions (Shi et al., 2018; Castle et al., 2022).
CC	0.60 – 0.70	Improves nutrient cycling and soil cover but limited climate mitigation benefits when biomass is removed (Powlson et al., 2016).
OA	0.50 – 0.60	Benefits depend strongly on source of organic inputs and upstream emissions (Cobo et al., 2018).
ICL	0.75 – 0.85	High circularity potential when manure recycling and feed–crop integration are optimized (Herrero et al., 2020).

Conservation agriculture and cover crop systems exhibit moderate composite performance, with index values clustering around 0.55–0.70 (Figure 2B; Table 2). These systems perform strongly in erosion control and energy-use efficiency but show more limited biodiversity and nutrient-cycling benefits when implemented without broader system integration (Sapkota et al., 2017; Jat et al., 2022). Organic amendment systems occupy the lower end of the composite index (approximately 0.50–0.60), reflecting trade-offs between soil improvement and potential increases in nutrient losses or greenhouse gas emissions when amendments are poorly managed (Cobo et al., 2018). Overall, the dispersion observed in Figure 2B underscores that environmental performance depends on system configuration rather than practice labels alone.

Greenhouse gas emission intensity reductions

Figure 2C and Table 3 summarize reported reductions in greenhouse gas (GHG) emission intensity relative to conventional systems. Agroforestry systems demonstrate the largest and most consistent mitigation benefits, with emission intensity reductions typically ranging from 20% to 45%. These reductions are attributed to a combination of carbon sequestration, reduced fertilizer dependence, and improved system efficiency (Lorenz & Lal, 2014; Shi et al., 2018).

Table 3. Greenhouse gas emission intensity reduction relative to conventional systems (%)

RA practice	Reduction range (%)	Evidence base
CA	5 – 20	Energy savings from reduced tillage are partially offset by residue management emissions (Aravindakshan et al., 2015; Powlson et al., 2016).
AF	20 – 45	Net reductions due to carbon sinks and reduced fertilizer demand, but methane trade-offs possible in humid systems (Lorenz & Lal, 2014; Shi et al., 2018).
CC	5 – 25	N_2O emissions can offset carbon gains if nitrogen management is poor (Powlson et al., 2016).
OA	5 – 30	Strongly dependent on amendment type and life-cycle emissions (Cobo et al., 2018).
ICL	15 – 35	Emission intensity declines when livestock productivity and manure management improve (Herrero et al., 2020).

Integrated crop–livestock systems show moderate to high mitigation potential, with reductions generally between 15% and 35% (Figure 2C; Table 3). Evidence indicates that improved nitrogen use efficiency and manure recycling are key drivers, although benefits depend on livestock productivity and manure management practices (Herrero et al., 2020; Jat et al., 2022). Conservation agriculture systems achieve smaller reductions, typically between 5% and 20%, driven primarily by lower fuel use and improved energy efficiency rather than large biophysical carbon gains (Powlson et al., 2016; Aravindakshan et al., 2015). Cover crops and organic amendment systems exhibit wide variability, with reductions ranging from negligible to approximately 25–30%, reflecting sensitivity to nitrogen management and life-cycle emissions associated with input production and transport (Cobo et al., 2018).

Climate adaptation and resilience performance

Figure 2D and Table 4 highlight differences in adaptation-related performance across RA systems. Agroforestry systems consistently achieve the highest adaptation index values, typically between 0.75 and 0.90, reflecting strong evidence for microclimate buffering, improved water regulation, and livelihood diversification (Dhyani et al., 2021; Zomer et al., 2016). Integrated crop–livestock systems also score highly (approximately 0.70–0.90), consistent with studies showing that diversification enhances resilience to both climatic and market shocks (Herrero et al., 2020; Aravindakshan et al., 2020).

Table 4. Climate adaptation performance index (0–1)

RA practice	Adaptation index	Supporting evidence
CA	0.55 – 0.75	Improved water infiltration and drought buffering, but yield stability varies (Jat et al., 2022).
AF	0.75 – 0.90	Microclimate regulation, livelihood diversification, and risk buffering consistently documented (Dhyani et al., 2021; Castle et al., 2022).
CC	0.55 – 0.70	Benefits depend on water availability and biomass retention (Chivenge et al., 2011).
OA	0.45 – 0.65	Improves soil structure but adaptation benefits are slower and context specific (Lal, 2021).
ICL	0.70 – 0.90	Diversified income streams and nutrient recycling enhance resilience (Herrero et al., 2020; Aravindakshan et al., 2020).

Conservation agriculture and cover crop systems demonstrate moderate adaptation benefits, with indices generally between 0.55 and 0.75 (Figure 2D; Table 4). These benefits are primarily associated with improved soil structure and moisture retention, although yield stability remains context dependent (Jat et al., 2022). Organic amendment systems show the widest range of adaptation outcomes (approximately 0.45-0.65), reflecting variability in input access, labor requirements, and institutional support (Cobo et al., 2018).

Synthesis and implications for circular–regenerative integration

Taken together, Figure 2 (Panels A-D) and Tables 1-4 demonstrate that systems-level regenerative configurations-particularly agroforestry and integrated crop-livestock systems-consistently outperform practice-level interventions across soil restoration, mitigation, and adaptation dimensions. Practices emphasizing single objectives, such as reduced tillage or organic input substitution, deliver partial benefits but exhibit greater variability and higher risk of trade-offs when implemented without circular system integration. These results provide a robust empirical basis for distinguishing genuinely integrated circular-regenerative systems from nominal or fragmented interventions, setting the stage for the analysis of pathways and challenges in Section 5.

Discussion:

Conceptual and operational challenges at the CE–RA interface

Despite growing enthusiasm for Regenerative agriculture (RA) and circular economy (CE) principles, embedding circularity within regenerative systems remains conceptually and operationally challenging. A central issue lies in the mismatch between the industrial origins of circular economy frameworks and the ecological complexity of agroecosystems. Systematic reviews of CE in agriculture highlight that many circular interventions prioritize material reuse and waste valorization without sufficiently accounting for soil processes, biological feedbacks, and spatial heterogeneity (Peng et al., 2025). As a result, circular strategies risk optimizing resource flows while failing to restore-or even undermining-ecosystem functions central to regeneration.

Regenerative agriculture, in contrast, emphasizes soil health, biodiversity, and resilience but often lacks explicit system-level accounting of material and energy flows. Recent syntheses note that this conceptual gap can lead to regenerative practices being evaluated narrowly through plot-level indicators, without consideration of upstream and downstream externalities (Tittonell et al., 2022; Jayasinghe et al., 2023). Embedding circularity within RA therefore requires reconciling process-based ecological regeneration with systems-based resource governance, rather than assuming their automatic alignment.

Efficiency versus regeneration: limits of incremental transitions

A recurring challenge in South Asia is the tendency to equate incremental efficiency gains with regenerative transformation. Empirical studies on conservation tillage systems demonstrate improvements in energy-use efficiency and reductions in fuel consumption, yet these gains alone do not guarantee broader environmental regeneration (Aravindakshan et al., 2015; Aravindakshan et al., 2018; Aravindakshan et al., 2022). Such findings underscore the risk of efficiency-led pathways becoming end points rather than steppingstones, particularly when policy incentives and performance metrics reward short-term gains. This concern aligns with broader critiques of circular economy implementation, where efficiency improvements can trigger rebound effects that offset environmental benefits in the absence of sufficiency thresholds and governance controls (Nogueira et al., 2025). In agrifood systems, efficiency-oriented circular interventions-such as residue-based bioenergy or nutrient recycling-may inadvertently intensify production or externalize emissions unless bounded by regenerative principles.

Greenwashing risks and the politics of "regeneration"

The growing institutional and market interest in Regenerative agriculture has amplified concerns about greenwashing, particularly when regeneration is framed as an outcome rather than a measurable process. Critical analyses argue that the absence of standardized definitions and metrics allows chemically intensive or emission-increasing technologies to be rebranded as regenerative or circular without delivering net environmental benefits (Tittonell et al., 2022; Choudhury et al., 2024). This risk is especially acute at the CE–RA interface, where waste reduction narratives can obscure life-cycle emissions or soil degradation.

Emerging literature on circular economy governance highlights similar dynamics, noting that circularity discourses are increasingly mobilized to legitimize business-as-usual practices under sustainability branding (Peng et al., 2025; Nogueira et al., 2025). In South Asia, where monitoring and verification capacity is limited, the danger is not merely symbolic: misclassified interventions may divert public resources and policy attention away from genuinely regenerative pathways.

Socio-ecological pathways and context dependency

Embedding circularity in Regenerative agriculture is fundamentally shaped by context-dependent socio-ecological dynamics. Longitudinal evidence from mixed farming systems in Bangladesh shows that agrarian change is driven by interacting ecological, economic, and institutional forces, rather than by isolated technological adoption (Aravindakshan et al., 2020). These findings highlight that circular–regenerative transitions unfold along trajectories influenced by labor availability, risk perceptions, and access to services.

Cognitive and institutional dimensions further mediate adoption pathways. Studies using fuzzy cognitive mapping reveal that farmers' mental models, trust in institutions, and perceived trade-offs strongly influence engagement with sustainable intensification and regenerative practices (Aravindakshan et al., 2021). These insights suggest that circular-regenerative transitions cannot be engineered solely through technical packages but require learning-oriented governance and participatory design.

Measurement, finance, and the challenge of credible scaling

Another major challenge lies in the measurement and monetization of regenerative and circular outcomes. While interest in carbon markets and soil-based climate finance is growing, critical assessments caution that simplified carbon accounting frameworks may conflict with broader soil health and ecosystem service objectives (Næss & Jakobsen, 2025). Reviews of AFOLU emissions in India further stress that mitigation strategies must be evaluated at sectoral and system scales to avoid burden shifting across land-use categories (Kumar & Aravindakshan, 2022).

Recent CE–RA literature emphasizes the need for multi-dimensional monitoring frameworks that integrate carbon, biodiversity, water, and livelihood indicators (Herrero et al., 2020; Peng et al., 2025). Without such frameworks, scaling regenerative circular systems risks privileging easily monetized outcomes over more complex but critical ecosystem functions.

Pathways forward: embedding circularity without diluting regeneration

The synthesis of challenges points toward several pathways for embedding circularity in Regenerative agriculture without diluting its ecological foundations. First, circular interventions must be ecologically bounded, ensuring that material reuse and recycling reinforce-rather than substitute for-soil regeneration and biodiversity enhancement. Second, governance frameworks should prioritize outcome-based metrics and safeguards to prevent greenwashing and rebound effects. Third, scaling strategies must recognize heterogeneity and transition pathways, supporting gradual system redesign rather than uniform technological adoption.

Recent reviews suggest that Regenerative agriculture offers a promising platform for integrating circular economy principles precisely because of its emphasis on system integrity and long-term resilience (Jayasinghe et al., 2023; Peng et al., 2025). However, realizing this potential requires moving beyond aspirational narratives toward transparent, evidence-based, and context-sensitive implementation.

Conclusions

This chapter demonstrates that embedding circular economy principles within Regenerative agriculture offers a credible but conditional pathway for agrifood transitions in South Asia. Evidence synthesized across soil carbon, greenhouse gas mitigation, and climate adaptation outcomes shows that systems-level regenerative configurations-particularly agroforestry and integrated crop-livestock systems-deliver more consistent environmental benefits than isolated practice-based interventions. These systems align circular resource flows with biophysical regeneration, reinforcing soil restoration, nutrient cycling, and resilience rather than optimizing efficiency alone (Herrero et al., 2020; Tittonell et al., 2022).

At the same time, the analysis highlights critical challenges that constrain the transformative potential of circular-regenerative pathways. Incremental efficiency gains, while valuable, are insufficient to achieve regeneration when pursued in isolation, as demonstrated by empirical work on conservation tillage and energy efficiency in South Asia (Aravindakshan et al., 2015; Aravindakshan et al., 2018). The growing ambiguity surrounding regenerative and circular labels further raises the risk of greenwashing, particularly where outcome-based metrics, life-cycle accounting, and governance safeguards are weak (Tittonell et al., 2022; Choudhury et al. 2024).

The findings underscore that circularity enhances Regenerative agriculture only when it is ecologically bounded, systemically integrated, and socially grounded. Longitudinal and socio-cognitive evidence from South Asian farming systems illustrates that transitions are shaped by agrarian trajectories, farmer perceptions, and institutional contexts, not solely by technical prescriptions (Aravindakshan et al., 2020; Aravindakshan et al., 2021). Without attention to these dimensions, circular interventions risk reinforcing partial or inequitable transitions.

Overall, this synthesis advances a framework for distinguishing genuinely integrated circular–regenerative systems from nominal or fragmented interventions, providing a more robust basis for policy design, investment, and future research. Advancing agrifood transitions in South Asia will require moving beyond aspirational narratives toward evidence-based, outcome-oriented, and context-sensitive approaches that safeguard regeneration while leveraging the systemic strengths of circularity.

Acknowledgement

The first author gratefully acknowledges the technical support of the CGIAR Scaling for Impact (S4I) program. The analysis and preparation of this chapter were further supported by the Cereal Systems Initiatives for South Asia Mechanization Extension Activity (CSISA MEA), implemented by the International Maize and Wheat Improvement Center (CIMMYT) with funding from the United States Government. The first author also acknowledges the South Asian Association for Regional Cooperation (SAARC) and its SAARC Agriculture Centre (SAC) in Dhaka for the invitation to contribute this chapter.

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Proceedings of the

Regional consultation meeting on promotion of Regenerative Agriculture in SAARC Member States

Date: 4-6 August 2025

Background

The proposal of this regional consultation meeting on "Promotion of Regenerative Agriculture in SAARC Member States" was aproved by the 16th SAC Governing Board meeting and 60th session of the Programming Committee meeting.

Introduction

Agriculture is the backbone of SAARC Member States. It provides food and fibre and is also the main source of employment in these countries. Present population of SAARC Member States is about 2.0 billion which is about 25% of the total global population. Due to burgeoning population, per capita land availability is decreasing very rapidly and in addition to it, improper land management has resulted in the form of reduction of soil fertility. Likewise improper use of land management practices and higher use of chemicals has resulted in the form of emissions of Greenhouse gases. Improper use of chemicals is resulting in the form of pollution of water bodies and these chemicals have become the part of food chain, resulting in the form of different kinds of diseases for the human beings. Improper tillage operations have negatively affected the soil fertility, mono cropping systems, no use of leguminous crops in the crop rotations and similarly no use or even burning of crop residues has also resulted in the form of soil health and environmental deterioration.

Depletion of natural resources, deterioration of soil health, climate and natural crises are jeopardising productivity and resilience of lands. Agriculture sector itself is the single largest driver of global biodiversity loss, but it has also been proven that adaption of regenerative agriculture can help to mitigate this damage and restore ecosystems.

Related to agroecological principles, Regenerative agriculture is an outcome - based farming approach that generates agriculture products while improving soil health, biodiversity, climate, water resources and supporting farming livelihoods. It is a holistic approach that aims to, simultaneously promote above-and below ground carbon sequestration, lessens greenhouse gas emissions, protect and enhance biodiversity in and around farms, improve water retaining in the soil, decrease the use of pesticides, improve nutrient use efficacy and support farming livelihoods. Regenerative agriculture is becoming a cornerstone in the evolution of agriculture sector, signalling a significant shift in the approach to sustainability and ecological responsibility. Its emphases on revitalizing the soil, increasing its organic matter and promoting biodiversity. This is a movement towards a commitment to preserving the earth's natural resources while maintaining the economic visibility of the farming. The significance of adapting Regenerative agriculture for farmers is multifaceted. It leads to better water use efficiency, decreases the dependence of synthetic fertilizers and pesticides and increases the resilience of agriculture sector to extreme weather and diseases. These improvements not only contribute to the reduction of environmental impacts allied with the farming sector but also helps farmers to benefit from higher yields, and potentially greater financial returns. Cover crops and tillage (i.e., reduced, minimum, no tillage or zero tillage) are the most frequent practices referred in Regenerative agriculture networks. Similarly crops rotations, livestock grazing and reduction in synthetic inputs (pesticides and fertilizers) are also included in Regenerative agriculture. All practices adaption depends upon the farm size, water availability, mechanization and livestock. The adaption of Regenerative agriculture depends upon the available technologies and equipment's. As many interactions exist between Regenerative agriculture practices and farm categories, so promotion of Regenerative agriculture requires greater scrutiny, especially, related to benefits, risks and needed changes.

In 1980's the Rodale Institute began using the term Regenerative agriculture. In 2014, this institute released a white paper titled "Regenerative Organic Agriculture and Climate Change". Its summary states "We could sequester more than 100% of current annual CO_2 emissions with a switch to widely available and inexpensive organic management practices which we term "regenerative organic agriculture". The practices include crop rotation, compost application and reduced tillage, similar to most organic agriculture. Author of restorative development consultant Storm Cunnigham (1951) documented the rise of what he then called "restorative agriculture" in his first book 'The Restoration Economy'. He defined it as a technique that rebuilds the quantity and quality of top soil, while restoring local biodiversity (especially, native pollinators) and watershed functionality. Carbon sequestration has more recently been added to that definition, to help achieve climate restoration.

Different Regenerative agriculture related pratices are: soil management practices (i.e., reduced tillage, soil cover, methods which help in building the soil organic carbon and mulching), crop management practices (i.e., cover cropping, crop rotations and crop diversifications), agroforestry crop practicing (i.e., wind breaks, alley cropping and multi crop farming) and Silvopasture (i.e., integrated livestock/grazing practices). In small farms, adoption of different technologies like permaculture, agroecology, agroforestry, restoration of ecology and other related management practices can be adopted, while in case of large farms utilization of "no till" or low till can be used. Ideally, on a regenerative farm, yield production should grow more ample over time. As the soil deepens, yields may increase and external composting inputs decreases. Actual output is however dependent on the nutritional value of composting materials and the nutritional status of the soil.

Now adaption of the RA is also getting popularity among the farming community of SAARC Member States. So, there is need of further working on it, for its promotion in a scientific way in this region.

Objectives

1. To collect the information about the on-going research and development activities about the Regenerative agriculture and its adoption by the farmers in the SAARC Member States.

2. To discuss the merits and demerits of Regenerative agriculture in the context of the SAARC Member States.

3. To develop the future strategy for the promotion of Regenerative agriculture in the SAARC Member States.

Methodology

A 3 day long regional consultation meeting was conducted in virtual mode, in which focal points of SAARC Member States presented their country papers on the above subject including the status of Regenerative agriculture, policies and practices and also shared their experiences and views. The meeting was interactive, participatory and there were group discussions on the above-mentioned subject.

Expected Output

1. It will be helpful in identifying the Regenerative agriculture related issues and opportunities in the SAARC Member States.

2. It will be helpful for developing a mechanism for the further research and development work on Regenerative agriculture.

3. It will be supportive in finding out the ways, for the promotion of Regenerative agriculture in a scientific way in this region.

Target participants

National Focal Experts of SAARC Member States, including researchers/ Agriculture Engineers/Extension officers involved in research and as well as in the promotion of Regenerative agriculture, experts of SAARC Agriculture Centre, invited guest speakers and scientists of different organization participated in this meeting.

Mode: Virtual mode

Schedule: 4-6 August, 2025

Proceedings of the meeting

Agriculture is the backbone of the SAARC Member States, it provides food and fibre and is also the main source of employment in these countries. Present population of SAARC Member States is about 2.0 billion which is about 25% of the total global population. Due to burgeoning population, per capita land availability is decreasing very rapidly and in addition to it, improper land management has resulted in the form of reduction of soil fertility. SAARC Agriculture Centre (SAC), Dhaka, Bangladesh, arranged regional consultation meeting on promotion of Regenerative agriculture in the SAARC Member States on 4-6 August 2025, in virtual mode. Nominated focal points and scientists of five SAARC Member States including Bangladesh, Bhutan, Nepal, Pakistan and Sri Lanka and similarly scientists of different international research organizations like CIMMYT and IRRI participated in this meeting.

Ambassador Abdul Motaleb Sarker, Additional Foreign Secretary & Director General, SAARC and BIMSTEC Wing, Ministry of Foreign Affairs, Bangladesh was the Chief Guest, while Mr. Tanvir Ahmad Torophder, Director (ARD & SDF), SAARC Secretariat, Kathmandu, Nepal was the Special Guest in the inaugural session of this meeting.

Dr. Md. Harunur Rashid, Director, SAARC Agriculture Centre welcomed all the participants and reiterated SAARC Agriculture Centre's dedication to regional cooperation, noting that a unified strategy is vital for soil health and sustainable growth. Dr Sikander Khan Tanveer, Senior Program Specialist (Crops), SAARC Agriculture Centre briefed the participants about the objectives of conducting this meeting.

Dr. Debashis Chakraborty, Senior Scientist & Cropping Systems Agronomist (CWANA), CIMMYT office, Bangladesh was the speaker of this meeting and gave presentation on "Regenerative agriculture: Restoring Earth's Balance through soil Stewardship". According to him, water scarcity is a big global issue and similarly agriculture sector is also a big source of emissions of greenhouse gases (GHGs). So urgent actions are needed to handle the climate crises. There is need of promotion of RA instead of degenerative agriculture. According to him, mostly agriculture research is conducted as a component focused, which often limits scaling up of RA. For the vibrant industry, resilient agriculture is very important and for this purpose capacity development of farmers and all stakeholders is needed, which develops the confidence among the stakeholders. There is need of global and regional missions on RA.

Special guest of the meeting, Mr. Tanvir Ahmad Torophder, Director (ARD&SDF), SAARC Secretariat, Kathmandu, Nepal, thanked Dr. Debashis Chakraborti for his paper on Regenerative agriculture as a Key Note speaker. He said that available land is continuously decreasing and currently used agricultural practices are creating big issues in different forms. In this regard RA can play an important role and now this is the need of the time that the Governments of the SAARC Member States should encourage the Regenerative agriculture in their countries. He also suggested that farmers should have direct excess to the markets and industry and similarly farmers and especially the small farmers should work together.

Chief Guest of the meeting, Ambassador Abdul Motaleb Sarker congratulated SAARC Agriculture Centre, for arranging this regional consultation meeting and he said that he is happy to see that so many scientists are together in this very important meeting. He further said that SAC was established in 1988 to promote agriculture in SAARC Member States. He futher said that present population of the SAARC Member States is about 2.0 billion and food requirement of this region is increasing with the passage of time while arable land availability is decreasing and in addition to it, this region is also facing different types of environmental issues. Although this region has made a great progress in the agriculture sector, but still this region is facing many issues due to the present agricultural production systems. Current production system is very difficult and now, RA needs to be promoted, along to the RA principles. Integrated production of livestock and fisheries along with multi-cropping encourages farmers. There is need of forward-looking strategy to promote RA on large scale in this region. It should be climate smart and gender friendly and it should be analyzed on economic basis. Further research needs to be conducted in this field and future cooperation can further help in the promotion of RA on large scale in this region. By working together SAARC Member States can progress more in this sector and these countries can help each other in the promotion of RA, through cooperation in research, capacity building of extension workers and farmers, sharing of knowledge and joint projects etc. SAARC countries need sustainable water management. At the end, he thanked SAARC Agriculture Centre for inviting him, as the Chief guest and he also said that we will continue to support the endeavors of SAARC Agriculture Centre and SAARC.

Dr Md. Jamal Uddin, focal point Bangladesh, presented his country paper and told that agriculture is one of the main pillar of country's economy and its share in the GDP of the country is 11.55%. There are 30 different cropping systems in the country and maximum farmers are smallholders and even land less farmers. According to him, all crops production increased in the country with the passage of time, except wheat. With the increasing population, food demand is increasing in the country. Currently high inputs are used for the production of all crops and similarly the use of pesticides is increasing with the passage of time and every year 40000 MT pesticides are imported in the country. There are challenges in each cropping system and presently there is no policy for Regenerative agriculture in the country. However, country has Biosecurity Act. 2017. National agricultural research systems have 14 research institutes. Different RA related practices include use of Zero tillage technology for different crops like maize and sunflower, planting of crops by using the strip tillage, minimum tillage, organic farming, and use of biochar, diversification of crops, crop rotations, use of different cropping patterns, relay cropping, use of renewable energy in farming, use of drip irrigation, IPM, cultural practices, planting of stress tolerant varieties, agroforestry, agroforestry and intercropping etc.

Mr.Yenten Namgay, focal point Bhutan, presented country paper and according to him, agriculture sector is very important for the economy of the country. He informed that temperature is rising in the country which is not a good sign. Bhutan has developed a number of policies like National Framework for Organic Farming (2016), Forestry Act 1995. Similarly different Sustainable Land Management (SLM) are being practiced and there is potential of 50-60% soil carbon sequestration by adopting the different SLM practices. Livestock integration and management are also being practiced in the country. There are, however, different constraints in the promotion of RA in the country, which include technical, economic and environmental constraints. Soil erosion, soil fertility, human and wildlife conflict are the different issues. Similarly, more cost of production as compared to the less income from the crops, labor shortage and marketing issues etc. are the challenges. According to him, further research in the field of RA, capacity building of scientists, staff of Agriculture Extension Department and farmers, Research - Extension integration and market development can be helpful in the promotion of RA in the country.

Mr. Mukunda Bhusal, focal point of Nepal, presented the country paper. He informed that conventional farming systems are not good for soil health and environment of the country. According to him, mostly chemical fertilizers are used in the country but now organic fertilizers, biofertilizers, vermi compost, mulching and Jholmol are also being used by the farmers. Wheat crop is also planted on beds and similarly Direct Seeded Rice (DSR) technology is also being used for rice crop. It is a good technology but it has some issues like weed management, stubble management, calibration of the drills, and similarly planting of crop during the rainy and dry conditions is difficult to manage. Planting of rice crop under the wet DSR, soil improvement through legumes, promotion of water saving technologies, Alternate Wetting & Drying (AWD), rain water harvesting, use of resistant/tolerant wheat varieties can be helpful for the promotion of RA in the country. For conservation of agro biodiversity in the country, every year a fair is arranged to make aware concerned stake holders and farmers about the importance of conservation of biodiversity in the country. Nepal has also developed a pesticides revised policy, work is in progress for the digital soil mapping, and similarly for the promotion of millet is also in progress. Different issues being faced by the agriculture sector of the country are climate issues, including different types of stresses (i.e., heat, drought and cold), biodiversity loss and use of more chemicals. For the promotion of RA in the country, it was recommended that RA policy needs to be developed by the country. There is also need of soil restoration and capacity building of the farmers through Farmers Field Schools etc. Similarly, there is also need of further research and development in the field of RA in the country. Such types of varieties of different crops are needed to be developed which should perform better in Regenerative agriculture. There is need of revisiting of cropping systemsfor soil health improvement, better nutrients management and for saving of natural resources like water etc. There is need of development of market linkages and certification system for the promotion of RA on large scale in the country. Start of Carbon credit program for the farmers, can be helpful in the promotion of RA in the country.

Dr. Hafiz Sultan Mahmood, Director, Agricultural Engineering Research Institute (AEI) PARC-NARC, focal point Pakistan along with Dr Muhammad Bashir, Principal Scientific Officer, Climate, Energy and Research Institute (CAEWRI), and Dr. Tariq Sultan, Chief Scientific Officer Land Resource Research Institute (LRRI), PARC-NARC, Islamabad presented the country paper of Pakistan. According, to Dr M. Bashir, Pakistan is one of the main climate vulnerable countries of the world. Similarly soil fertility of the country is also poor due to less soil organic matter. According to him, about 80 million tonnes crops residues are produced in the country, which are managed in situ or ex-situ. For in-situ management, Zero-tillage, Pak-seeder, Happy -seeder, Pak-seeder/Combine seeder and similarly Straw chopper/Shredder are being used. Some farmers are also practicing RA. Planting of crops on raised beds is also being practiced by the farmers to save the irrigation water. Different farming practices like No-till farming after sugarcane, intercropping of different crops in sugarcane, inter cropping in orchards and similarly grazing of sheep in the fields etc. are also being practiced in the country. Now Government has started a mega project, in which Precision agriculture machinery will be given to the farmers, Biopesticides will be promoted and for Carbon credits, farmers who will adopt Regenerative agriculture, they will be financially supported through this project. Biofertilizers, composts, vermicompost, PGPR, and Biozote Max. etc. are also being promoted on commercial scale in the country. For this purpose, demonstration plots are being planted on the farmers' fields and for the awareness purpose, farmers field days are also arranged.

Dr. N.R.N. Silva, Principal Scientist (Soil Science), Horticulture Crop Research Development Institute Gannoruwa, focal point Sri Lanka and Dr (Ms.) D.M.P. Dissanayake, Assistant Director of Agriculture (Research), Sustainable Agriculture Research and Development Centre, Makandura, presented their country paper. According to them, soil erosion is one of the biggest issues of the country. Policies needs to be developed to handle this issue and similarly, institutional support is need to control this issue. Major issues/threats to agriculture sector of the country include soil degradation, biodiversity loss, soil erosion, soil fertility decline etc. Government issues soil health cards to the rice crop growing farmers and Integrated Plant Nutrient Management (IPNM) is also being promoted in the country. Similarly Organic Farming is also being promoted and it is being encouraged that instead of burning the rice straw, these residues should be incorporated into the soil. Use of biochar and vermi compost are also being promoted in the country and these technologies need further support to be spread on large scale. Similarly, there is need of long-term assessment of soil fertility, under the different cropping systems and crop rotations. There is need of popularization of use of biofertilizers on large scale in the country. There is need of development of farmers friendly cost-effective bio-liquid formulation. Different raw materials need to be analyzed for their nutrients. Compost pellets are produced in the country. Vermicompost production and its promotion is in progress in the country. Similarly, biochar granules are being promoted in the country.

A number of invited guest speakers delivered their lectures on the different topics related to the Regenerative agriculture. Their presentations covered different aspects of RA, including Conservation Agriculture, Carbon Sequestration and Biofertilizers with reference to Regenerative agriculture, Water Management in Regenerative Agriculture, Agroforestry in relation to Regenerative agriculture, Agrobiodiversity in Regenerative agriculture, Community Engagement and Education in Regenerative agriculture, Use of Biopesticides for crops insects, pests' management in Regenerative agriculture, Crops disease management in Regenerative agriculture, Horticulture and Regenerative agriculture, Use of Biochar in relation with soil health, Compost use and Regenerative agriculture for sustainable crop production, Precision agriculture with reference to Regenerative agriculture, Crop-Livestock Integration and Regenerative agriculture and Circular Farming / C. Economy in R.A.

As a invited guest speaker, Dr. Mahesh Gathala (Country Head CIMMYT, India), told about the history of increase of Conservation Agriculture in the world. He also mentioned in detail, the benefits of Conservation Agriculture and accoding to him, CA performed better in those years, when there were no rains and according to him, crops yields continue to increase overtime under Conservation Agriculture/Regenerative Agriculture and similarly system productivity improves under Conservation Agriculture/Regenerative Agriculture with the passage of time.

Dr. Anupam Das (Assistant Professor, BAU, Bhagalpur, India,)told that carbon amends are essential for augmenting carbon sequestration. Carbon sequestration increases carbon stocks in the soil and it improves soil quality index. Co-inoculation of biofertilizers also improves soil health. Microbial nutrient limitation is an important indicator for soil health during crop diversification. Similarly, selection of variety and root architecture is important aspect for continuous crop cover. According to him, chemical fertilizers, FYM and compost should be applied together, it will be better for soil health and crops productivity. According to him, biofertilizers are also good for soil health.

Mr. Mohammed Faiz Alam (IWMI-India), in his talk, told that RA is very important and it can be helpful in avoiding the over exploitation of water from the soil. According to him water is both an input and a contributor of RA. There is need of use of latest technologies, like use of soil moisture sensors, which can be helpful in saving the water. According to him, a lot number of technologies have been developed, but these technologies, need to be promoted on large scale. According to him, there is also need of restoration of degraded land.

Dr. Benukar Biswas, (Professor, BCKV Nadia, India), gave presentation on Agroforestry in relation to RA and told that land degradation is now the global concern in the form of food security, environmental hazards and loss of biodiversity and ecosystem services. He mentioned that according to a report, during 2015-19, one hundred million hectare/year land has been degraded (UNCCD,2019). According to him, there are certain advantages of integrating, RA with agroforestry, which include environmental, economic and social benefits. He mentioned that there is need of identification of site-specific regenerative agroforestry models and their scaling-up; and integrate these with climate action plans and regional collaboration in the SAARC Member States.

Dr. Bal Krishna Joshi (Head Genebank, NARC Kathmandu Nepal), gave presentation on Agrobiodiversity in Regenerative agriculture. Accoding to hin, with good agrobiodiversity, ecological pest management is better and there is also need of promotion and utilization of site specific genetic diversity. He also suggested that donot monotype the world and donot creat conditions for pandemics.

Dr. Md. Mosharraf Uddin Molla, Member Director (AERS Division BARC, Dhaka, Bangladesh), gave presentation on community engagemant and eduaction in Regenerative agriculture. According to him, we should use the latest technologies to make the people aware about RA and in this regard use of latest digital tools, practical trainings of the people and publication and distribution of practical guidelines and manuals can be useful. He stated that by the engagement of community through education tools i.e. practical guidelines and manuals, online platforms and digital tools, on-farm training, knowledge exchange and youth engagement, RA needs to be promoted.

Dr.Mustafizur Rahman (PSO, BMWRI, Dinajpur, Bangladesh), delivered lecture on use of Biopesticides for crop insects, pests management in Regenerative agriculture. He informed that out of total 8.74 million species on earth 2.6 million are insects. Out of the 1.5 million known insect species in the world, over 97% are beneficial or harmless. According to a study around 24.5 million km^2 or 64% of global agricultural land is at risk of pollution from multiple pesticides with 31% of these areas are at high risk. Pesticides have effects on human health and ecosystems, so Biopesticides are the best alternative to synthetic chemical insecticides. According to him, the advanatges of Biopesticides in RA are that, these are cost-effective for small farmers and are compatible with IPM, and these also help in soil health improvement. He stated that still there are certain challanges in the adoption of Biopesticides on large scale.

Dr. Karishno Kanta Ray (PSO, BMWRI, Dinajpur, Bangladesh), gave presenattion on Disease management in RA and told that a number of diseases are increasing on large scale, so there is need of proper monitoring and control of diseases.

Prof. Jasimuddin, from Sher-e-Bangla Agricultural University in Dhaka, Bangladesh, gave presentation on Horticulture and Regenerative agriculture. In his presentation, he showed the results of his one study, which has been conducted on Broccoli crop by using the Pinching technology (Removal of apical bud i.e., growing tip). Pinching is an alternative novel cultural management technique for growth, quality and higher yield of Broccoli. By using this technology, the Broccoli plant develops the lateral branches and side shoots. This method helps in increasing branches of plants, improves the air flow, controls plant height and ultimately gives better yields by giving multiple marketable heads.

Dr. Gajanan Sawargaomkar (Principal Scientist -1, Agronomy Resilient Farm and Food Systems ICRISAT-IN, India), gave presentation on the use of Biochar in relation with soil health and told that burning of crops residues is a big issue, so instead of burning the residues, these can be converted into Biochar. Use of Biochar will have a number of positive effects on soil health.

Dr. Zannatul Ferdous Manik (Senior Scientific Officer, OFRD Rangpur, BARI, Bangladesh), in his presentation toldabout the benefits of use of different types of composts and their beneficial effects on soil health. According to him, use of compost is a big source of nutrients and it is beneficial in all countries. Composting is a natural process that turns organic materials into nutrient - rich soil conditioner. He mentioned in detail about the RA and told that Regenerative agriculture restores and improves, the soil health. It helps in reducing GHGs emissions and promotes carbon sequestration. He also mentioned that for promotion of use of composts, there is need of involvement of community.

Dr. Navid Tahir (Associate Professor, PMAS, Arid Agriculture University, Rawalpindi, Pakistan), in his talk told that, by the use of latest precision agriculture technolgies, we can save water and other inputs i.e. 45% less chemicals are used in RA and it will not only cut down the cost of production and will be also enviromental friendly. Similarly by using the Seed Depth Monitoring System, 8% more germination has been recorded.

Dr. Murtaza Hassan Indrabi (Member Animal Sciences PARC, Islamabad, Pakistan), gave presentation on Crop - livestock integration and Regenerative agriculture and told that livestock is an integral part of our economy, and better management of crops and rearing of animals together can have a positive effect on soil health and it is financially supportive to the farming community. According to him, simultaneously management/production of crops and livestock at the same farm helps in reduction of use of chemical fertilizers. He informed that 189 farms in Bahawalpur district of Pakistan have adopted Regenerative agricultural practices. He further informed that although mixed farming is common in this region, but there is a lack of focus on promotion of Regenerative agriculture.

Dr. Sreejith Aravindakshan (Scientists, CIMMYT-Bangladesh) gave presentation on Circular Farming / C economy in Regenerative agriculture, and mentioned the benefits of RA on soil health, water saving, nutrient saving and overall productivity.

In each session, there was detailed discussion on the different aspects of RA, hurdles in its promotion and the ways to promote it on large scale in the SAARC Member States. It was suggested that the policy is needed for the promotion of Regenerative agriculture in the SAARC Member States. The policy should be helpful in reducing the cost of production and it should be supportive in the protection of environment. It was also concluded that yield should not be sacrificed under Regenerative agricultureAgriculture.

At the end of this regional consultation meeting, there was detailed discussion on the different aspects of Regenerative agriculture and recommendations of the meeting are given as under:

1. Research

- Research is needed to be conducted on different aspects of Regenerative agriculture, like use of different tillage methods, different types of nutrients, use of manures, composts, biofertilizers and crop rotations etc.
- Varietal development of crops must focus on root architecture (Root: Shoot ratio) for their promotion under Regenerative agriculture.
- Deep rooted crop varieties need to be developed to explore unexploited nutrients under Regenertive agriculture.
- Quality assurance of Biopesticides and Biofertilizers for their use on large scale under Regenerative agriculture.
- There is need of revamping of science/education syllabus regarding soil health and soil health care.
- There is need to conduct research on mitigation/adaptation .
- There is need of conducting research regarding Regenertive agriculture on the basis of system based approach.
- There is need of development of modern and acceptable Regenerative agriculture technologies for their rapid promotion on farmers' fields.
- There is need of continuous research on the different aspects of Regenerative agriculture.
- There is need of demonstration of different Regenerative agriculture technologies in the different agro ecological zones of each SAARC Member State.
- There is need of research on Regenerative agriculture with reference to Agroforestry and Silviculture.
- There is need of research on the development of soil organic matter with reference to use of composts.
- There is need of use of latest technologies/tools for Regenerative agriculture.
- Research on Regenerative agriculture with reference to crop-livestock integration system.
- There is need of promotion of climate-smart agricultural practices such as conservation tillage and cover cropping.
- There is need to encourage multi-cropping systems for soil enrichment and income diversification.
- There is need to focus on women's engagement in composting, Bio-fertilizer production, and seed saving.
- Promotion of use of plastic-free, eco-friendly materials in farming.
- Encourage use of cow dung, compost, and other organic inputs in Regenerative agriculture.
- There is need to support seed preservation techniques to maintain indigenous crop varieties.
- There is need to develop crop preservation and storage techniques to reduce post-harvest losses.
- There is need to link organic practices with income generation by accessing niche markets and certification schemes.
- Promote homestead agroforestry for household nutrition and income.
- There is need to design such types of agroforestry models that should improve soil health and reduce erosion.
- Development of agroforestry systems that are economically viable for smallholder farmers.

- There is need of integration of eco-tourism opportunities with agroforestry (e.g., farm visits for tourists).
- Encourage diversified tree–crop systems to increase resilience and biodiversity.

2. Extension System Suggestions/ Recommendations

- Develop inclusive extension programs targeting youth and women.
- Provide incentives or subsidies for adopting Regenerative agriculture practices.
- Create community-based resource centers to support knowledge sharing.
- Partnerships with NGOs, research institutions, and private sectors to scale up successful models of RA on large scale.
- Awareness among the farmers by using the latest technologies like IT tools for promotion of Regenerative agriculture.
- Use participatory extension approaches to ensure farmer ownership and sustainability.
- Conduct awareness campaigns and sensitization programs for farmers.
- Use digital tools and media platforms (videos, SMS, social media) to spread knowledge.
- Offer trainings for farmers on bio-pesticide preparation and sustainable inputs.
- Establish field demonstrations showcasing Regenerative agriculture techniques.
- Strengthen Farmer Field Schools (FFS) to improve crop intensity and knowledge exchange.
- Organize capacity-building programs led by trained master trainers.

3. Policy recommendations for capacity building

- Capacity building of the different stakeholders including farmers, service providers, agri. business entrepreneurs, researchers and scientists.
- Financial support for further research and extension of Regenerative agriculture.
- Human resource development on Regenerative agriculture, especially for higher education.
- Trade support policy including certification and market access etc.
- Development of a crop and livestock integration policy.
- Support policies for the farmers who adopt Regenerative agriculture for Carbon credit.
- Policies for linking Regenerative agriculture promotion with NGOs/INGOs by the Governments.
- Policy for Regenerative agriculture promotion by engaging community through Agriculture Extension Departments.
- Development of policy for adaptation of Regenerative agriculture by the farmers.
- Development of policies for standardization of bioproducts like biofertilzers and compost etc.

Meeting Agenda

Regional Consultation Meeting on
"Promotion of Regenerative Agriculture in SAARC Member States"

Date: 04-06 August, 2025

Organized by SAARC Agriculture Centre (SAC), Dhaka, Bangladesh

Venue: Virtual

Program Schedule

Meeting Time: August 04 to 06, 2025 (10:30 am to 14:00 pm, every day, Bangladesh Time)

Day-1: (04 August 2025)- Inaugural M.C: AHM Taslima, STO, SAC

Time	Program	Responsibility
	Inaugural Session	
10:30-10:40	Welcome address	**Dr. Md. Harunur Rashid** Director, SAARC Agriculture Centre, Bangladesh
10:40-10:50	Introduction of the participants	
10:50-11:00	Regenerative Agriculture, consultation meeting objectives and overview of the program.	**Dr. Sikander Khan Tanveer** Senior Program Specialist (Crops), SAC
11:00-11:25	Regenerative Agriculture: Restoring Earth's Balance Through Soil, Science, and Stewardship.	**Dr. Debashis Chakraborti** Senior Scientist & Cropping Systems Agronomist (CWANA) , CIMMYT Office Bangladesh.
11:25-11:30	Remarks by the Special Guest	**Mr. Tanvir Ahmad Torophder** Director (ARD & SDF) SAARC Secretariat, Kathmandu, Nepal
11:30-11:40	Remarks by the Chief Guest	**Ambassador Abdul Motaleb Sarker** Additional Foreign Secretary (SAARC & BIMSTEC), MoFA, Dhaka Bangladesh.
11:40-12:00	**Break**	
Technical Session: 01, Session Chair: **Dr. Md. Harunur Rashid, Director, SAC** **Rapporteurs:** SPS (NRM) and SPO (NRM)		
Country Paper Presentations		
12:00-12:20	Country paper presentation of Bangladesh	
12:20-12:40	Country paper presentation of Bhutan	
12:40-01:00	Country paper presentation of India	
01:00-01:20	Country paper presentation of Maldives	
01:20-01:30	Open Discussions	
Technical Session: 02, Session Chair: Dr. Md. Harunur Rashid, Director, SAC **Rapporteurs:** SPS (NRM) and SPO (NRM)		
01:30- 01:50	Conservation Agriculture.	**Dr. Mahesh Gathala** Country Head CIMMYT, India
01:50- 02:00	Open discussion	
Closing of the Day 01		

Day-2 (August. 05, 2025) **Technical Session-03 (Session Chair: Dr. Md. Baktear Hossain, Member Director (NRM), BARC)** **Rapporteurs:** SPS (Livestock) SAC and SPO (NRM) SAC		
Country paper Presentation		
10:30-10:50	Country paper presentation of Nepal	
10:50-11:10	Country paper presentation of Pakistan	
11:10-11:30	Country paper presentation of Sri Lanka	
11:30- 11:40	Open discussion	
11:40- 11:50	Break	
Technical session-04 Session Chair: **Dr. Wais Kabir, Former Executive Chairman, BARC** **Rapporteurs:** SPS (NRM) SAC and SPO (NRM), SAC		
11:50- 12:10	Carbon Sequestration and Biofertilizers with reference to Regenerative Agriculture	**Dr. Anupam Das** Assistant Professor, BAU, Bhagalpur, India
12:10- 12:30	Water Management in Regenerative Agriculture.	**Mr. Mohammed Faiz Alam** IWMI-India
12:30- 12:50	Agroforestry in relation to regenerative agriculture.	**Dr. Benukar Biswas,** Professor, BCKV, Nadia, India
12:50-01:20	Agrobiodiversity in Regenerative Agriculture	**Dr. Bal Krishna Joshi** Nepal
01:20-01:40	Community Engagement and Education in Regenerative Agriculture	**Dr. Md. Mosharraf Uddin Molla** Member Director (AERS Division) BARC, Dhaka, Bangladesh
01:40 -02:00	Discussions	
End of the day 02		
Day-3 (August. 06, 2025)		
Technical Session -05: Session Chair: Dr Md. Abdur Razzaque, Former Executive Chairman, BARC **Rapporteurs:** SPS (Livestock) SAC and SPO (NRM), SAC		
10:30-10:50	Use of Biopesticides for crops insects, pests' management in Regenerative Agriculture	**Dr. Mustafizur Rahman** PSO, BMWRI Dinajpur Bangladesh
10:50-11:10	Crops disease management in Regenerative Agriculture	**Dr. Karishno Kanta Ray** PSO, BMWRI Dinajpur Bangladesh
11:10-11:30	Horticulture and regenerative agriculture.	**Prof. Jasim Uddain,** Sher-e-Bangla Agricultural University in Dhaka, Bangladesh.
11:30-11:50	Use of Biochaar in relation with soil health.	**Dr. Gajanan Sawargaomkar** Principal Scientist -1 Agronomy Resilient Farm and Food Systems ICRISAT-IN, India
11:50-12:10	Compost use and Regenerative Agriculture for Sustainable crop production	**Dr. Zannatul Ferdous Manik** Senior Scientific Officer, OFRD Rangpur BARI, Bangladesh

12:10-12:30	Tea Break	
Technical Session -06: Session Chair: Dr. Md. Akkas Ali, Director Crops, KGF, Bangladesh **Rapporteurs:** SPS (NRM) SAC and SPO (NRM) SAC		
12:30-12:50	Precision Agriculture with reference to Regenerative Agriculture	**Dr. Navid Tahir** Associate Professor PMAS, Arid Agriculture Uni.Rawalpindi Pakistan
12:50-01:10	Crop-Livestock Integration and Regenerative Agriculture	**Dr. Murtaza Hassan Indrabi** Member Animal Sciences PARC, Islamabad, Pakistan
01:10-01:30	Circular Farming / C economy in RA.	**Dr. Sreejith Aravindakshan** CIMMYT-Bangladesh
01:30 - 01:50	**Discussion** • Technologies related to Regenerative Agriculture • Technologies adoption • Machinery • Research • Economic issues • Social Issues • Extension • Role of NGO's / INGO's role / Private Sector • Government Support/Policy	
01:50- 02:00	Recommendations / Conclusion	**Dr. Sikander Khan Tanveer, SPS (Crops), SAC, Dhaka Bangladesh**

List of participants

Regional Consultation Meeting on "Promotion of Regenerative Agriculture in SAARC Member States"

Date: 04-06 August, 2025

Organized by: SAARC Agriculture Centre (SAC), Dhaka, Bangladesh

Mode: Virtual

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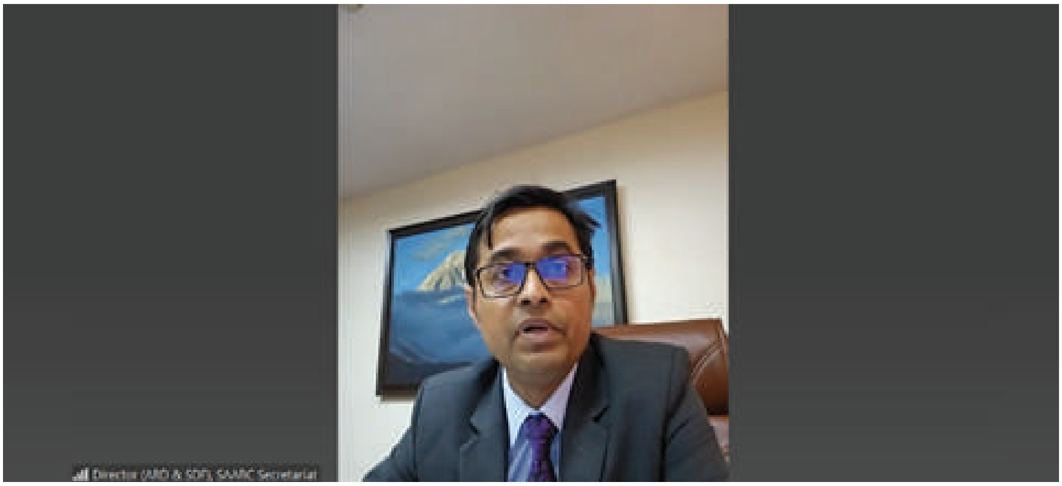
Photo Gallery

Ambassador Mr. Abdul Motaleb Sarker, Additional Foreign Secretary (SAARC & BIMSTEC), MoFA, Dhaka, Bangladesh, Chief Guest of the Meeting.

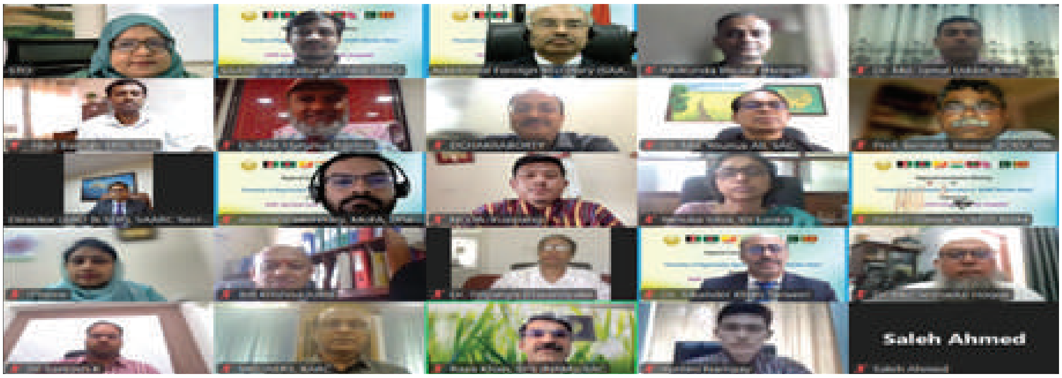


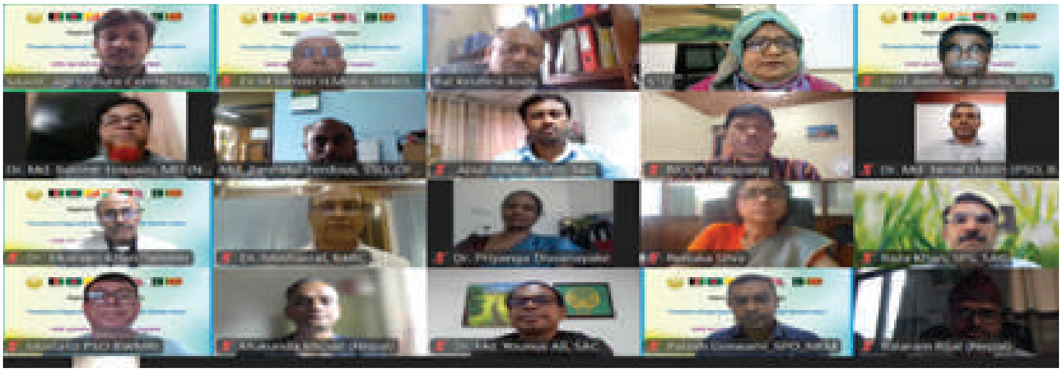
Mr. Tanvir Ahmad Torophder, Director (ARD & SDF) SAARC Secretariat, Kathmandu, Nepal, Special Guest of the Meeting

Dr. Md. Harunur Rashid, Director, SAARC Agricultural Centre, Dhaka, Bangladesh,
Welcoming the Meeting Participiants.

Dr. Debashis Chakraborti, Senior Scientist & Cropping Systems Agronomist (CWANA) CIMMYT
Office, Bangladesh, Keynote Speaker of the Meeting.

Dr. Sikander Khan Tanveer, Senior Program Specialist (Crops), SAARC Agricultural Centre, Dhaka, Bangladesh, Presenting objectives and overview of the Program.





Photos of Regional Consultation Meeting on, “Promotion of Regenerative Agriculture in SAARC Member States” 04-06 Auguest 2025.

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978-984-35-9315-3