



Fig. 3. Paddy straw biogas plant

- through solar-powered irrigation
- Lowering carbon emissions from diesel usage
- Supporting sustainable practices like organic farming and zero-budget natural farming
- Enabling climate-smart technologies such as remote sensing, IoT-based irrigation, and weather-informed crop management

By improving water-use efficiency and reducing environmental impacts, renewable energy reinforces the long-term sustainability of the agricultural ecosystem.

SOCIO-ECONOMIC BENEFITS FOR RURAL INDIA

The adoption of renewable energy generates far-reaching socio-economic benefits:

- **Higher farmers' income** through lower input costs and opportunities to sell excess power
- **Rural employment** in installation, operation, and maintenance of renewable systems
- **Women's empowerment** through increased comfort level in agriculture and household

- activities
- **Development of rural enterprises** such as solar-powered mills, food-processing units, and cold-chain systems

Renewable energy thus becomes a driver of holistic rural development, not merely an alternative source of electricity.

POLICY SUPPORT AND THE WAY FORWARD

India has already made substantial progress through supportive policies such as PM-KUSUM, the National Solar Mission, and various state-level initiatives. However, to fully unlock the potential of renewable energy in agriculture, further steps are needed:

- Expanding financing options for small and marginal farmers
- Strengthening local manufacturing of renewable components
- Promoting farmer cooperatives and FPOs for large-scale adoption
- Integrating renewable energy with digital agriculture and precision farming
- Developing region-specific renewable energy models
- Employing Agricultural Engineers



and diploma holders in rural India to cater repair, maintenance and trainings at farmers' doorsteps.

Public-private partnerships and community-based implementation can ensure that renewable energy solutions are equitable and efficient.

In conclusion renewable energy represents a transformative paradigm for the growth of Indian agriculture. It addresses longstanding challenges—energy access, irrigation reliability, rising costs, and climate vulnerability—while opening new avenues for income and innovation. As India moves toward its goals of sustainability, food security, and rural prosperity, the marriage of renewable energy and agriculture stands as a powerful catalyst. By empowering farmers with clean, affordable, and reliable energy, India is not only modernizing agriculture but also building a resilient and future-ready agrarian economy.

Regenerative Agriculture: Building Resilience and Sustaining our Future



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INTRODUCTION

Today, agriculture is confronted with serious challenges due to multiple factors, including ever-increasing population pressure on limited natural resources. From depletion of soil health to water scarcity to the increasing impact of climate change, the current farming systems are under pressure to meet the future food demands without compromising soil and environmental health. Non-scientific farming and livestock rearing practices, intensive imbalanced use of chemical fertilizers and pesticides, and soil degradation are all contributing to greenhouse gas emissions (TAAS, 2021). Hence, the need for a transformative approach to food production is more urgent now than ever. Regenerative agriculture (RA)

offers a solution—one that works with nature, restores ecosystems, and helps combat climate change by rebuilding our soil health (Khangura et al., 2023; Choudhari et al., 2024). Unlike conventional practices that drain the land, regenerative farming is based on the principle that agriculture practices should serve as tools for healing and restoring the ecosystems, rather than exploiting our natural resources. This holistic approach to agriculture aims not only to restore soil health but also to boost biodiversity, improve water retention capacity, and mitigate the impacts of climate change. In this article, an attempt has been made to examine the real-world applications and benefits of regenerative agriculture, the challenges involved in transitioning towards regenerative

WHAT IS REGENERATIVE AGRICULTURE?

At its core, RA is an agricultural system that focuses on regenerating the soil and restoring ecological balance. Unlike conventional farming, which often deteriorates the soil through excessive tilling, chemical inputs, and monocropping, regenerative agriculture works in harmony with nature to improve soil health, increase biodiversity, and sequester carbon in the soil (TAAS, 2021). Regenerative agriculture emphasizes practices that build long-term soil fertility and ecosystem health. The regenerative

agricultural framework comprising the principles, practices, benefits and operative microbial mechanisms are given in Table 1.

ORIGIN OF REGENERATIVE AGRICULTURE

The Rodale Institute originally articulated the concept of regenerative agriculture during the early 1980s as a farming paradigm that goes beyond the notion of sustainability. Publications by Rodale Press in 1987 and 1988 laid the foundation for defining regenerative systems of agriculture as those that continuously restore, renew, and revitalize ecosystem functions rather than merely maintaining existing productivity levels (Taylor et al., 2025). Robert Rodale emphasized that the dominant discourse of sustainability in agriculture is inherently limited because it implies merely preserving the status quo rather than restoring or improving the underlying ecological and social systems. In contrast, regenerative agriculture was envisioned as a dynamic, proactive approach aimed at enhancing soil fertility, biodiversity, and ecological resilience through continuous improvement processes (Tindwa et al., 2024). The term experienced a decline in mainstream usage during the late 1980s. However, it regained prominence following the publication of a white paper in 2014 titled 'Regenerative Organic Agriculture and Climate Change' by the Rodale Institute. This seminal document positioned regenerative agriculture as a key strategy for mitigating climate change. It outlines practices such as diverse crop rotations, use of organic manure and compost, cover cropping, reduced tillage, and other organic management approaches. These practices collectively enhance carbon sequestration, improve nutrient

Table 1. Regenerative agriculture framework

| RA Principles | RA Practices | RA Benefits | Microbial Mechanisms |
|--------------------------------------|--------------------------------------|--|---|
| Minimise soil disturbance | No/minimum tillage | Improved soil health through: <ul style="list-style-type: none"> Increased soil carbon Improved microbial functions and associated nutrient cycling Improved soil moisture Improved resilience to pests and diseases | Liquid carbon pathway |
| Keep soils covered | Stubble retention | - | Improved uptake of water and minerals |
| Keep living roots in soil year-round | Diverse crop rotations | - | Enhanced soil aggregation, plant growth, and photosynthesis |
| Encourage diversity | Multispecies cover crops | - | |
| Integrate livestock | Intercropping | - | - |
| | Composting and use of bio-stimulants | Nutrient-rich food | - |
| | Rotational grazing | Reduced greenhouse gas emissions | - |
| | Reduce synthetic inputs | | - |

cycling, stimulate soil microbial activity, and strengthen resilience against climatic variability. By integrating these regenerative methods, agricultural systems can contribute meaningfully to both environmental sustainability and climate adaptation objectives.

CURRENT SCENARIO OF RA

In the contemporary context, regenerative agriculture has evolved into a globally recognized framework for sustainable intensification and climate-resilient farming systems. Multiple institutions and organizations are promoting adoption across varied agro-ecosystems:

- The Savory Institute, founded by Allan Savory, has advanced the principles of holistic management, with a focus on

large-scale grazing systems. Its approach emphasizes the integration of managed livestock, the restoration of degraded rangelands, and the reversal of desertification through soil carbon sequestration and improved water retention.

- Kiss the Ground, a nonprofit organization, has played a key role in popularizing regenerative agriculture through educational programs, media campaigns, farmer support networks, and policy advocacy platforms. Central to its mission is the improvement of soil organic matter, soil carbon pools, and the resilience of farmers' livelihoods.

In India, RA is being increasingly integrated into policy frameworks and development programs. Both Union

and State Governments are promoting initiatives aimed at reducing dependency on chemical fertilizers and pesticides, lowering input costs, and enhancing long-term soil fertility. These policies emphasize the use of organic amendments, biofertilizers, crop diversification, integrated nutrient management, and ecological pest regulation (TAAS, 2021). The broader objective is to transform conventional high-input systems into low-external-input, climate-smart, and resource-efficient production systems that ensure food security, ecosystem sustainability, and farm profitability. Regenerative agriculture has now emerged as a multifunctional paradigm capable of simultaneously addressing the challenges of soil degradation, biodiversity loss, greenhouse gas emissions, and the vulnerability of rural livelihoods, while contributing to the global agenda of sustainable development and climate resilience.

PRINCIPLES OF REGENERATIVE AGRICULTURE

The guiding principles of regenerative agriculture centre on nurturing the soil, enhancing biodiversity, and establishing systems that promote environmental and social sustainability.

1. Minimizing soil disturbance

In conventional farming, tillage is often used to prepare the soil for planting. This practice disturbs the soil structure, disrupts beneficial microbial communities, and releases carbon dioxide into the atmosphere. One of the main principles of regenerative agriculture is to minimize soil disturbance (TAAS, 2021). Practices such as no-till farming or low-till farming minimize soil disturbance which has several benefits, namely, soil structure preservation, carbon sequestration, improved water

retention and habitat protection for soil life enabling beneficial soil organisms, including worms, fungi, and bacteria, to thrive. These organisms help break down organic material, cycle nutrients, and improve soil structure over time (Davis et al., 2025). By keeping soil undisturbed, regenerative farmers can increase soil organic matter, which improves soil structure and enhances its ability to store water and nutrients. Healthy soil also sequesters carbon, playing a vital role in mitigating climate change.

2.

Maximizing crop diversity

Monocropping,

the continuous cultivation of a single crop increases efficiency but depletes soil nutrients

and encourages pest and disease outbreaks

making farming less sustainable over time.

Regenerative agriculture promotes crop diversity, which is essential for the health of the soil and the surrounding ecosystem.

Crop diversification can be achieved

through crop rotations, where different crops are planted in a specific sequence over several seasons.

Polyculture, or

planting different crops together, also

plays a role in enhancing biodiversity

and soil health (TAAS, 2021).

For example, growing a mix of legumes, cereals, and root vegetables provides a variety of nutrients and root structures, enriching the soil and promoting the health of beneficial organisms.

Crop diversity can also be expanded

through agroforestry, which integrates trees into farming systems.

Trees can

help prevent soil erosion, improve water retention, and provide habitat for wildlife.

By incorporating various

species and plants, regenerative farmers

can enhance ecosystem services such as

pollination and pest control.

4. Keeping the soil covered

Soil erosion is a significant challenge in conventional agriculture, particularly in areas prone to wind and water erosion.

In regenerative agriculture, one of the key principles is to keep the soil covered at all times. This practice is essential for maintaining and improving soil health.

This can be achieved by planting cover crops or leaving crop residues, such as straw or leaves, on the soil's surface.

The benefits of keeping the soil covered are manifold (TAAS, 2021; Choudhary et al., 2024).

First, it helps to prevent soil erosion by protecting the surface from wind and water.

Second, it helps to conserve moisture, reducing the need for irrigation.

Third, organic matter from crop residues and cover crops

breaks down over time, enriching the soil with nutrients and improving its structure.

5. Integrating livestock

While industrial farming often separates crop production from livestock,

regenerative agriculture encourages the integration of animals into farming systems. Properly managed livestock can play a crucial role in maintaining healthy soils and ecosystems. Through rotational grazing, where animals are moved between pastures, livestock can help to recycle nutrients, control weeds, and improve soil fertility by dispersing manure evenly across the land (Davis et al., 2023). Livestock can also break down organic matter, which contributes to the improvement of soil structure and nutrient cycling. Moreover, they can help to diversify the farm system, making it more resilient to climate change and market fluctuations.

BENEFITS OF REGENERATIVE AGRICULTURE

The benefits of regenerative agriculture extend far beyond the farm and have the potential to positively impact the global ecosystem and society at large. Some of the most significant advantages of regenerative farming are as follows:

1. Improved soil health

Regenerative agriculture focuses on rebuilding soil health by increasing organic matter, improving soil structure, and encouraging biodiversity (TAAS, 2021). Healthy soils are more resilient to environmental stresses such as droughts and floods. They also sequester more carbon, contributing to climate change mitigation. As soil health improves, it enhances the soil's ability to retain water and nutrients, which results in higher crop yields (Choudhari et al., 2024). Over time, regenerative practices such as cover cropping, crop rotation, reduced tillage, and compost application can lead to healthier, more productive, and more resilient soils that support greater biodiversity and long-term agricultural sustainability.

2. Mitigating climate change through carbon sequestration

One of the key environmental benefits of regenerative agriculture is its ability to sequester carbon. Regenerative practices such as no-till farming, agroforestry, and cover cropping all help to capture carbon dioxide from the atmosphere and store it in the soil (TAAS, 2021; Choudhari et al., 2024). Soil is a significant carbon sink, and improving its health can help to mitigate climate change. The process of carbon sequestration in soil reduces the amount of carbon dioxide in the atmosphere, thereby helping to counteract the effects of global warming. Furthermore, regenerative farming practices contribute to reducing greenhouse gas emissions by decreasing reliance on synthetic fertilizers and fossil fuels.

3. Enhanced biodiversity

By promoting diverse cropping systems, agroforestry, and the integration of livestock, regenerative agriculture helps to foster rich biodiversity both above and below the soil surface. Diverse ecosystems are more resilient to pests, diseases, and environmental fluctuations (TAAS, 2021). Biodiversity also provides crucial ecosystem services, including pollination, pest control, and nutrient cycling, as these are essential for maintaining healthy ecosystems. By integrating a variety of plants and animals, regenerative farms create healthy habitats for wildlife, beneficial insects, and microorganisms, all of which play important roles in maintaining ecosystem health.

4. Improved water management

Regenerative practices improve the water retention capacity of soils, reducing the need for irrigation. By increasing organic matter, maintaining

living roots, and protecting the soil with cover crops, regenerative farming enhances the soil's ability to hold moisture and absorb rainwater. Improved soil structure also leads to better water infiltration and reduced surface runoff, thereby decreasing the risk of flooding and soil erosion. In drought-prone regions, these practices are critical, as they enable farmers to manage their water resources more efficiently.

5. Economic sustainability for farmers

Transitioning to regenerative agriculture can provide farmers with long-term economic benefits by improving soil health, reducing input costs, and increasing resilience to climate stress. While the initial investment in regenerative practices may be higher, these costs are offset by the reduced need for synthetic inputs (such as fertilizers and pesticides) and improved yields over time. Moreover, regenerative agriculture offers farmers the opportunity to participate in carbon markets. By adopting practices that sequester carbon, farmers can earn carbon credits and sell them to corporations and governments seeking to offset their emissions (TAAS, 2021; Choudhari et al., 2024). This additional income stream provides farmers with a financial incentive to adopt sustainable practices.

6. Resilience to climate change

As climate change continues to disrupt agricultural systems, regenerative agriculture offers a pathway to resilient farming. By rebuilding soil health and enhancing biodiversity, regenerative farming systems are better able to withstand extreme weather events, such as droughts, floods, and heatwaves. The practices of regenerative agriculture improve the farm's ability to recover



from shocks, making farming more resilient in the face of climate change. In the regions where unpredictable weather patterns have compromised traditional farming, regenerative practices can provide a more reliable and sustainable solution.

CHALLENGES IN IMPLEMENTING REGENERATIVE AGRICULTURE

Despite its apparent benefits, the adoption of regenerative agriculture faces several challenges, particularly for smallholder farmers and those transitioning from conventional farming systems. These include:

1. Initial investment and transition costs

Transitioning from conventional farming to regenerative practices requires an initial investment in new tools, training, and infrastructure. While regenerative practices often reduce input costs over time, the upfront financial commitment can be a barrier for farmers, especially those with limited access to capital.

2. Knowledge and training

Regenerative agriculture requires a

deep understanding of soil health, ecosystem dynamics, and ecological processes. Farmers need specialized knowledge on how to implement practices such as crop rotations, no-till farming, and cover cropping effectively. Providing training and support is crucial for successful adoption, especially for farmers who are accustomed to traditional methods.

3. Policy and market access

Government policies and market access play a crucial role in the widespread adoption of regenerative agriculture. Supportive policies, such as subsidies for sustainable practices, incentives for carbon sequestration, and grants for education and training, are vital in making regenerative farming accessible to farmers.

4. Resistance to change

In many regions, traditional farming practices have been deeply ingrained for generations. Changing to regenerative methods requires not only financial investment but also a cultural attitude shift. Overcoming this resistance requires education,

outreach, and strong support from both local communities and agricultural organizations.

REAL-WORLD APPLICATIONS AND SUCCESS STORIES

1. Dryland farming in India

In India's dryland regions, covering about 52 per cent of total cultivated land, where water scarcity is a significant challenge, regenerative practices such as conservation tillage, rotation of cereal-legumes in the cropping system, direct-seeded rice, and mulching have demonstrated significant successes. These methods help improve soil water retention, reduce irrigation needs, and increase crop productivity in arid environments.

Unfortunately, Conservation Agriculture in drylands in India, having great potential to make these grey areas green, has not been adopted yet on large scale as happened in Latin America, USA, Canada, Australia etc. On the contrary, CA or no till cultivation is adopted in rice-wheat system in the indo-gangetic plain to a level of around 3.5 million hectares.

The scope to double it in next 5 years exists but would require a concerted effort.

2. Agroforestry in Africa

In many parts of Africa, agroforestry—the integration of trees with crops and livestock—is helping restore degraded lands, enhance biodiversity, and improve soil fertility. Farmers in countries such as Kenya and Tanzania have seen increased yields and better resilience to droughts by adopting agroforestry systems.

3. Carbon credits in the United States of America

Farmers in the United States have been able to earn carbon credits by adopting regenerative practices, such as no-till farming, crop rotation like corn-soybean, and agroforestry. These carbon credits provide farmers with an additional revenue stream, incentivizing them to continue sustainable agricultural practices that also benefit the environment.

4. No-till and Broader Conservation Agriculture

The global area under conservation agriculture CA particularly no-till and reduced-till practices, has expanded substantially over the past two decades. A widely cited synthesis of national datasets covering the period 2000 - 2020 estimates that over 205 million hectares of cropland are now managed under conservation/no-till practices — roughly doubling the area recorded a decade earlier.

Growth in the use of CA- has been rapid especially in the United States, Brazil and Argentina which are the largest single-country holders of no-till area, while other important adopters include Australia, Canada, China and a few selected countries in southern



Africa and South Asia.

CONCLUSION

In the United States, the share of cropland managed under no-till or reduced-till systems continue to rise across major field crops such as maize, soybean, and wheat. Similar trends are observed in other major producing regions, where conservation tillage is increasingly recognized for its benefits in soil health, moisture conservation, erosion control, and input efficiency.

MAIN BENEFITS REPORTED

Farmers and researchers have reported several benefits associated with successful implementation of no-till practices. These include: reduced soil erosion, enhanced water infiltration and retention, and lower fuel/labor requirements and costs due to fewer field operations. Additionally, maintaining surface residue improves soil cover, and over time, the system contributes to increased soil organic matter and improved soil structure—particularly when integrated with crop rotations and cover crops. These benefits are the primary drivers of adoption of no-till systems in the regions facing acute water scarcity or severe erosion challenges.

in stark contrast to conventional farming, which often releases carbon into the atmosphere through practices like tillage and monocropping. Additionally, regenerative agriculture fosters biodiversity by encouraging a wider variety of plants and animals on the farm. This increased biodiversity leads to stronger, more resilient ecosystems, which can help to buffer against the unpredictable impacts of climate change. For farmers, the transition to regenerative agriculture may require some upfront investment in education, equipment, and time to see tangible results. However, the long-term rewards are substantial. Healthier soils lead to higher yields, reduced dependency on synthetic fertilizers and pesticides, and lower input costs. Regenerative practices can also increase farm profitability by diversifying revenue streams through products like livestock, timber, or even carbon credits for sequestration efforts.

The global adoption of regenerative

agriculture requires a policy framework that fosters collaboration between farmers, policymakers, businesses, researchers and consumers. Policymakers play a pivotal role in enabling this transition by creating an environment that rewards sustainable land management and long-term environmental stewardship. Knowledge-sharing and access to resources are essential, as farmers need the right tools, support, and incentives to make the transition. Targeted financial incentives, such as subsidies for using sustainable practices or access to markets that value regenerative products, can further encourage the adoption of regenerative agriculture. Moreover, governments play a crucial role in implementing policies that support regenerative agriculture, such as providing tax breaks, funding for research, and creating systems for tracking and rewarding environmental benefits. Ultimately, regenerative agriculture has the potential to reshape our food systems, creating a future

where farming is not only productive but also ecologically sustainable and climate-resilient. Through education, effective knowledge sharing and extension systems, easy availability of inputs like biofertilizers, biopesticides, herbicides, growth promoters, soil mulching, easy credit and availability of implements and tools, enabling policy support, and market incentives, we can unlock the full potential of regenerative agriculture and create much healthier, more sustainable agriculture for our future generations



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