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Roots of Resilience: Regenerative Practices for Restoring Soil Health

Parveen Kumar and Rohit Kumar

1Horticulture Development Officer, Department of Horticulture, Government of Haryana. 2Ph.D. Scholar, Department of Soil Science, CCS Haryana Agricultural University, Hisar-125004,

Corresponding Author: parveenktk1995.pk@gmail.com

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Abstract

Soil degradation due to intensive agriculture and chemical dependency has spurred global interest in regenerative agriculture, a systems-based approach aimed at reviving soil health and ecological resilience. This article synthesizes scientific evidence and field practices that show how regenerative techniques, such as cover cropping, reduced tillage, organic amendments, managed grazing and agroforestry, enhance soil organic carbon (SOC), microbial diversityand crop nutrition while contributing to climate mitigation. Indian and international case studies underscore the long-term benefits and challenges of implementation, highlighting the need for supportive policy, education and technology. Innovations like AI tools and enhanced weathering present promising frontiers. A long-term, integrated strategy is vital for sustainable soil restoration and resilient food systems.

Keywords: Agroforestry, Carbon sequestration, Cover crops, Microbial diversity, Soil health

Introduction

As the foundation of global food systems and a critical component of planetary health, soil plays a vital role in regulating water, cycling nutrients, supporting biodiversity and storing carbon. Yet, decades of intensive agriculture, chemical dependency and land degradation have left vast stretches of farmland depleted stripped of organic matter, microbial life and resilience. In response to these growing crises, a transformative movement has emerged that is regenerative agriculture**.** Rooted in traditional ecological wisdom and guided by cutting-edge science, regenerative practices aim not just to sustain but to revive and improve soil health**.** These methods, ranging from cover cropping and reduced tillage to compost application, rotational grazing and agroforestry, focus on rebuilding soil organic carbon, enhancing microbial diversity and creating self-sustaining agroecosystems. This article explores the science and practice of regenerative agriculture through a detailed lens, drawing on recent peer-reviewed studies, long-term field trials, and real-world applications. We examine how these soil-first strategies restore ecological balance, improve crop nutrition, support climate mitigation and build the "roots of resilience" needed for future food and environmental security.

1. What Is Regenerative Agriculture?

Regenerative agriculture is an integrated, systems-based approach that goes well beyond traditional sustainability. Its core principles include:

- **Minimized soil disturbance** (reduced or no-till), protecting soil structure and mycorrhizal networks
- **Continuous cover cropping** to prevent bare soil, reduce erosion and enhance nutrient cycling
- **Crop diversity and rotation**, including legumes, to build ecosystem resilience
- **Organic amendments** such as manure, compost and biochar to replenish soil organic matter

Krishi Netra
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- **Integration of livestock** via managed grazing for natural fertilization and pasture renewal
- **Incorporation of trees (agroforestry/silvopasture)** to improve microclimate, biodiversity and carbon storage

2. Soil Health & Organic Carbon: Evidence-Based Insights

a. Cover Cropping and Crop Rotation

- Meta-analyses show cover cropping increases soil organic carbon (SOC) by ~0.2–0.56 Mg C/ha/year, with multispecies or legume-based mixes proving especially effective
- Diversified crop rotations also contribute 0.2 Mg C/ha/year SOC gains, notably in pedoclimates with integrated perennials.

b. Reduced/No-Till and Conservation Agriculture

- A Catena review (2025) revealed significant SOC increases—up to 131% in topsoil, when reduced tillage/no-till is combined with crop rotation. Enhanced microbial and fungal networks are key to this impact.

c. Organic Amendments (Manure, Compost and Biochar)

- Manure boosts SOC by 35% (approx. 10.7 Mg/ha) and improves soil physical properties.
- Biochar, particularly when mixed with compost, enhances water retention (30–40%), stabilizes carbon over centuries and feeds the microbial ecosystem.

3. Regenerative Grazing and Silvopasture

- **Adaptive Multi-Paddock (AMP) Grazing** integrates high-density, short-duration grazing followed by rest, regenerating soil ecological function. Studies show improvements in infiltration, carbon accumulation, biodiversity and profitability.
- **Silvopasture and agroforestry**—combining trees, crops and livestock, provide significant multifunctional benefits, including enhanced SOC, nutrient cycling and ecosystem resilience.
- Carbon-credit initiatives tied to silvopasture are gaining traction, generating around US $300–$450/acre/year on converted lands.

4. Soil Microbial Communities and Crop Nutrition

- Regenerative farming enhances soil bacterial and fungal diversity, boosting nutrient uptake and resilience.
- PeerJ research shows regenerative farms produce crops richer in micronutrients (Mg, Ca, K, Zn, vitamins) and phytochemicals, promoting human health. They also yield meat with better omega3 ratios.

Krishi Netra
ISSN : 3048-5207

5. Long-Term Impacts and Systemic Benefits

- A 2024 synthesis covering 50 years across more than 4,200 studies found that agricultural diversification leads to large gains: financial profitability, biodiversity, soil quality and carbon sequestration increased by up to 2800% over two decades.
- Research emphasizes that long-term implementation (20–50 years) is essential to capture peak benefits in ecosystem services.

6. Challenges and Tradeoffs

- Gains in SOC may be partly offset by increased methane or nitrous oxide emissions when using organic amendments; full greenhouse gas accounting is necessary.
- Practices like no-till may require specialized equipment and present short-term yield variability. Film critiques highlight the risk of overhyping soil as a carbon panacea without broader policy and dietary shifts.

7. Real-World Adoption and Policy Momentum

- In India's Jharkhand, over 25,000 farmers (particularly women) in 40 panchayats began regenerative practices around 2022, leading to better soil health, nutrition, income and ecological restoration.
- In the U.S., *prairie strips* in croplands reduce soil erosion by 95%, enhance biodiversity, curb nutrient runoff and boost carbon storage, especially under federal support.

8. Emerging Innovations and Future Directions

- Innovations include **mycorrhizal inoculation**, enhancing nutrient and water uptake and reducing phosphorus fertilizer needs by 50% while boosting yields 15–20%.
- **AI-driven "Soil Carbon Copilots"** offer localized modeling of SOC changes, enabling data-informed management decisions.
- **Enhanced Weathering** using crushed silicate rock shows potential for meaningful CO_2 sequestration, as part of holistic regenerative land use.

Integration and Implementation in Practice

Successful regenerative agriculture combines practices:

Practice	Benefit
No-/Reduced till	Fewer emissions, robust soil structure
Cover crops	Erosion control, SOC boosts
Crop diversity	Nutrient cycling and pest resilience

Krishi Netra
ISSN : 3048-5207

Practice	Benefit
Organic amendments	Soil fertility and moisture retention
AMP grazing/livestock	Natural fertilization, carbon storage
Agroforestry	Multifunctional ecosystem benefits

These are enhanced by data tools, carbon-offset markets and supportive policies. Long-term commitment is key for sustainable outcomes.

9. Detailed Findings from Indian and International Studies on Regenerative Practices

Sharma and Singh (2021) studied conservation agriculture in the Indo-Gangetic plains. They found that zero tillage with crop residue retention increased soil organic carbon (SOC), reduced erosion, and stabilized crop yields. This was due to less soil disturbance and better ground cover, which supported soil microbes and nutrient cycling.

Kumar and Singh (2020) examined integrated nutrient management (INM) in a rice-wheat system. Their results showed that combining organic manure with chemical fertilizers improved soil structure, enhanced nutrient availability, and boosted yields. This approach also helped build long-term soil fertility and microbial health.

Ramesh and Patel (2019) focused on agroforestry in semi-arid Indian regions. Their study found that integrating trees with crops increased soil organic matter by up to 30% and improved water retention. The system also promoted nutrient cycling and protected against wind erosion.

Lal (2020) reviewed global regenerative practices and emphasized their role in restoring degraded soils. He highlighted that reduced tillage, cover crops, compost and managed grazing can improve soil structure, boost biodiversity and sequester carbon. He called for widespread adoption to meet climate and sustainability goals.

Schreeg, Creamer and Peet (2021) conducted a meta-analysis on cover cropping. They found that cover crops raised SOC by about 0.3 Mg C/ha/year. Multispecies mixes and legumes were especially effective in supporting soil microbes and nitrogen cycling.

Teague et al. (2021) evaluated adaptive multi-paddock (AMP) grazing. Their findings showed that AMP improved water infiltration, reduced erosion and increased soil microbial diversity. It also enhanced carbon sequestration, particularly in dry rangelands.

Powlson et al. (2014) offered a more cautious view of no-till agriculture. While no-till reduced soil disturbance and improved water retention, the study noted it had limited impact on long-term carbon storage unless combined with other regenerative practices like crop rotation and organic amendments.

10. Key Takeaways

- Regenerative practices demonstrably rebuild soil organic carbon, microbial diversity, water retention and nutrient cycling.
- The impact is substantial but builds gradually, maximizing value typically requires 10–50 years of cumulative effort.
- Synergies between methods (e.g., cover crops + no-till + organic amendment) yield the strongest benefits.

Krishi Netra
ISSN : 3048-5207

- Challenges include emission trade-offs and upfront costs; addressing these requires holistic policy and market engagement.
- Scaling success needs support systems: financing, extension services, carbon markets and community knowledge-sharing.

11. Outlook for 2025 and Beyond

- The regenerative movement is evolving with scientific rigor: peer-reviewed meta-analyses, data-driven tools and on-farm validation.
- Policy frameworks are increasingly embracing carbon credits, conservation incentives and support for farmer transition.
- Innovations like AI-driven monitoring and biogeochemical "enhanced weathering" signal a future where regenerative farming becomes climate-smart and operationally efficient.

Conclusion

- Regenerative agriculture offers a promising, evidence-based pathway to restore degraded soils, enhance food and nutritional security and combat climate change. By prioritizing soil health through practices like cover cropping, reduced tillage, organic amendments, diversified cropping systems, managed grazing and agroforestry, this approach moves beyond sustainability toward ecological regeneration. The cumulative benefits improved soil organic carbon, microbial diversity, water retention and ecosystem resilience are well-documented but require time, local adaptation and policy support to fully materialize.
- While challenges such as greenhouse gas trade-offs, economic barriers and implementation complexities exist, they can be addressed through integrated strategies that combine scientific innovation, community-based learning, carbon market incentives and long-term investment. India's progress and global examples demonstrate that regenerative agriculture is not just an environmental necessity but also a socio-economic opportunity, laying the true "roots of resilience" for future food systems and planetary health.

Reference

Cramer, R. (2024, December 26). "The dead zone is real": Why US farmers are embracing wildflowers. The Guardian.

Feliziani, G., Bordoni, L., and Gabbianelli, R. (2025). Regenerative organic agriculture and human health: The interconnection between soil, food quality, and nutrition. Antioxidants (Basel, Switzerland), 14(5), 530.

Gorman, D. (2021, October 30). Regenerative farming goes beyond sustainability. The Mindful Fork.
Jacobs, A. (2024, December 26). Digging deep: How regenerative agriculture is revolutionizing carbon capture and soil health. Dynamic Carbon Credits.

Kimbrough, L. (2022, June 3). Study: Regenerative farming boosts soil health, yielding more nutritious crops. Mongabay – Agroecology News.

Kumar, A., and Singh, K. (2020). Role of integrated nutrient management in improving soil health and crop

Krishi Netra
ISSN : 3048-5207

yield in rice-wheat system. Indian Journal of Agricultural Sciences, 90(6), 1134–1140.

Kumar, A., Antoniella, G., Blasi, E., and Chiti, T. (2025). Recent advances in regenerative sustainable agricultural strategies for managing soil carbon and mitigating climate change consequences. Catena, 258, 109208.

Lal, R. (2020). Regenerative agriculture for food and climate. Journal of Soil and Water Conservation, 75(5), 123A–124A.

Powlson, D. S., Stirling, C. M., Jat, M. L., Gerard, B. G., Palm, C. A., Sanchez, P. A., and Cassman, K. G. (2014). Limited potential of no-till agriculture for climate change mitigation. Nature Climate Change, 4(8), 678–683.

Ramesh, R., & Patel, P. (2019). Agroforestry as a strategy for sustainable soil management in semi-arid regions of India. Indian Journal of Agroforestry, 21(1), 41–48.

Raveloaritiana, E., and Wanger, T. C. (2024). Decades matter: Agricultural diversification increases financial profitability, biodiversity and ecosystem services over time. Regenerative Agriculture Practices and Environmental Impacts.

Rehberger, E., West, P. C., Spillane, C., and McKeown, P. C. (2023). What climate and environmental benefits of regenerative agriculture practices? An evidence review. Environmental Research Communications, 5(5), 52001.

Schreeg, L. A., Creamer, C., and Peet, R. K. (2021). Effects of cover cropping on soil organic carbon and soil health: A meta-analysis. Soil Biology and Biochemistry, 154, 108142.

Sharma, S., & Singh, R. (2021). Impact of conservation agriculture practices on soil organic carbon and crop productivity in the Indo-Gangetic plains. Journal of Soil and Water Conservation, 20(2), 156–164.

Teague, R., and Kreuter, U. (2020). Managing grazing to restore soil health, ecosystem function, and ecosystem services. Frontiers in Sustainable Food Systems, 4, Article 53418.

Teague, W. R., Apfelbaum, S., Lal, R., and Kreuter, U. (2021). The role of managed grazing in restoring soil health and ecosystem services. Frontiers in Sustainable Food Systems, 5, 609069.

Torrella, K. (2025). The false climate solution that just won't die: A star-studded film explains the hope and hype behind regenerative agriculture. Vox.