



# Compendium of Regenerative Agriculture: A Guide to Sustainable and Resilient Production Systems

**Citation:** Pushpajeet L Choudhari, Rajesh Pasumarthi, Mukund Patil, Padmaja Karanam, Ramesh Singh, Gajanan Sawargaonkar, Kaushal Garg, Rakesh Savan, Santosh Kale, Biswanath Behera, Munmun Dihudi and ML Jat (2024). Compendium of Regenerative Agriculture: A Guide to Sustainable and Resilient Production Systems, Patancheru 502 324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 48 pp.

## Acknowledgement

This compendium is one of the outputs of the project “Development and Validation of Carbon Standards for Incentivizing Farmers for Regenerative Agricultural Practices (CSIFRA)” funded under the aegis of innovative funds, Govt. of Odisha. We acknowledge and express our sincere gratitude to the Department of Agriculture and Farmers’ Empowerment, Government of Odisha for the partnership and unwavering financial support. We also thank the Department of Agriculture and Farmers’ Empowerment-Odisha, innovative project scheme officers-Bhubaneswar and all the district agricultural officers from the state of Odisha. We are grateful to the One CGIAR– An Initiative on Agroecology which aims to promote sustainable agricultural practices that enhance biodiversity, improve soil health, while ensuring food security and livelihoods for farmers.

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# Compendium of Regenerative Agriculture: A Guide to Sustainable and Resilient Production Systems



2024







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Department of Agriculture  
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## Foreword

It is my pleasure to introduce the Compendium of Regenerative Agriculture: A Route to Sustainable and Resilient Production Systems. As we face intersecting global crises – land degradation, biodiversity loss, climate change, and malnutrition – it is imperative that our agricultural methods and policies prioritize both environmental sustainability and human well-being.

This comprehensive compilation provides a well-informed approach to harnessing regenerative agriculture's potential to address these pressing issues. Regenerative agriculture represents a paradigm shift toward holistic, resilient, and sustainable food systems that harmonize with natural ecosystems by prioritizing soil health, biodiversity, carbon sequestration, and community resilience.

Key regenerative practices, such as direct seeded rice, minimum tillage, crop diversification, nutrient management, and organic amendments, should be integrated to develop resilient food systems.

The policies we enact today, informed by scientific evidence, will shape the future of agriculture. Governments, organizations, and stakeholders have a unique opportunity to transform the agriculture industry using the insights presented in this compendium.

By incorporating regenerative methods into national and local policies, we can enhance farmers' livelihoods while restoring ecosystems and promoting economic resilience.

I commend the authors and contributors for their dedication to compiling this valuable resource for practitioners, scholars, and policymakers.

Together, we can create a future where agricultural systems regenerate our soils, replenish ecosystems, and support sustainable livelihoods.

I urge decision-makers and leaders in the agriculture sector to utilize this compilation as a roadmap for crafting innovative, practical policies that support sustainable agricultural systems and ensure food security for future generations.

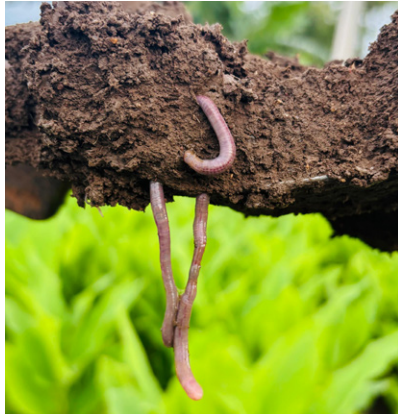
As a pioneering state in championing regenerative agriculture for carbon farming, Odisha takes pride in its commitment to this critical cause.

"Regenerative agriculture isn't just a farming method – it's a culture for healing the land, restoring ecosystems, and securing food systems for future generations."

I wish this publication great success.

(Dr. Arabinda K. Padhee)









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# PREFACE

In a world grappling with the profound impacts of climate change and environmental degradation, the need for a transformative shift in our approach to agriculture has never been more urgent. While conventional farming has significantly increased our food supply, it has also contributed to climate change through greenhouse gas emissions, soil depletion, and a decline in biodiversity. As the effects of these practices become increasingly evident, the call for more sustainable solutions grows louder. Enter regenerative agriculture—a beacon of hope and a promising path forward. This compendium offers a deep dive into the essence of regenerative agriculture, exploring its principles and practices and uncovering how it can address the complex challenges facing modern farming.

Climate change, driven by human activities, has led to rising temperatures, erratic weather patterns, and more frequent extreme weather events. Agriculture, inherently connected to these climatic shifts, is particularly vulnerable. Traditional farming methods exacerbate these challenges by relying on intensive chemical inputs, monocultures, and soil-degrading practices. Livestock, rice paddies, and synthetic fertilizers release significant amounts of methane and nitrous oxide—potent greenhouse gases that intensify global warming. These conventional practices emit greenhouse gases and compromise soil health, diminishing its ability to sequester carbon and support productive agriculture.

Against this backdrop of environmental strain, regenerative agriculture emerges as a transformative and hopeful vision. It invites us to reimagine agriculture not merely as a place of production but as a vibrant, interconnected ecosystem. By focusing on rejuvenating soil health, conserving water, and fostering biodiversity, regenerative practices offer a path to mitigate climate impacts and enhance food security. This shift is especially crucial in countries like India, where agriculture is not only a way of life but a lifeline for millions and where pressing issues such as water scarcity, soil degradation, and climate vulnerability demand urgent attention.

At the heart of regenerative agriculture lies the understanding that soil is a living, breathing entity rich with microbial life—an essential foundation for agricultural productivity. Regenerative practices—such as minimizing soil disturbance, employing cover crops, and diversifying crop rotations—are designed to enhance soil health and resilience. These methods align with natural processes, harnessing the power of ecosystems to restore and sustain the land. Unlike industrial farming, which often depletes soil and biodiversity, regenerative agriculture aims to heal and balance our natural resources.

This compendium delves into the fundamental principles of regenerative agriculture: minimizing soil disturbance, maximizing crop diversity, keeping soil covered, maintaining living roots year-round, and integrating livestock. Each principle is explored in depth, highlighting its significance for soil health, carbon sequestration, and farm resilience. By adopting a holistic perspective that transcends individual farm boundaries, regenerative agriculture fosters collaborative efforts to build resilient and sustainable food systems.

This compendium reveals how regenerative agriculture can redefine our relationship with the land by comprehensively examining these principles. It underscores the necessity of moving beyond traditional practices and advocating for methods that sustain and enhance the health of our ecosystems.

As we navigate the complexities of climate change and environmental degradation, regenerative agriculture offers a pathway to a more sustainable and resilient future. This compendium invites you to explore these transformative practices, appreciate their benefits, and envision a future where agriculture harmoniously coexists with the natural world, ensuring a healthier planet for future generations.



# 1. Regenerative Agriculture: A Route to Sustainable and Resilient Production Systems



It is more important than ever to radically change our view of agriculture in a world where environmental degradation and climate change are having a significant negative influence. While conventional farming has significantly increased our food supply, it has also contributed to climate change through greenhouse gas emissions, soil depletion, and a decline in biodiversity. As the effects of these practices become increasingly evident, the call for more sustainable solutions grows louder. In this scenario, regenerative agriculture emerges as a beacon of hope, pointing to a promising path forward. This compendium offers a deep dive into the essence of regenerative agriculture, exploring its principles and practices and uncovering how it can address the complex challenges facing modern farming.

Rising temperatures and unpredictable weather, driven by climate change caused by human activity, make agriculture highly vulnerable. Traditional farming methods, relying on chemicals, monocultures, and soil-degrading practices, worsen the issue. Paddy fields, livestock, and synthetic fertilizers emit large amounts of methane and nitrous oxide, intensifying global warming. These practices also harm soil health, reducing its capacity to sequester carbon and sustain productive farming. Against this backdrop, regenerative agriculture offers a solution to environmental challenges, reimagining farming as an interconnected ecosystem. By focusing on biodiversity, water conservation, and soil health, it improves food security and mitigates climate change. This shift is especially critical in countries like India, where agriculture sustains millions and faces urgent issues like water scarcity, soil degradation, and climate vulnerability.

Understanding that soil is a dynamic living system teeming with microbial life is fundamental to agricultural productivity and lies at the heart of regenerative agriculture. Regenerative practices—such as reducing soil disturbance, using cover crops, and diversifying crop rotations—are designed to improve soil health and resilience. These methods work harmoniously with ecosystem natural processes, supporting land restoration and sustainability. In contrast to industrial farming, which often depletes soil and biodiversity, regenerative agriculture seeks to heal and restore the balance of natural resources.

This compendium explores the fundamental principles of regenerative agriculture, including minimizing soil disturbance, enhancing crop diversity, maintaining soil cover, keeping living roots in the ground year-round, and integrating livestock. Each principle is examined in detail, highlighting its critical role in improving farm resilience, sequestering carbon, and fostering healthy soils. By adopting a holistic approach beyond individual farms, regenerative agriculture is a way to create resilient and sustainable food systems.

Regenerative agriculture provides a way forward for a more resilient and sustainable future as we negotiate the complexity of climate change and environmental degradation. This compendium helps us



explore transformative practices, appreciate their benefits, and envision a future where agriculture harmoniously co-exists with the natural world, ensuring a healthier planet for future generations.

The details highlight its critical role in improving farm resilience, sequestering carbon, and fostering healthy soils. By adopting a holistic approach beyond individual farms, regenerative agriculture can create resilient and sustainable food systems.

Regenerative agriculture provides a way forward for a more resilient and sustainable future as we negotiate the complexity of climate change and environmental degradation. This compendium explores transformative practices, appreciates their benefits, and envisions a future where agriculture harmoniously coexists with the natural world, ensuring a healthier planet for generations to come.

Central to regenerative agriculture is acknowledging soil as a living organism, teeming with microbial life and the foundation of agricultural productivity. Practices such as minimal soil disturbance, cover cropping, and diverse crop rotations are key tenets that foster healthy and resilient soil development. Regenerative agriculture harnesses the power of innate microbial diversity to restore and sustain the health of the land.

Diversity is another hallmark of regenerative practices, both in terms of crops grown and the integration of livestock. Polyculture and agroforestry systems maximize resource utilization and contribute to enhanced biodiversity, fostering a balance often absent in monoculture systems. The incorporation of livestock, when managed thoughtfully, not only provides additional income streams for farmers but also contributes to nutrient cycling and soil fertility.

Regenerative agriculture has been suggested as a novel approach to food production that might have less impact on the environment and/or society or a net positive impact. It is a concept and method of managing land that urges us to consider how all parts of agriculture are interconnected through a web that grows, enhances, exchanges, distributes, and consumes goods and services. It is about farming to feed both the planet and people, with methods differing from farmer to farmer and area to area.

Regenerative agriculture holds great potential for mitigating climate change, enhancing biodiversity, improving soil health, and redefining the human-land relationship. Farmers who adopt regenerative practices take on the role of earth stewards, caring for the soil that provides our food. The ideas pitched in this compendium are proven regenerative agricultural practices that can be scaled up to have a significant impact on the ground.









## 2. Principles and Benefits of Regenerative Agriculture

Minimizing soil disturbance enhances soil fertility, preserves pore connections and soil structure.

### 1 Minimizing Soil Disturbance

According to this principle, increasing community variety is crucial for fostering robust ecosystems and reducing the incidence of pests and diseases. One way to promote plant diversity is to use techniques like companion cropping, cover cropping, and crop rotation.

### 2 Maximizing Crop Diversity

This principle emphasizes how vital the soil surface—a layer of mineral soil with a high concentration of organic matter—is for controlling water content, maintaining soil structure, and obtaining nutrients. Living plants or agricultural residues covering the soil's surface, prevent weathering and erosion damage to the soil and the organisms that live there.

### 3 Keeping the Soil Covered

### 4 Maintaining Living Root Year-round

Living roots in the soil are essential for the organisms at the base of the soil food web to have something to eat.

Appropriate cattle grazing enhances plant development, boosts nutrient cycling, and disperses organic matter. Managed cattle grazing reduces soil disruption, enhances soil health, supports carbon sequestration, and combats climate change.

### 5 Integrating Livestock



5-12% System Yield (increased)



46-62% Energy (saving)



10-30% in WUE (increased)



20-27% Profitability (increased)



26-44% Labor (saving)



12-33% reduction in GWP





## 2.1 Minimizing Soil Disturbance



**Physical disturbance:** Tillage and grazing are examples of physical disturbances that compromise the biological integrity of the soil ecosystem. Avoiding overgrazing, decreasing mechanical compaction, and cutting back on tillage techniques can reduce this.



**Chemical disturbance:** Pesticides and fertilizers, which may be harmful to the soil's microbial population, should be minimized to prevent disruption.



**Biological disturbance:** It occurs when there are no living roots in the soil. The section below on “Maintain Living Roots” covers this.

Various creatures inhabit the soil, including nematodes, arthropods, bacteria, fungi, protozoa, and worms. Because only certain organisms can withstand the damage, mechanical soil disturbance is particularly detrimental to soft-bodied organisms like earthworms. It can lead to a drop in biological diversity in the soil. Reducing tillage can enhance a farm's soil biodiversity and achieve an ideal soil structure. Farmers have been plowing their fields for years because it can reliably promote uniform crop establishment regardless of the weather.

Plowing or power harrowing disturbs the physical structure of the soil and improves aeration. This hastens the decomposition of soil organic matter, leading to the oxidation of the soil's organic carbon. Similarly, excess fertilizer treatment imbalances the soil, causing nutrient leakage and/or decreases in soil carbon.

### Why is this principle so crucial?

- Carbon sequestration and soil aggregation are improved by no-till or minimal-tillage farming.
- Improved soil health and higher-quality fodder can improve animal health and nutrition.
- Crop yields can benefit from increased soil organic matter because of its better nutrient delivery.
- Soil that has not been disturbed enables living things to locate and operate as intended.
- Soil pores at the top are related to the soil fabric below, minimizing soil disturbance, which enhances water infiltration and reduces the chance of flooding and surface runoff.





## 2.2 Maximizing Crop Diversity

It is extremely rare to see a monoculture in a natural ecosystem (where one crop is planted in a field as opposed to several crop varieties). Monocultures are the foundation of modern agricultural techniques since they are easy to maintain. On the other hand, because different plant species are associated with different soil creatures that provide food for the natural soil food web, above-ground crop diversity also contributes to below-ground diversity. Different organisms are responsible for different nutrient cycles, the soil food web functions optimally when as many of these linkages as possible are present.

Cereal- and legume-based cropping systems are the best examples of crop rotation and intercropping that could harness the potential of biological nitrogen fixation.

### Why is this principle important?

- Biodiversity enhances ecosystem function by allowing different species to perform varied roles.
- Improving crop diversity increases resilience to drought and flooding, reducing the risk of crop damage.
- Cover crops, diverse crop rotations, and perennial crops boost soil fertility and enhance biological ecosystem diversity, which is crucial for crop resilience.
- Perennial pastures improve water quality and enhance soil water storage capacity through organic matter accumulation.
- Increasing on-farm species diversity supports various ecosystem services, including food provision, water supply, and nutrient cycling, leading to greater ecological function.
- Crop diversity can help suppress diseases and control pests.





## 2.3 Keeping the Soil Covered

There are numerous advantages to having the soil covered, such as shielding it from wind and water erosion and keeping it from drying out during a drought. For instance, in Scotland, it is common practice to leave the soil bare during the winter months, in between harvesting and seeding the spring crops. Maintaining soil cover can be accomplished in several ways, such as by planting a cover crop to shield the soil or by forming a mat of dead plant material from agricultural residues, like straw. Non-cash crops, known as cover crops, are planted in between two cash crops. The main function of these crops is to cover the soil's surface, shielding it from the elements and enriching it. Depending on what is needed, there are two alternatives for cover crops:

**Legumes** (cowpea, berseem, and mustard) and non-legumes (rye, wheat, oats, barley, sorghum, pearl millet, maize, and fodder grass)

**Rainfed areas:** rice is followed by cover crops of green gram, black gram, lentil, horse gram, lathyrus, pea and groundnut.



### Why is this principle so crucial?

- Cover crops physically defend soil against damage from rain, frost, and trampling and prevent soil erosion.
- They serve as a buffer against wind and lessen soil erosion.
- Enhance the soil structure, leading to a more varied network of pores, efficient infiltration, and gas exchange.
- Promote elevated microbial and worm activity.



## 2.4 Maintaining Living Root Year- round

Plant and soil biology have an interdependent relationship centered around plant roots and root exudates. Soil is a dynamic medium hosting organic substances excreted by plants. These exudates provide an energy source for soil biology in the rhizosphere and play a role in quorum sensing by sending signals to specific microorganisms.

This principle emphasizes how crucial it is to keep living roots in the soil to preserve nutrients, enhance plant development, and increase the diversity of microbes. Energy from the sun is converted by living plants through photosynthesis into chemically bonded energy, which is subsequently absorbed by plant root systems and the soil environment. In the absence of active roots, soil continues to break down organic materials and releases carbon dioxide (CO<sub>2</sub>) into the atmosphere. Thus, it is critical to preserve live roots to preserve soil carbon sequestration. Plant-to-plant and plant-to-soil communications through root exudates depend on living roots. Exudates from live root cells are chemical substances that serve as messenger molecules in the interactions between plants and microorganisms.

These exudates boost soil health and plant growth through a variety of processes, such as improved nutrient availability, better nitrogen fixation, and increased stress tolerance. Mycorrhizal fungi, an extension of the plant root, are responsible for this. The plant receives water and nutrients from the fungi, and the fungi, in turn, receive organic molecules from the plant through photosynthesis. By joining various plant species together to create shared mycorrhizal networks, this mycorrhizal fungus acts as a natural pest control for the plants, sending signals in response to pathogen invasion.

### Why is this principle important?

- Long-term plants develop deeper roots, which promote the accumulation of organic matter and lower the risk of soil erosion.
- When the cash crop biomass decomposes, nitrogen and other nutrients are available for the succeeding crop.
- It enhances nutrient flows and the distribution of organic matter through improved bioturbation, which is the process by which plants and animals rework soils and sediments.
- Enhances soil aggregation, runoff reduction, and infiltration by excreting polysaccharides from root exudates.
- The base of the food web receives its energy (polysaccharides) from root exudates.
- In comparison to plant roots, mycorrhizal fungal strands that act as extended roots are smaller and grow in smaller soil pores to improve nutrient and water uptake.
- Plant-to-plant signals are conveyed by mycorrhizal fungus, allowing healthy plants to react to possible pest or pathogen infection risks prior to attack.



## 2.5 Integrating Livestock

The concept emphasizes how essential it is to graze cattle properly to enhance plant growth, increase the cycling of nutrients, and disperse organic matter. The control and modification of five important grazing fundamentals must be examined to ensure this principle is successfully implemented: these are time, frequency, intensity, length, and rest. Even though integrating animals is not feasible in some farming systems, this idea remains viable, for example by using slurry and manure as inorganic fertilizer sources.

### Why is this principle so crucial?

- In addition to increasing soil carbon deposits and promoting plant growth, well-managed grazing techniques also improve soil fertility, plant biodiversity, and soil carbon sequestration.
- By letting cattle graze one area before moving on to the next, mob grazing lessens competition for grass between cattle, which in turn reduces stress and disease incidence in livestock.
- Performance on pastures can be enhanced by appropriate livestock integration. Long recovery times promote the biodiversity of multispecies grassland by permitting plant and soil species to recover.



# 3. Unearthing Potential: Tillage and Crop Establishment

## 3.1 Conservation Agriculture - A Climate-Smart Technology

### Introduction








Modern farming practices increasingly impact social, ecological, economic, and environmental realms, raising significant concerns about agricultural sustainability. Among the various agricultural tasks, plowing is often the most time-consuming operation. Reducing soil disturbance through tillage is a viable substitute that not only cuts down on water and time needed for land preparation but also safeguards the physical structure of the soil. Given Odisha's longstanding issues with soil erosion, declining fertility, and rising input costs, the widespread adoption of minimum tillage could significantly enhance agricultural sustainability in the region.

### Understanding Conservation Agriculture

Conservation agriculture is an agricultural practice characterized by reduced soil cultivation intensity and frequency compared to conventional tillage methods. This approach focuses on disturbing the soil minimally, preserving crop residues on the field, and utilizing specialized machinery for sowing without extensive plowing.

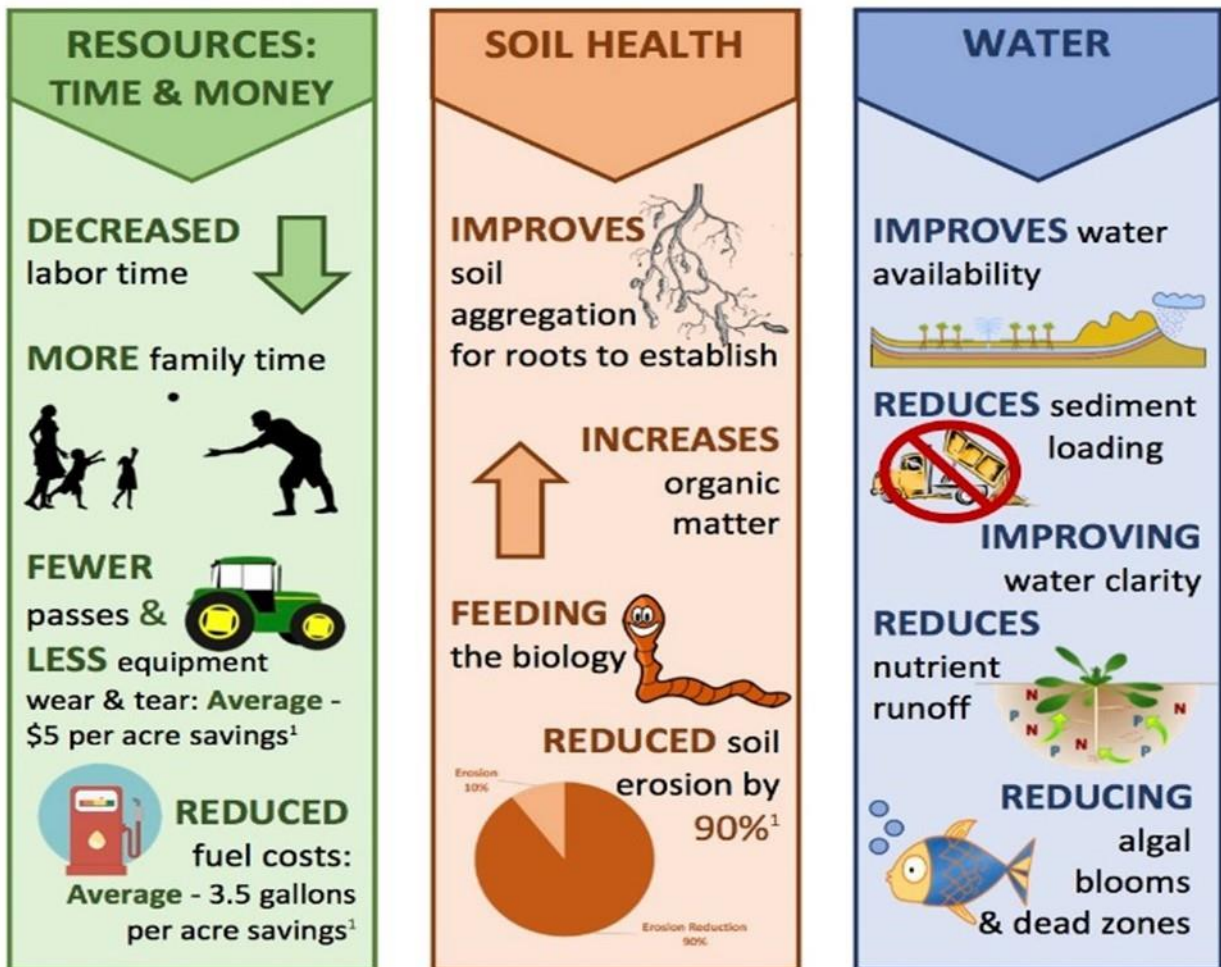
### Advantages of Conservation Agriculture

Conservation agriculture has a wide range of positive effects.

-  **Soil Conservation:** Reduces soil disturbance, thereby minimizing erosion and preserving the soil structure.
-  **Water Conservation:** Enhances water retention by reducing evaporation and improving infiltration rates.
-  **Increased Soil Fertility:** Preserves organic matter and nutrients, which raises crop yields and improves soil fertility.
-  **Resource Efficiency:** Lowers energy inputs and costs associated with traditional tillage practices, making farming more sustainable and cost-effective.
-  **Environmental Benefits:** Reduces greenhouse gas (GHG) emissions, aligning agricultural practices with environmental sustainability goals.
-  **Time and Labor Savings:** Requires significantly less time and labor compared to intensive tillage methods, increasing operational efficiency.
-  **Crop Residue Management:** Leaves crop residues on the field, providing soil cover and contributing to organic matter content.



## Benefits of conservation agriculture



Source: Fox demo farms

### Adoption sphere

- **Cost and Emission Reduction:** Minimum tillage significantly reduces costs by 2000 – 3000 Rs ha<sup>-1</sup> and GHG emissions associated with crop cultivation
- **Regional Practices:** This method is widely adopted in countries like India, Bangladesh, and Nepal, particularly in regions dominated by rice-wheat cultivation systems.
- **State Variability:** While adoption rates vary across regions, states like Haryana and Punjab in India showcase relatively high rates of minimum tillage adoption.
- **Challenges to Puddling:** The traditional practice of puddling for rice cultivation faces challenges due to water scarcity resulting from erratic rainfall patterns, emphasizing the need for alternative practices.
- **Future Trends:** The adoption of minimum tillage is anticipated to surge in India, particularly in Odisha, as farmers seek sustainable solutions to prevailing agricultural challenges.

### Conclusion

The implementation of minimum tillage represents a strategic shift towards practices that prioritize soil health, water conservation, and long-term agricultural sustainability. For this, the first step would be to identify a suitable production and cropping system for conservation agriculture. For example, the adoption of maize-based conservation agriculture production systems (CAPS) in rainfed uplands of Odisha can lead to crop intensification in marginal lands along with high economic returns.<sup>1</sup> Through capacity building and policy support for specific needs of farm machinery and chemicals, conservation agriculture practices may provide one of the solutions for sustainable agriculture in the state.



## 3.2. Direct Seeded Rice: A Sustainable Future for Odisha's Rice Production

### Background

Over half of the global population relies on rice (*Oryza sativa* L.), with Odisha, India, being a major producer of the staple food item. The traditional Manual Puddled Transplanted Rice (PTR) method faces numerous challenges, including declining water tables, increased labor costs, adverse soil health impacts, and heightened methane emissions. This has necessitated a shift toward more sustainable and economically viable rice cultivation practices. One such substitution that is becoming steadily more popular is the Direct Seeded Rice (DSR) method.

#### Direct-Seeded Rice (DSR)

DSR represents an innovative approach to rice cultivation, characterized by:

- **Direct Sowing:** It involves sowing seeds directly into the field after 2 harrowings and one puddling.
- **Resource Efficiency:** It employs Multi-Crop Planters or Turbo Seeders, allowing for efficient seed placement in puddled conditions.
- **Water Conservation:** DSR significantly reduces water requirements, addressing issues of water scarcity prevalent in many regions.
- **Labor Reduction:** The method is less labor-intensive than traditional practices, making it more economically viable for farmers.

#### Benefits of technology 2

- **Increased Productivity:** Yields from DSR can be 12-16% higher compared to PTR.
- **Enhanced Profitability:** Farmers adopting DSR can experience up to a 20% increase in profitability.
- **Water Savings:** DSR can save approximately 25% more water compared to transplanted puddled rice.
- **Reduced Cultivation Costs:** The overall cost of cultivation is about 10.44% lower with DSR.
- **Labor Efficiency:** Human labor costs can be reduced by up to 112%.
- **Environmental Benefits:** Methane emissions can decrease by 30-80%, contributing to a lower Global Warming Potential (GWP) by 20-44%.





## Existing Limitations

Despite its advantages, DSR faces several challenges:

- **Increased Seed Rates:** Higher seed rates can lead to increased costs and potential over-planting.
- **Predation Risks:** Seeds may be more vulnerable to bird and pest predation.
- **Weed Control:** Managing weeds can be more challenging in DSR systems.
- **Lodging Susceptibility:** Crops may be more prone to lodging, affecting yield and harvestability.
- **Inconsistent Establishment:** Crop establishment can sometimes be uneven or inadequate.

## Complementary Practices and Implementation

To maximize the benefits of DSR, the following complementary practices can be implemented:

- **Good Agronomic Practices:** Incorporating effective soil and crop management techniques is essential for optimizing yields.
- **Irrigation Strategies:** Utilizing sub-surface drip irrigation enhances water efficiency and crop health.
- **Crop Diversity:** Relay planting of pulses alongside DSR can improve system productivity and enhance soil quality.
- **Flexibility:** Both wet and dry DSR methods are viable, accommodating varying environmental conditions.





## Adoption Statistics

The resurgence of DSR is evident, particularly in South Asia, where it is being practiced on terraced and sloped lands. Globally, DSR is utilized over 33 million hectares, with about 7.2 million hectares in India. Adoption rates vary, with Punjab and Haryana leading, while Odisha presents significant potential for increased implementation. In addition to helping smallholder farmers boost their output and income, the DSR approach tries to lessen agricultural emissions and restore biodiversity.

## Conclusion

A groundbreaking development in rice cultivation is represented by the Direct-Seeded Rice (DSR) method, especially considering the difficulties brought about by resource shortages and climate change. As global rice demand continues to rise, DSR offers a promising pathway toward achieving food security while promoting environmental sustainability.

Key Initiatives by the Government of Odisha and ICRISAT

- ✓ **Agricultural Mechanization:** Promoting mechanized crop establishment and harvesting.
- ✓ **Varietal Selection:** Choosing suitable rice varieties based on local agro-climatic conditions.
- ✓ **Seed Treatment:** Enhancing seed viability and pest resistance through effective treatments.
- ✓ **Water and Nutrient Management:** Implementing efficient water and nutrient management strategies.
- ✓ **Pest Management:** Integrating holistic pest management, including weed control techniques.
- ✓ **Technology Integration:** Utilizing GIS and drone technology for precise agricultural monitoring.



## 4. Crop Diversification and Intensification

### 4.1 Intercropping: Strengthening Crop Resilience Amidst Changing Climate Conditions

#### Introduction

Conventional agriculture faces several second-generation agricultural problems, including soil degradation, water scarcity, climate change, weed infestation, and pest and disease proliferation.



**Soil Degradation:** Continuous cropping depletes soil nutrients.



**Water Scarcity:** Increased demand for irrigation amidst changing rainfall patterns.



**Weed Infestation:** Monocultures often lead to heightened weed pressure.



**Pest and Disease Proliferation:** Lack of crop diversity can exacerbate pest issues

Intercropping serves as a strategic response to the limitations of conventional rice-rice cultivation, thereby enhancing the region's agricultural economy. This sustainable farming method uses crop variety and the introduction of complementing species to address important challenges such as soil degradation, water scarcity, proliferation of weeds, and insect management.

Farmers may increase food security, optimize resource use, and stabilize their income in the face of market and climate volatility by putting intercropping systems into place. In addition to fostering agricultural resilience, this strategy supports the sustainable use of natural resources and offers a strong framework for tackling the region's ongoing environmental and economic issues.


#### Importance of Intercropping

Intercropping involves the simultaneous cultivation of multiple crops in designated row patterns, allowing farmers to diversify their outputs and optimize resource utilization. This strategy not only enhances resilience against climate change and market fluctuations but also fosters a more sustainable agricultural ecosystem.






## Types of Intercropping



**Row Intercropping**

It involves planting at least one companion crop in a single or double row. Significant interspecific interactions, including root mixing, shade, are made possible by this type of intercropping.



**Strip Cropping**

Planting crops in parallel strips, each with several rows, is known as strip cropping. The crops planted might be either different species or different cultivars of the same species.

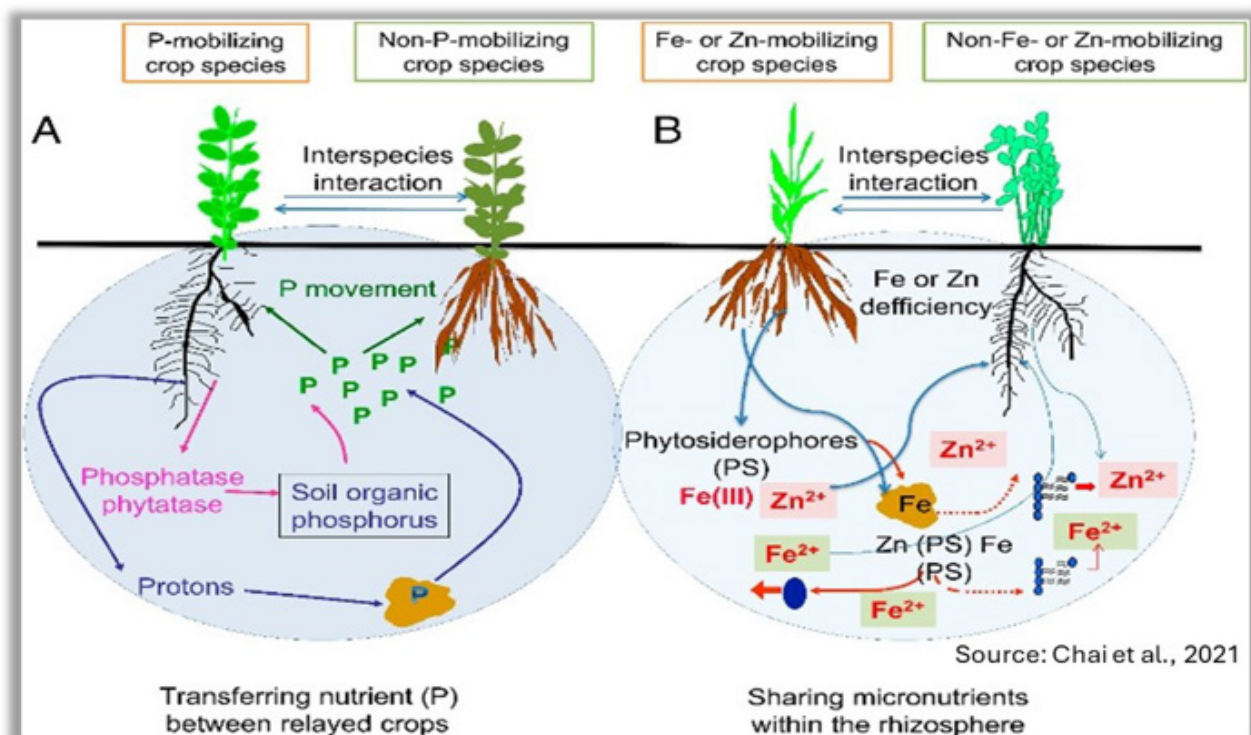


**Relay Cropping**

Planting a second crop within a first crop that is already standing before it is harvested.

In relay planting systems, below ground interspecies interaction occurs that facilitate nutrient sharing between nutrient mobilizing and non-nutrient mobilizing crop species.

For instance crop species having capacity to mobilize phosphorus makes the phosphorus available to the non phosphorus mobilizing crop species by releasing phosphatases, proton/or carboxylates into rhizosphere.<sup>3</sup>



## Role of Legumes in Intercropping

Research indicates that legumes, when intercropped with cereals, significantly enhance soil fertility through biological nitrogen fixation, adding approximately 80 to 350 kg N per hectare. This not only boosts yield but also improves protein output and fosters functional diversity within the ecosystem.

### Benefits of Intercropping

- **Increased Yield:** Optimizes land use for higher productivity.
- **Sustainable Production:** Enhances soil health and reduces input requirements.
- **Economic Stability:** Diversifies income sources, mitigating risks from crop failure.
- **Environmental Stability:** Supports ecosystem services and reduces reliance on chemical inputs.

### Challenges in Intercropping

- While intercropping is beneficial, it is labor-intensive and can complicate farm management.
- **Manual Labor Requirements:** Increased need for manual sowing and weeding can elevate operational costs.
- **Machinery Constraints:** Difficulties in operating machinery within intercropped fields necessitate more hands-on management.

### Recommended Crop Combinations

- **Rice and Legumes:** Mung beans, black gram, or pigeonpea for nitrogen fixation.
- **Rice and Mustard:** Commonly intercropped in winter, helps suppress weeds and provides additional income.





## Complementary Practices for Implementation

To optimize intercropping systems, farmers should:

- **Choose Suitable Crops:** Selecting crops that are adapted to local conditions ensures they can grow efficiently, reducing stress from environmental factors and increasing overall productivity.
- **Practice Precision Fertilization and Irrigation:** Implementing precise management of nutrients and water helps to fulfill the distinctive demands of various crops while boosting robust development and reducing waste.
- **Use Effective Management Practices:** Utilizing techniques that support the growth of both the main crop and intercrops, such as crop rotation and optimal spacing, can enhance the overall productivity of the farming system, leading to better yields and healthier crops.

## Adoption Statistics

Intercropping presents significant opportunities to boost agricultural productivity and diversification across various agro-ecologies. In Odisha, introducing new niche areas for pulse cultivation could substantially enhance grain production and improve farmer livelihoods. The Indian Council of Agricultural Research - Indian Institute of Farming Systems Research (ICAR-IIFSR) estimates that about 1 million hectares are currently dedicated to intercropping, involving approximately 0.70 to 0.90 million farmers. This practice is effective in both irrigated and rainfed regions of South Asia, particularly in rice-fallow areas covering around 71.7 million hectares.

The diversity of intercropped crops—ranging from cereals and pulses to horticultural products—provides farmers with flexible planting options while minimizing risks. Pigeonpea, for example, is often intercropped with cereals and short-duration pulses, yielding multiple benefits. Despite facing mechanization challenges, smallholder farmers continue to adopt intercropping for its advantages in meeting nutritional needs and reducing agricultural risks.

## Conclusion

In Odisha, intercropping is a prime example of a dynamic and adaptable agricultural strategy that builds resilience in the face of changing environmental and financial difficulties. It is a crucial plan for the future of agriculture in the area since it increases food security, creates jobs, and supports sustainable agricultural methods. To truly understand the impacts of intercropping on labor dynamics and gender roles, additional research is required.

## 4.2. Crop Diversification for Enhancing Agricultural Resilience and System Profitability

### Introduction

The practice of monocropping rice in Odisha presents significant challenges to both environmental sustainability and the long-term economic viability of the region. Continuous reliance on rice cultivation depletes essential soil nutrients, resulting in reduced soil fertility and increased susceptibility to pests and diseases. Furthermore, rice farming contributes to water scarcity due to its high water requirements. To combat these issues, crop diversification emerges as a crucial strategy to break the cycle of soil degradation and water stress.

### Importance of Crop Diversification

Crop diversification is the practice of growing a range of crops on the same plot of land for a predetermined amount of time. This technique, which attempts to improve overall productivity, sustainability, and resilience, can be executed through sequential or simultaneous cultivation.

### Benefits of Crop Diversification

- ✓ **Enhanced Productivity:** Crop diversification can increase productivity by 14-18% compared to traditional monocropping methods.
- ✓ **Increased Profitability:** Farmers can expect a profit increase of approximately 20% by diversifying their crops.
- ✓ **Improved Resource Efficiency:** Diversification enhances both water and nitrogen use efficiency.
- ✓ **Food and Nutritional Security:** A diversified crop portfolio ensures a stable and varied food supply, enhancing food security.
- ✓ **Reduced Greenhouse Gas Emissions:** A shift from Rice-Rice cropping system to a diversified cropping practices can lead to lower greenhouse gas emissions.
- ✓ **Mitigated Natural Resource Degradation:** Crop diversification helps in preserving soil fertility and water resources.
- ✓ **Mitigated Natural Resource Degradation:** Crop diversification helps in preserving soil fertility and water resources.
- ✓ **Insurance Against Crop Failure:** By reducing reliance on a single crop, diversification serves as a safety net against potential crop failures.
- ✓ **Pest and Weed Control:** This practice reduces the incidence of weeds and diseases, benefiting overall crop health.



## Implementation Domains

Under varied ecological conditions, crop diversification can be performed in a variety of regions, cropping systems, and soil types:

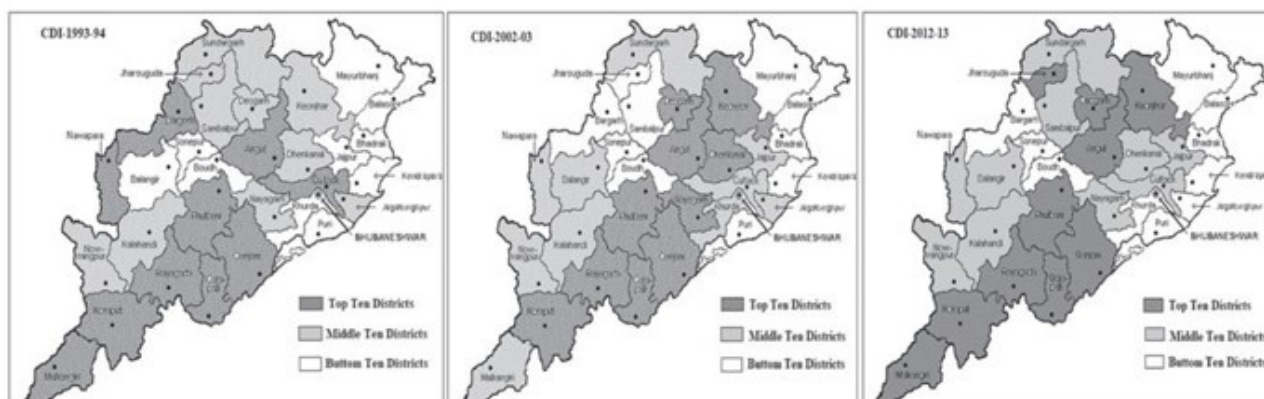
- **Versatile Applicability:** It can be implemented in both irrigated and rainfed conditions in Odisha.
- **Potential in Rice-Fallow Systems:** There is significant scope for crop diversification within the rice-fallow cropping systems in Odisha<sup>4</sup>.
- **Integration of Pulses:** Including pulses after rice harvest can enhance both farm profitability and soil quality.
- **Response to Groundwater Concerns:** Given the declining groundwater levels in rainfed/upland areas of Odisha, crop diversification presents a more sustainable option than traditional rice farming.
- **Resilience to Climate Variability:** This practice is particularly beneficial in areas experiencing resource degradation, moisture shortages, and climate variability.



## Crop Diversification in Odisha: 1993, 2002, and 2012

Data analysis reveals shifts in crop diversification across districts in Odisha from 1993 to 2012. A focus on the Crop Diversification Index (CDI) shows that districts in central and southern Odisha consistently rank among the top ten, indicating relative stability. In contrast, districts in the middle and bottom categories experience notable fluctuations.

Notably, the southern and south-coastal regions, particularly the KBK (Koraput, Bolangir, and Koraput) area, are less developed compared to the north-coastal regions. This disparity suggests a disconnect between economic development and crop diversification efforts.



## Current Initiatives and Statistics

The primary objective of the rice fallow management initiative is to use fallow land for non-paddy crops like oilseeds and pulses. A demonstration program showcasing crops such as Black Gram, Green Gram, Field Pea, Bengal Gram, Lentil, Grass Pea, Mustard, and Sesamum is a key component of this initiative.

In *rabi* (post-rainy) 2023–24, the Odisha Government plans to manage 400,000 hectares of rice fallows, up from 70,000 hectares extended over 30 districts in the previous fiscal year.

## Complementary Practices

To enhance the effectiveness of crop diversification, complementary agricultural practices should be employed. These methods attempt to concurrently increase soil and environmental quality, system production, and farm profitability.

Strategies may include effective soil management techniques, integrated pest management, and optimized nutrient application.

## Conclusion

Crop diversification stands as a vital solution to the challenges posed by monocropping in Odisha. By improving soil health, enhancing water efficiency, and providing alternative income sources, diversification not only fosters agricultural resilience but also contributes to a more sustainable and balanced agricultural system. With ongoing government initiatives and collaborative efforts from various agencies, the potential for crop diversification in Odisha continues to expand, eliminating the path for a future in agriculture that is more sustainable. ICRIAT, in collaboration with the Department of Agriculture and Farmers' Empowerment, has embarked on a research and development initiative on crop diversification: Millets in upland regions of Odisha (MURO), Rice fallow management.





## 5. Regenerative Cropping Systems: An Example from Dryland Living Lab



### Background

About 44% of India's food grain production comes from dryland farming, which makes a substantial contribution to the nation's food security. About 52% of India's total cultivated land, i.e., 80 million hectares, is under dryland farming which receives <750 mm of rainfall each year. Dryland agriculture has several difficulties, such as limited water availability, soil erosion, restricted access to irrigation facilities, erratic weather patterns, and the possibility of crop failure from droughts. Crops like oilseeds, pulses, and millets that can withstand low moisture levels are essential to dryland cultivation. The Dryland Living Lab of ICRIASAT demonstrates scalable regenerative agricultural technologies that improve soil and water conservation and overall crop productivity of dryland alfisol and vertisol soil types.

### Objectives

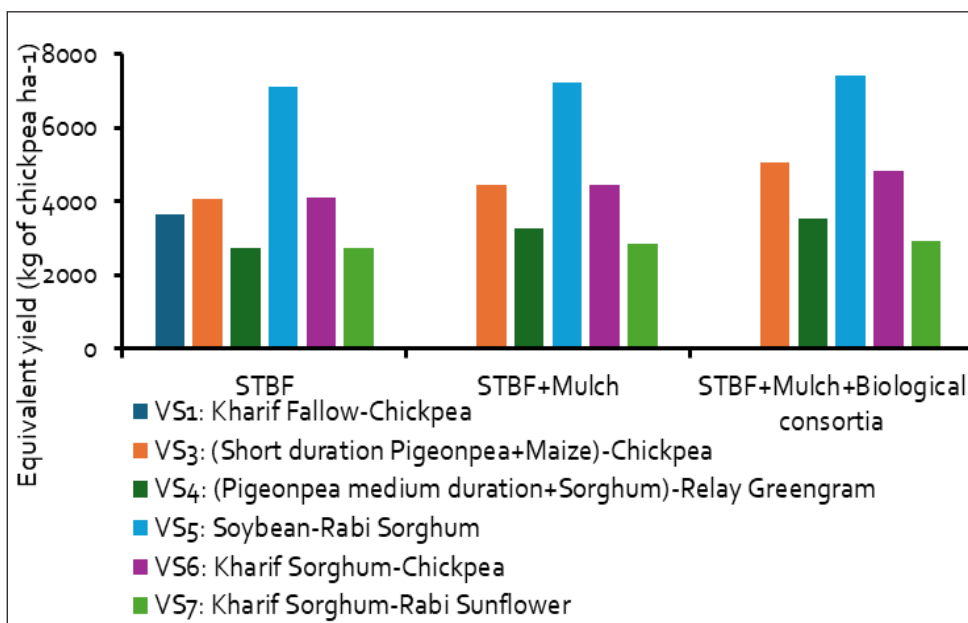
- Generating Science-based evidence on regenerative agricultural packages with a continued feedback loop through dynamic component technologies for major production systems for dryland alfisol and vertisol.
- Multi-criteria analysis of bundled regenerative practices for building future scenarios and their recommendation domains.
- Capacity development of value chain actors of regenerative agriculture (contributing to the Dryland Academy) and informing policy.

### Research Study

There are three major treatments under the Broad Bed Furrow (BBF) + Conservation Tillage management. Both of these management practices are soil and water conservation techniques that increase crop output and optimize water consumption. Treatments as shown below.

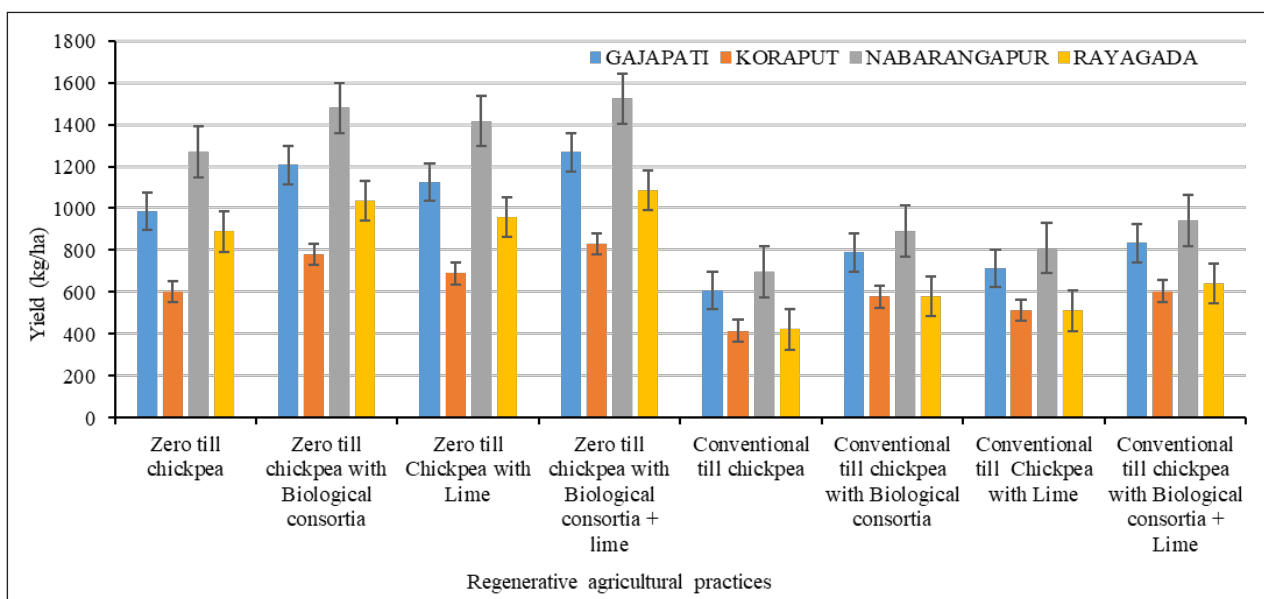
- Soil test-based fertilizer (STBF) recommends nutrient application rates based on the soil test.
- The mulching technique improves soil moisture conservation by minimizing exposure to direct sunlight besides enhancing the carbon sequestration.
- Biological consortia improve the nutrient absorption rates in the soil system.

## Scientific Evidences



The amalgamation of soil test-based fertilizer (STBF), mulching, and biological consortia significantly increased the equivalent yields of chickpea under regenerative agriculture practice in millet-based cropping systems of vertisols.

### Regenerative Agriculture in Millet-Based Systems –Vertisols



Case Study: Regenerative Agriculture Practices for Enhancing Chickpea Productivity: OLM-ICRISAT Experiences from Odisha.

## Key Finding

- Zero-till chickpea with biological consortia + liming is a promising climate-resilient technology for cultivating rabi rice fallows across four districts.

## Outcomes

- Validation of bundled regenerative agricultural practices across different agro-ecologies
- Standardization of best soil and water conservation technique for dryland ecosystems
- Recommendation of cost-effective farm mechanization under regenerative cropping systems
- Scaling-up of validated regenerative agriculture practices in collaboration with NARS, Government agencies, and stakeholders.



## 6. Unveiling a Sustainable Tomorrow: A Comprehensive Exploration of Strategies to Minimize Synthetic Dependency

### Context

Synthetic fertilizers have significantly boosted food production globally. However, their excessive use has led to environmental degradation, particularly impacting water quality and introducing toxic impurities into the food chain, which can lead to health issues, including cancers. To combat these challenges, a transition towards biofertilizers is crucial. Composts from organic waste from poultry and dairy are rich in essential nutrients. Dairy waste compost, for instance, contains 45,100 mg/kg of nitrogen, 7,300 mg/kg of phosphorus, and 9,100 mg/kg of potassium. Raising awareness about the benefits of these nature-based solutions is vital for fostering a healthier agricultural ecosystem.

### Insight into Methodology

Regenerative agriculture represents a sustainable, eco-friendly approach that enhances resilience to climate change. It typically requires fewer financial inputs making it accessible to a wider range of farmers. Grounded in health, ecology, fairness, and care, organic practices yield nutrient-rich, pesticide-free products while promoting biodiversity and natural pest control.

#### Advantages

The global interest in sustainable practices has positioned regenerative agriculture as a leader in agricultural innovation. Key advantages include:

- **Soil Health:** Enhances soil structure and water retention, increasing yields and reducing synthetic chemical reliance.
- **Biodiversity:** Practices like crop rotation protect pollinators and promote ecological balance.
- **Water Quality:** Reduces chemical runoff, improving surrounding water quality.
- **Nutri-dense products:** Free from harmful residues, organic foods are recognized for their nutritional value.
- **Climate Change Mitigation:** Prioritizes carbon sequestration, contributing to lower GHG emissions.
- **Economic Benefits:** Supports local economies and reduces carbon footprints.



*Adopting nano urea as an alternative to granule urea.*



*Adopting green manure as a source of nitrogen.*

## Application Sphere

Farmers in India use regenerative methods of farming for a variety of reasons:

- **Resource Constraints:** Low rainfall regions often rely on uncertified organic practices.
- **Adverse Effects of Conventional Practices:** Many farmers transition from chemical-intensive agriculture due to declining soil fertility and rising costs.
- **Commercial Opportunities:** Some seek certified organic methods for better market prices.

Through the availability of resources and market access, government efforts such as the Paramparagat Krishi Vikas Yojana (PKVY) and the Mission Organic Value Chain Development for North East Region (MOVCD-NER) facilitate these changes.

## Supplementary Approaches

Organic farming in India includes two main strategies:

- **Pure Organic Farming:** Strictly avoids synthetic chemicals, relying solely on natural fertilizers.
- **Integrated Nutrient Farming:** Combines various practices, including nutrient and pest management, to enhance soil fertility.

## Inclusivity and Generational Considerations

The scientific exploration of women's roles and empowerment in organic farming in India is limited, but existing case studies reveal their significant contributions and the challenges they face<sup>6</sup>.

Organic farming serves as a catalyst for enhancing the agency of rural women, who often assume leadership roles in promoting and scaling organic practices. However, challenges such as insufficient knowledge, complex certification processes, and stringent organic standards can hinder market access and price stability. Additionally, women experience increased workloads, particularly with weeding, and face inadequate support and risk coverage during the initial transition to organic farming.





## 6.1. Biological Consortia for Enhancing Soil Health and Sustainability in Regenerative Agriculture

### Introduction

Biological consortia, comprising collaborative interactions among various microorganisms—such as bacteria, fungi, and algae—play a pivotal role in regenerative agriculture. These interactions, which can be cooperative, competitive, or neutral, often yield emergent traits that individual species cannot achieve alone. By fostering these diverse microbial communities, biological consortia significantly enhance soil health and contribute to sustainable agricultural practices. Their influence extends to nutrient availability, pest resistance, and plant resilience under varying environmental conditions.

### Key Benefits of Biological Consortia

#### Soil Health and Structure Improvement:

- **Nutrient Cycling:** Microbial consortia facilitate decomposition and mineralization, enhancing nutrient availability.
- **Mycorrhizal Networks:** Fungi improve soil structure, water retention, and aeration, promoting healthy root development.

#### Carbon Sequestration:

- Certain microbial communities enhance the stabilization of organic matter, sequestering carbon and reducing atmospheric CO<sub>2</sub> levels.

#### Biological Pest Control:

- Beneficial microbes suppress plant pathogens, reducing crop losses and minimizing the need for chemical interventions.

#### Water Management:

- Improved soil health leads to better water infiltration and retention, which is crucial in drought-prone areas. Healthy soils also mitigate runoff and erosion.

#### Cost Efficiency:

- Enhanced plant health and yields through biological consortia can lower overall costs related to conventional agricultural inputs.

#### Stress Resilience:

- These microbial communities help plants cope with abiotic stresses, such as drought and salinity, leading to improved yields.

## Azolla in Agriculture

Azolla, a floating aquatic fern, presents numerous benefits for agricultural practices:

- **Nitrogen Fixation:** Symbiotic relationships with blue-green algae (*Anabaena*) enable Azolla to fix atmospheric nitrogen.
- **Soil Amendment:** Azolla enriches organic matter in the soil, improving soil structure, moisture retention, and nutrient availability.
- **Biomass Production:** Rapid growth allows for harvesting as green manure, further improving soil fertility.



## Microbial Consortia Granules (MCG)

Plant growth and soil health are enhanced by Microbial Consortia Granules, which are novel formulations of free-living nitrogen fixers, phosphate-solubilizing bacteria (PSB), and potassium-mobilizing bacteria (KMB).

### Benefits of Microbial Consortia Granules

- **Azotobacter:** Increases nitrogen uptake and produces plant growth hormones and vitamins, enhancing the uptake of essential nutrients like sulfur, iron, and zinc.
- **Azospirillum:** An associative microaerophilic nitrogen fixer contributing to atmospheric nitrogen fixation.
- **Phosphate Solubilizing Bacteria (PSB):** Solubilizes phosphorus by secreting organic acids, converting unavailable phosphate into usable forms.
- **Potassium Mobilizing Bacteria (KMB):** Mobilizes potassium from soil sources, reducing reliance on chemical fertilizers and minimizing wastage.

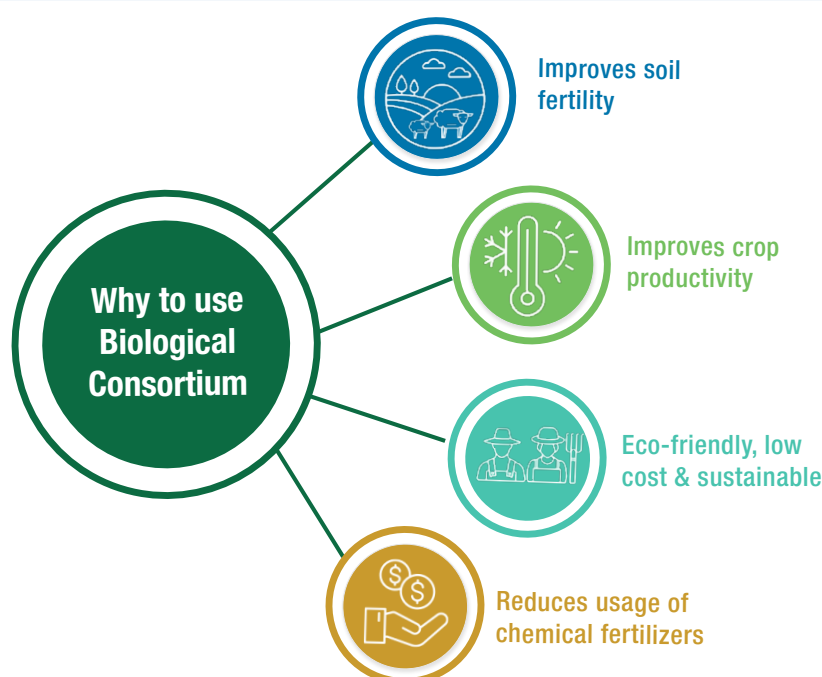
### Impact on Greenhouse Gas Emissions

- **Reduction of Nitrous Oxide Emissions:** Improved nitrogen use efficiency by biological consortia results in lowering nitrous oxide ( $N_2O$ ) emissions.
- **Carbon Dioxide Sequestration:** Enhanced microbial activity and soil organic matter promote carbon sequestration, capturing atmospheric  $CO_2$ .
- **Methane Emissions Management:** Some microbial consortia can mitigate methane emissions from practices like rice cultivation and livestock management.
- **Resilience to Climate Variability:** Biological consortia help maintain production in healthy ecosystems by making them more adaptable to climate shocks and lowering the demand for inputs that could raise greenhouse gas emissions.



## Limitations and Challenges

- **Stability and Viability:** Ensuring the stability and viability of microbial consortia during storage and application remains a challenge.
- **Initial Costs:** The upfront investment required for developing and implementing biological consortia can be higher than conventional methods.
- **Lack of Standardization:** Variability in formulations and application methods may lead to inconsistent performance across different agricultural settings.
- **Complex Interactions:** The intricate relationships among microorganisms can be difficult to predict, complicating outcome forecasts.
- **Environmental Variability:** Various factors, including soil type, climate, and agricultural practices, can impact the efficacy of biological consortia, resulting in differing outcomes.



## Statistics on Adoption in India

- **Growth in Organic Farming:** By 2021, more than 3 million hectares in India were farmed organically, and a large number of farmers have used biological consortia to improve the productivity and soil health<sup>7</sup>.
- **Nutrient Management:** Microbial consortia can improve nutrient use efficiency by 15-30%, particularly for nitrogen and phosphorus.
- **Increased Crop Yields:** Field trials suggest yields can improve by 10-50%, especially in staple crops like rice and pulses.
- **Regional Adoption:** States such as Punjab, Haryana, and Tamil Nadu are seeing increased use of biological amendments, with farmer cooperatives advocating for their benefits.
- **Research and Development:** Institutions like, ICRISAT, ICAR, and agricultural universities are driving research on biological consortia, expanding the range of microbial formulations available<sup>8,9</sup>.
- **Sustainability Goals:** The Government of India aims to cut chemical fertilizers and pesticides by 30% by 2025, encouraging a shift toward biological solutions.
- **Community Engagement:** Initiatives involving farmer training programs show a 70-80% acceptance rate among farmers testing biological consortia in their fields.

## Conclusion

In regenerative agriculture, biological consortia are a game-changing strategy that uses a variety of microorganisms to improve soil health, increase nutrient availability, and stimulate plant growth. Consortia help ensure that agro-ecosystems are resilient to climate change and that farming is sustainable by promoting positive interactions between various creatures. Their ability to boost biodiversity and lessen dependency on synthetic inputs is a perfect fit with the ideas of regenerative agriculture. Biological consortia integration into farming systems promises a more productive, ecologically friendly, and sustainable agricultural future as research and practical applications grow, promoting healthy soils and vibrant ecosystems for future generations.

Sl.No	Groups	Examples
<b>Nitrogen fixing Bio-fertilizers</b>		
1	Free-living	<i>Azotobacter sp., Klebsiella sp., Clostridium sp., Beijerinckia</i>
2	Symbiotic	<i>Rhizobium, Frankia sp., Anabaena azollae</i>
3	Associative Symbiotic	<i>Azospirillum</i>
<b>Phosphorus solubilizing Bio fertilizers</b>		
1	Bacteria	<i>Bacillus megaterium var.phosphaticum, Bacillus subtilis</i>
2	Fungi	<i>Penicillium sp., Aspergillus sp.</i>
<b>Phosphorus mobilizing Bio fertilizer</b>		
1	Arbuscular mycorrhiza	<i>Gigaspora sp., Glomus sp., Scutellospora sp.</i>
<b>Bio fertilizers for Micronutrients</b>		
1	Zinc solubilizers	<i>Bacillus sp.</i>
<b>Plant growth promoting Rhizobacteria</b>		
1	Pseudomonas	<i>Pseudomonas fluorescens, Streptomyces sp.</i>





## 6.2 Waste to Wealth Initiative for Advancing Regenerative Agriculture

### Context

Compost, a carbon-rich product derived from organic materials such as livestock manures, plays a crucial role in the waste-to-wealth initiative. Proper management of compost, along with other organic fertilizers (including sewage sludge and organic residues), is essential to mitigate potential adverse effects on environmental, human, animal, and soil health. While the utilization of these nutrient sources is encouraged, it is vital to prioritize quality, safety, and associated environmental and biosecurity risks to maximize benefits and minimize harm.

### Insight into Methodology

The decomposition of organic materials in compost is facilitated by an optimal balance of water, oxygen, carbon, and nitrogen. Composting is categorized primarily into two types:

- **Vermicomposting:** mediated by earthworms
- **Aerobic composting:** mediated by microorganisms

### Advantages of Composting Methodology

- **Soil Health Restoration and Enhancement:** Compost enhances the biological, chemical, and physical properties of soil, promoting organic matter reconstruction and nutrient cycling. This fosters a resilient ecosystem in line with the USDA's Natural Resources Conservation Service's definition of soil health.
- **Climate Change Mitigation:** Composting sequesters atmospheric carbon and reduces greenhouse gas emissions, particularly methane from landfills. By diverting organic waste from landfills, composting significantly decreases anthropogenic methane emissions.
- **Water Quality Preservation:** Compost serves as an eco-friendly alternative to chemical fertilizers, mitigating eutrophication and protecting aquatic ecosystems. Soils treated with compost demonstrate improved water retention, which reduces the risk of flooding, erosion, and waterway contamination.







### Aerobic Composting – Scope and Application

- Aerobic composting mediated by microorganisms is a vital green technology for sustainable agriculture, recycling biowaste to improve soil and environmental health.
- Rapid aerobic composting:
  - a. Biological consortia in composting effectively break down organic waste and contaminants.
  - b. The integration of organo-mineral enrichment with indigenous rocks (such as phosphates, pyrites, and micas), mesophilic and thermophilic lignocellulolytic microbes significantly boosts compost quality and accelerates decomposition, reducing the typical composting period from 6-8 months to just a few weeks.
- Field experiments demonstrate that integrating compost or manure with chemical fertilizers at rates of 5-10 t/ha substantially increases soil active carbon pools, particulate organic matter, and carbon sequestration<sup>10</sup>.
- Research focusing on nutrient release has shown that composting effectively enhances potassium (K) availability compared to phosphorus (P) and nitrogen (N).

Integrated nutrient management systems incorporating composting show promising potential for enhancing crop production, improving soil fertility, and minimizing the impact on global warming.

The economic benefits of compost production, such as those seen in the Godhan Nyay Scheme, can increase farmer incomes while promoting environmental sustainability. Overall, composting is essential for optimizing crop production, mitigating climate change, and ensuring food security for future generations.





## 6.3. Biochar: A Nature-based Solution Enabling Regenerative Agriculture

### Background

Soil is the realm that is pivotal in facilitating the environment for natural geochemical cycles that are crucial for plant life. Soil organic matter (SOM) is made up of soil organic carbon (SOC). SOC constitutes about 45-60% of the total mass of SOM. Maintaining the SOC pool is essential for rhizosphere activities, water retention, nutrient retention, and appropriate soil structure and aeration. Regenerative agriculture strategies will increase the SOC and build resilience in agriculture. These methods include adding crop residues to the soil, mulching, composting, and producing biochar.

Within this framework, biochar, being a carbon-rich byproduct of organic material pyrolysis has attracted interest due to its several uses in waste management, soil amendment, and carbon sequestration.

### Low-cost Biochar Production Technology at ICRISAT

Decentralized production of biochar using low-cost portable pyrolytic kilns based on the vertical updraft principle is a great leap in scientific innovations in the pyrolysis process<sup>11,12</sup>.

ICRISAT's studies report that low pyrolysis results in high biochar conversion efficiency, thermal stability, and high fixed carbon content. However, an increase in pyrolytic temperature has improved the porosity of biochar, resulting in a reduction in yield and functional group intensity.



Schematic flow emphasizing agriculture residues to enhance soil carbon sequestration and benefits of biochar.

## Multi-fold Benefits of Biochar

- **Carbon Sequestration:** By lowering atmospheric carbon dioxide levels, biochar helps mitigate climate change by locking carbon in a stable form for centuries.
- **Soil Health Improvement:** Lowering the demand for irrigation enhances soil structure, increases water retention, and increases nutrient availability— all of which are especially useful in dry or arid locations.
- **Enhanced Soil Biodiversity:** Biochar provides a habitat for beneficial soil microbes, enhancing overall ecosystem health.
- **Waste to wealth:** Biochar production can be a sustainable way to recycle agricultural and forestry waste, turning biomass into a valuable resource.
- **Reduction in GHGs:** Biochar production through pyrolysis generates fewer emissions than open burning or decomposition of organic waste and reduces nitrous oxide and methane emissions from agricultural fields

## Way Forward

The biochar research that ICRISAT initiated is being expanded into a more comprehensive, long-term, strategic study. The purpose of this extension is to investigate the manufacture of biochar from diverse crop leftovers and to standardize its application in various farming systems and soil types. The intention is to develop a comprehensive set of techniques that will benefit farmers in a noticeable way.

This low-cost, decentralized biochar production technology will be an affordable and viable option for farmers and Self-Help Groups (SHGs) to solve the issues around crop residues in a sustainable manner. Moreover, this technology also aligns well with government incentives for voluntary carbon markets and environmental initiatives like the 'Mission LiFE (Lifestyle for Environment) program'.





## 6.4 GreenSeeker: Driving Efficiency through Targeted Nutrient Management and Variable Rate Application

### Background

Nitrogen (N) is essential for plant growth and is the most widely used fertilizer nutrient globally. However, research shows that only about 50% of applied nitrogen is effectively utilized by crops, with the rest lost through various pathways, negatively impacting both the environment and farmers' profits. In Odisha, India, farmers often apply nitrogen uniformly based on generalized recommendations, which leads to inefficient utilization and varying degrees of under- and over-application, ultimately reducing crop yields.

Current fertilizer guidelines, reliant on regional averages, overlook the spatial and temporal variability of fields. Thus, understanding local nitrogen supply fluctuations throughout the crop season is crucial, and implementing innovative fertilizer management practices that incorporate both preventive and corrective measures is vital for sustaining soil resources.

The introduction of innovative tools like GreenSeeker is imperative in Odisha's traditional farming context to optimize nitrogen application and improve crop productivity, a critical need in an economy heavily reliant on agriculture. GreenSeeker employs advanced sensor technology to accurately gauge crop nitrogen requirements in real time, enabling farmers to tailor their fertilizer application strategies.

### Features of GreenSeeker:

- **Optical Sensing:** Utilizes integrated optical sensing to assess crop health and vigor through reflectance measurements.
- **NDVI Metrics:** Employs metrics like the Normalized Difference Vegetation Index (NDVI) to determine crop yield potential and nitrogen needs.
- **Site Specific Nutrient Management (SSNM):** Enhances fertilizer use efficiency by promoting site-specific management practices.

### Benefits of Technology

- **Precision:** Utilizes advanced sensors for real-time measurement of crop nitrogen requirements, facilitating accurate and tailored fertilizer application.
- **Efficiency:** Optimizes nitrogen application to improve fertilizer use efficiency, minimizing waste and reducing environmental impact.
- **Cost-effectiveness:** Enables farmers to apply fertilizers more efficiently, lowering input costs while maximizing crop yields.
- **Sustainability:** Promotes sustainable farming practices by reducing nitrogen runoff and environmental degradation, contributing to long-term soil health.
- **Adaptability:** Versatile across diverse agro-climatic conditions, making it suitable for various regions and cropping systems.
- **Ease of Use:** User-friendly tools, including the Urea Calculator app, simplify the process of calculating fertilizer application rates based on GreenSeeker readings.
- **Enhanced Crop Productivity:** Real-time insights into nitrogen requirements optimize nutrient management, leading to improved yields and profitability.
- **Climate Resilience:** Offers a proactive approach to nitrogen management, helping farmers adapt to changing environmental conditions and lower GHGs.

## Implementation Domain

In regions like Odisha, where rice cultivation is predominant, excessive chemical fertilizer application is common among farmers seeking to boost yields. Additionally, while conservation agriculture practices are gaining traction, many farmers apply chemical fertilizers without considering the indigenous nutrient supply from crop residues. Implementing GreenSeeker- guided nitrogen recommendations can optimize fertilizer doses in these systems.

## Complementary Tools and Practices

- **Urea Calculator App:** Essential for accurately timing nitrogen application and adjusting dosage based on GreenSeeker readings.
- **N-enriched Plots:** Useful for refining nitrogen management strategies.
- **Coordination of Nitrogen Doses:** To enhance efficiency, initial nitrogen applications should be adjusted based on subsequent GreenSeeker readings.
- **Integration with Conservation Practices:** Combining GreenSeeker-guided nitrogen management with zero-till practices and precise water management maximizes benefits and promotes sustainable agricultural practices.
- The synergy of these agronomic, soil, and crop management practices can lead to significant input savings while fostering sustainability in agriculture.

## Statistics of Adoption

As a site-specific nutrient management tool, GreenSeeker has shown a great deal of promise for use in India's rice, wheat, and maize farming regions, especially in the roughly 14 million hectare Indo-Gangetic Plains (IGP). The technology's dependability and effectiveness have been confirmed by extensive field demonstration trials carried out by State Agricultural Universities, National Agricultural Research and Extension Systems (NARES)<sup>14</sup>, and institutions like as ICRISAT. This successful validation suggests that Green Seeker can effectively facilitate precise nitrogen management in Odisha when implemented appropriately.

## Conclusion

GreenSeeker technology significantly advances optimizing nitrogen use efficiency in agriculture, especially in Odisha. Providing real-time assessments of crop nitrogen needs enables precise fertilizer application tailored to specific requirements, enhancing productivity and profitability while reducing environmental impacts. The shift from traditional uniform application to data-driven, site-specific nutrient management promotes sustainability and strengthens resilience against climate variability. Adopting such innovative tools is essential for ensuring food security and long-term agricultural viability in a changing world.









## 7. Regenerative Landscape Management: A Multi-dimensional Approach for Transforming Livelihoods

### Background

Regenerative landscape management for achieving land degradation neutrality and strengthening ecosystem services is a core research strength of ICRISAT.

Various novel tools, methods, and technologies have been developed from ICRISAT's groundbreaking regenerative landscape management and conservation research. These include biological (such as appropriate crop rotation, agroforestry, and farming system designs) and engineering (such as in-situ and ex-situ soil and water conservation approaches) measures.

These customized technologies and innovations in varying landscapes of Asia and Africa have had an impact at scale. They have improved water retention in landscapes by reducing the velocity of surface runoff, improving infiltration, increasing greenery and carbon sequestration,

and controlling soil erosion. In addition, groundwater recharge and improved baseflow generated by these interventions have helped ensure the perennality of riverine ecosystems and the regulation of ecosystem services.

ICRISAT was awarded the UNDP-Mahatma Award 2023 for Biodiversity Conservation, recognizing its successful application of regenerative landscape strategies.

### Three Decades of Expertise

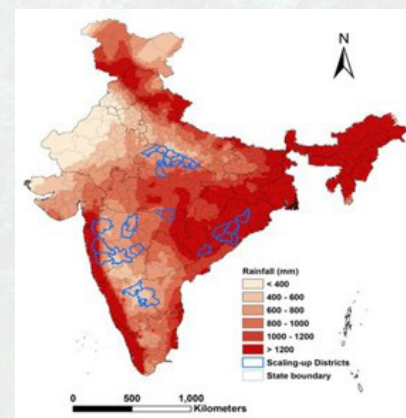
Over the past three decades, ICRISAT has successfully deployed and validated its landscape management approaches for areas between 500 and 5,000 ha in several Indian states (Maharashtra, Karnataka, Odisha, Uttar Pradesh, Madhya Pradesh, Rajasthan, Telangana, and Andhra Pradesh, etc.) and also in Africa (Ethiopia, Malawi, Mali, and Tanzania). These approaches have been mainstreamed in national government plans for sustainable resource management.





## Scientific Evidences

- **Farmer Income:** Increased threefold.
- **Water Table:** Elevated from 26 meters to 4.5 meters.
- **Base Flow:** Enhanced by 150%.
- **Emission Intensity:** Reduced from 0.14 to 0.06 kg CO<sub>2</sub>e/kg.
- **Livelihoods:** Improved, leading to increased in-migration.
- **Cropping Intensity:** Increased from 110% to 180%.
- **Land Degradation:** Effectively mitigated.
- **Sustainable Intensification:** Applied to 35,000 hectares of previously degraded fallow land.
- **Temperature Regulation:** Progressing towards 1.5°C climate targets.



## Skills Transfer and Benefits to Farmers:

The regenerative landscape management approach, including designing sustainable farming systems based on Land Resource Inventory (LRI) and hydrology, has also improved the knowledge and capacity of researchers, development practitioners, farmers, and other stakeholders through 60 well-established learning sites.

Significant impacts include the transformation of 15 million hectares of degraded lands, which benefit around 10 million smallholder farmers. These farmers have realized an additional income of US\$1.5 billion in addition to the indirect environmental benefits<sup>15</sup>.

The potential for transformation is enabled through increased water availability and enriched soils coupled with the deployment of climate-resilient, disease-resistant, high-yielding food and fodder crops, farm diversification, measures to boost livestock productivity, agro-processing, boosting market linkages, and more.

**Odisha Use Case:** Under the ICRIAT-Odisha Livelihoods Mission collaboration, regenerative landscapes were developed in Rayagada and Gajapati districts through interventions such as divergent drains, farm bunding, and construction of rainwater harvesting structures. These structures have benefited more than 500 farmers by converting 200 acres of mono-cropped land to double-cropping land.



## 8. Regenerative Agriculture for Carbon Credits

### Background

Carbon credits in agriculture are a vital mechanism for climate change mitigation, incentivizing farmers to sequester CO<sub>2</sub> through regenerative agriculture practices, allowing them to reduce GHGs to offset carbon footprints. This dynamic approach encourages farmers to implement regenerative agriculture practices that enhance soil carbon capture, transforming lands into effective carbon sinks.

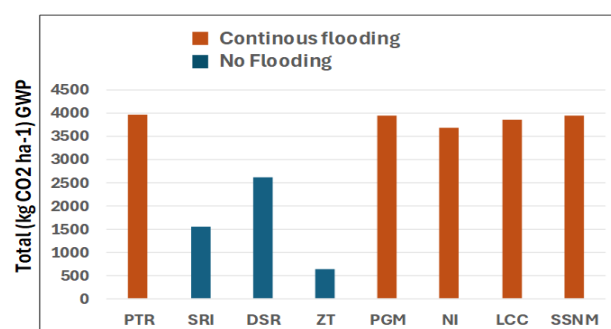
Carbon markets use measurement, reporting, and verification (MRV) protocols to calculate the number of soil carbon credits (SCCs) a project is expected to generate. Therefore, farmers must adopt regenerative techniques, precisely measure and confirm their carbon sequestration, sign up for carbon credit schemes, and sell confirmed credits to offset emissions and generate extra income streams to be eligible for credits.

ICRISAT, in collaboration with the Department of Agriculture and Farmers Empowerment, is implementing a project entitled “Development and Validation of Carbon Standards for Incentivizing Farmers for Regenerative Agricultural Practices (CSIFRA).”



### Objectives

- Validation of protocols and tools for quantification, tracking, and verification (measurement, reporting, and verification-MRV) of carbon footprints of agricultural production systems
- Provide data driven tools for incentivizing regenerative agricultural practices through carbon credit and ecosystem services as additional income opportunities for smallholder farmers.



GHG reduction potential of different agronomic practices



## Regenerative Agriculture Practices

- Water management
- Transplanting to direct seeding
- Minimum soil disturbance
- Optimum use of fertilizer in combination with organics, crop residue, and biologicals

## Site Selection

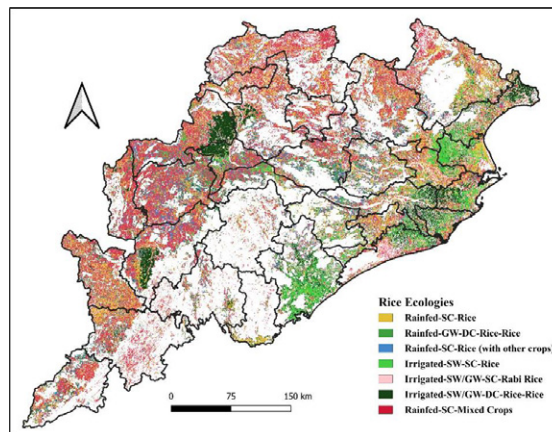
The target districts were prioritized considering the factors influencing the GHG emissions:

- Irrigated area
- Rice – rice cropping system
- High nitrogen usage

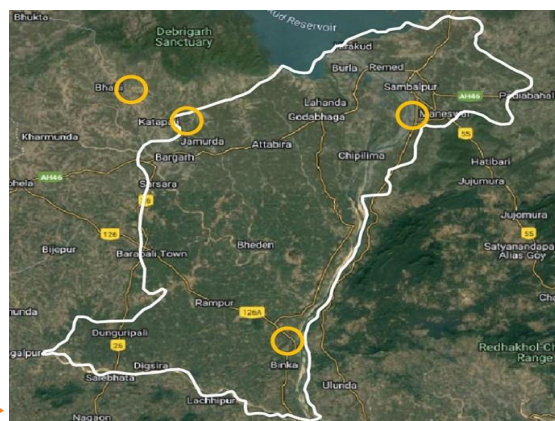
## Site Characteristics

- Transplanted rice in both *kharif* (Aug-Dec) and *rabi* (Jan-April)
- This area is part of Hirakud command area
- Two to three times higher doses of fertilizer during *rabi* season as compared to *kharif*
- Sowing by drum seeder or broadcasting, if direct seeding.

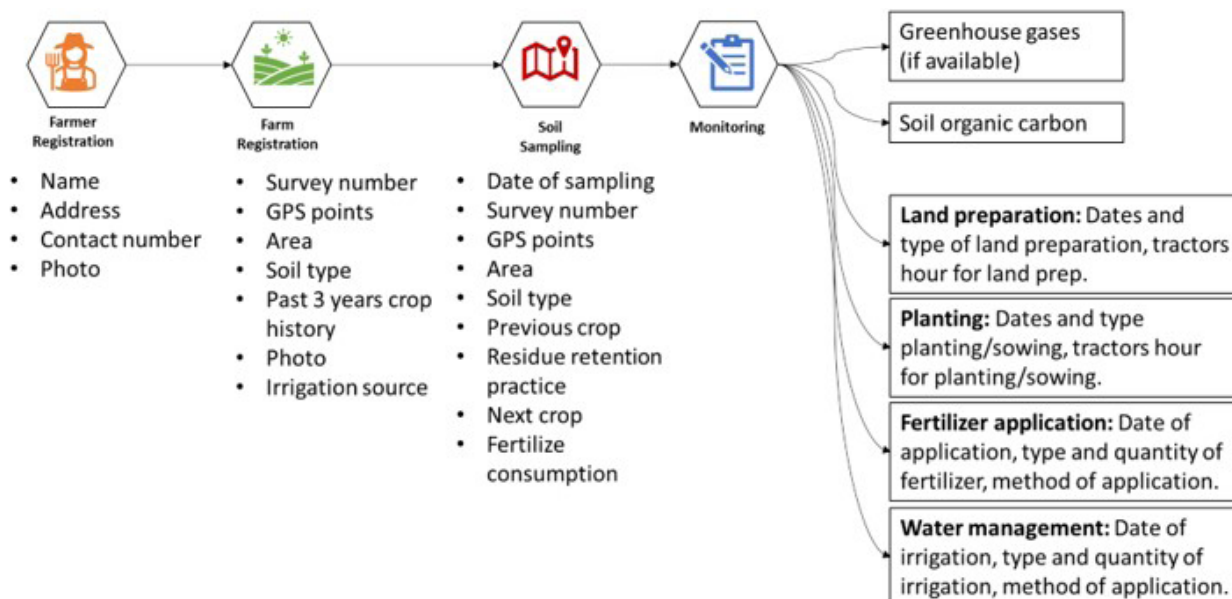
Project locations in Hirakud



Distribution of rice-ecologies across Odisha state. The district of Bargarh, Kalahandi, Sambalpur, and Subarnapur have satisfied the conditions for site selection.



Monitoring, Reporting, and Verification.



## References

1. Assessment of maize-based conservation agriculture production systems (CAPS) in rainfed uplands of Odisha, India. In Conservation agriculture in subsistence farming. Case studies from South Asia and beyond. Roul, PK. et al. Wallingford UK: CABI. pp. 95-108, 2015.
2. Comparative Evaluation of Direct Dry-Seeded and Transplanted Rice in the Dry Zone of Karnataka, India. Soriano, JB. et al. Philippine Journal of Science, 147 (1). pp. 165-174, 2018. ISSN 0031 – 7683.
3. Integrated farming with intercropping increases food production while reducing environmental footprint. Chai, Q. et al. Proceedings of the National Academy of Sciences, 118(38), 2021. p.e2106382118.
4. Comprehensive Project on Rice Fallow Management. Dar, M. et al. 2023. [https://oar.icrisat.org/12680/1/Project%20Report\\_Comprehensive%20Project%20on%20Rice.pdf](https://oar.icrisat.org/12680/1/Project%20Report_Comprehensive%20Project%20on%20Rice.pdf)
5. Assessing the environmental benefits of compost use-on-land through an LCA perspective. Martínez-Blanco, J. et al. Sustainable Agriculture Reviews: Volume 12, pp.255-318, 2013.
6. Effects of organic farming on the empowerment of women: A case study on the perception of female farmers in Odisha, India. Altenbuchner, C. et al. In Women's Studies International Forum, Vol. 64, pp. 28-33, Pergamon. 2017, September. [https://www.apeda.gov.in/apedawebsite/organic/data-Archive\\_2021-2022.htm#Total\\_farm\\_area\\_2022](https://www.apeda.gov.in/apedawebsite/organic/data-Archive_2021-2022.htm#Total_farm_area_2022)
7. Plant growth promoting rhizobia: challenges and opportunities. Gopalakrishnan, S. et al. 3 Biotech, 5, pp.355-377, 2015.
8. Agriculturally important microbial germplasm database. Gopalakrishnan, S. et al. 2014.
9. Carbon sequestration in Indian soils: present status and the potential. Pal, DK. et al. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 85, pp.337-358, 2015.
10. Innovative bio-pyrolytic method for efficient biochar production from maize and pigeonpea stalks and their characterization. Pasumarthi, R. et al. Journal of Cleaner Production, 448, p.141573, 2024.
11. Low-cost portable kiln for biochar production from on-farm crop residue. Venkatesh, G. et al. Indian farming, 64(12), pp.9-12, 2015.
12. Valorization of peanut shells through biochar production using slow and fast pyrolysis and its detailed physicochemical characterization. Sawargaonkar, G. et al. Frontiers in Sustainability, 5, p.1417207, 2024.
13. Optical sensor-based nitrogen management for irrigated wheat in the Indo-Gangetic Plains. Bijay Singh, et al. 2012.
14. Traditional rainwater management (haveli cultivation) for building system level resilience in a fragile ecosystem of Bundelkhand region, Central India. Singh, R. et al. Frontiers in sustainable food systems, 6, p.826722, 2022. <https://www.icrisat.org/assets/Flyers/Thematic-Flyers/Landscape-management.pdf>







## About

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a pioneering non-profit organization focused on scientific research for development, committed to transforming dryland farming and agri-food systems. Working with global partners, ICRISAT develops innovative solutions to address hunger, poverty, and environmental degradation, benefiting 2.1 billion people across the drylands of Asia, Africa, and beyond.

ICRISAT was established under a Memorandum of Agreement between the Government of India and CGIAR, dated 28 March 1972. In accordance with the Headquarters Agreement, the Government of India has extended the status of a specified "International Organization" to ICRISAT under section 3 of the United Nations (Privileges and Immunities) Act, 1947 of the Republic of India through Extraordinary Gazette Notification No. UI/222(66)/71, dated 28 October 1972, issued by the Ministry of External Affairs, Government of India.

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