Plant Archives Vol. 26, No. 1, 2026 pp. 2614-2624 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.362

REGENERATIVE AGRICULTURE AND ITS ROLE IN IMPROVING SOIL HEALTH AND ECOSYSTEM RESILIENCE: A REVIEW

Mayuri M. Jagtap*, B.M. Kamble, S.R. Shelke, Nikita. B. Gorde, Samiksha G. Ahire and R.B. Zodge

Department of Soil Science, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahilyanagar, Maharashtra, India -413722

*Corresponding author E-mail:mayurijagtap000@gmail.com

(Date of Receiving-07-01-2026; Date of Revision-02-03-2026; Date of Acceptance-18-03-2026)

ABSTRACT

Conventional farming is facing many challenges due to soil degradation, crop yield decline, and effect of climate change to overcome these challenges regenerative agriculture, emerge as a promising tool. Regenerative farming aspect mainly focusing on restoring soil health, reducing climate-related risks, and strengthening the resilience of entire ecosystems. Regenerative agriculture is a holistic, science-based approach that mainly works with nature to rebuild soil function, increase biodiversity, and create agroecosystems capable of sustaining productivity for long run. Conventional farming mainly depends on external inputs and also it disturbs the natural environmental processes while regenerative agriculture focuses on regenerating inputs required and also prioritizes practices that enhance and protect those processes to maintain a healthy, balanced environment. At its core regenerative agriculture mainly based on six guiding principles which are namely understanding and adapting to local conditions, minimizing soil disturbance, keeping the soil covered, maintaining living roots in the ground year-round, fostering biological diversity, and integrating livestock into the farming system. This paper discusses about various benefits of regenerative agriculture while also addressing the challenges related to adoption, scalability, and the need for long-term empirical research. Regenerative agriculture offers a realistic path towards farming systems that are both productive and resilient in the face of climate change.

***Key words*:** Regenerative agriculture concept, Principles of regenerative agriculture, benefits, Practices, Challenges of Regenerative agriculture

Introduction

Although soil is often referred to "the fragile, living skin of the Earth," the expansion of agriculture around the world has far too frequently ignored both its fragility and aliveness (Rhodes, 2017). According to (Montgomery, 2012), poor farming practices are causing us to lose topsoil at the alarming rate of one inch every decade. The Global Soil Partnership (GSP, 2017) led by the FAO indicates that 75 billion tonnes of soil are eroded annually from cultivated worldwide. According to the FAO-led Global Soil Partnership (2017), arable lands around the world lose 75 billion metric tonnes (Pg) of soil annually due to erosion. By 2050, over 90% of Earth's soils may have deteriorated from their present condition, a figure of 33% (FAO and ITPS, 2015). Over recent decades, land suitable for food production has deteriorated due to conventional land use and commercial farming practices (Yadav *et al.*, 2023). Land plays a vital role in other ecosystem services, including sustaining biodiversity (White, 2020). Currently, more than a million plant and animal species are at risk of extinction, with biodiversity vanishing at unprecedented rates (IPBES, 2019a). The health of humans, the environment, plants, animals, and soil are deeply interconnected. As soil quality diminishes, human health also suffers. A new global imperative includes the interlinked nature of climate change, food security, climate resilience, biodiversity, and soil health (Paustian *et al.*, 2020). We anticipate a 60% increase in food production by 2050 to feed the projected 9.5 billion people, up from the current 7 billion. As a result, we are depleting the soil's productivity, from which we expect an unrelenting rise in output (Rhodes, 2017). This has driven interest in creating farming methods and systems that are more sustainable and require fewer synthetic inputs (Jayasinghe *et al.*, 2023). In order to effectively replace expensive external inputs with human capital, new approaches that integrate biological and ecological processes into food production, minimise the use of non-renewable inputs that harm the environment or the health of farmers and consumers, and effectively utilise farmer knowledge and skills must be developed. These approaches should also make good use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest, and credit management (Pretty, 2008). Soil degradation affects one billion ha of land worldwide, with India accounting for approximately 10%. This degradation leads to biodiversity loss, the accumulation of contaminants and pollutants, and the risk of climate change. (TASS, 2021) There is a connection between the health of the soil, organisms, the ecosystem, and humans; when soil health declines, so does human health. One of the planet's five major carbon sinks is soil. (TASS, 2021, Al-Kaisi & Lal, 2020). According to UN estimates, topsoil will degrade within 60 years, resulting in no farming conditions. The primary causes of soil degradation are increased chemical use, deforestation, and climate change conditions. Soil nutrients are released into the atmosphere, leading to increased GHG emissions, decreased nutrient use efficiency (NUE), decreased SOC ($\leq$ 0.5), decreased soil biodiversity, imbalanced fertiliser use, and nearly 10 million metric tonnes of nutrient mining annually, Soil organic matter (SOM) declines within two to five years, while rejuvenation and build-up can take up to ten times longer and require additional effort (TASS 2021).

A possible approach for achieving sustainable food systems is regenerative agriculture (RA) (Schreefel *et al.*, 2020). Producers, consumers, researchers, retailers, politicians, and the mainstream media have all shown a great deal of interest in regenerative agriculture currently (Newton *et al.*, 2020). The Institute, located in the USA and named Rodale, introduced the regenerative agriculture concept in the 1980s to enhance food security by revitalising soil health, sequestering carbon, conserving water, improving drainage, and addressing climate change through increased productivity (TASS, 2021). Since its inception in the 1980s, the regenerative agriculture movement has consistently aimed to rebuild or increase the availability of resources essential for agriculture to achieve sustainability (O'donoghue *et al.*, 2022). Agriculture has a considerable environmental impact (Newton *et al.*, 2020). Conventional farming methods, as noted by (Khangura *et al.*, 2023), can lead to reduction in soil productivity and soil degradation. Globally, regenerative agriculture (RA) is a farming strategy being used to maintain agricultural output while enhancing biological services and environmental advantages (Jayasinghe *et al.*, 2023). It focuses on fostering life both above and below the soil, taking inspiration from nature's long-standing success in growing plants (White, 2020). Regenerative agriculture rethinks traditional farming practices through a holistic set of nature-based principles designed to restore soil health, biodiversity, and farm economics (Eckberg *et al.*, 2020).

Regenerative agriculture emerges as a viable and innovative alternative to conventional farming which offers integrated solutions to address various critical environmental and agricultural issues such as soil degradation, loss of biodiversity, and increasing climate variability (La Canne & Lundgren, 2018; Schreefel *et al.*, 2020). This review studied the core principles and also wide-ranging benefits of regenerative farming practices, which include improving soil structure, enhancing organic carbon sequestration, promoting efficient nutrient cycling, and strengthening the ability of agroecosystems to withstand stress. Despite having various potential benefits, the transition to regenerative agriculture is often constrained by practical and socio-economic factors. Financial barriers, the absence of region-specific technical guidance, inadequate institutional support, and persistent skepticism within farming communities present act as a significant barrier to broader adoption (Giller *et al.*, 2021; Newton *et al.*, 2020). The objective of this paper is to study findings from existing

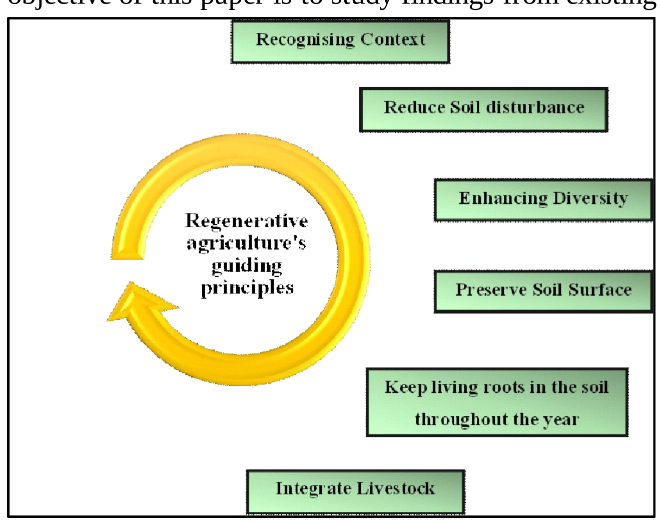

Fig. 1: Regenerative agriculture's guiding principles.

Table 1: Definitions of regenerative agriculture.

Definitions of regenerative agriculture	
"Holistic farming systems that, among other benefits, improve water and air quality, enhance ecosystem biodiversity, produce nutrient-dense food, and store carbon to help mitigate the effects of climate change, designed to work in harmony with nature, while maintaining and improving economic viability	**UN's Food and Agriculture Organization (FAO)**
RA as dynamically advanced modified technique involving the use of organic farming methods	**Malik and Verma (2014)**
RA as a farming approach that has the capacity for self-renewal and resiliency, contributes to soil health, increases water percolation and retention, enhances and conserves biodiversity, and sequesters carbon.	**Elevitch *et al.*, (2018)**
RA as an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple ecosystem services	**Schreefel *et al.*, 2020**
Regenerative Agriculture (RA) is a comprehensive system of farming combining a number of cultivation practices specifically focussing on regenerating top-soil to restore degraded soil biodiversity, rebuild soil organic matter, and improve water retention and nutrient uptake.	**Trust for Advancement of Agricultural Sciences (TAAS), 2021**
RA is an agricultural and transdisciplinary approach that integrates local and indigenous knowledge of landscapes, as well as their management, with established scientific knowledge. It combines a range of adoptable principles with context-specific practices, focusing on soil conservation as the initial step to restore soil health, enhance ecosystem functions, and promote improved socioeconomic outcomes".	**Jayasinghe *et al.*, 2023**

research to highlight both the environmental and agronomic advantages of regenerative systems, while also critically assessing the challenges that could limit their adoption and scalability.

Regenerative Agriculture – Definition & Concept

At its core, the term regenerative implies "the ability to return back into existence"; thus, if something is regenerative, it has the natural capacity to renew itself (Rhodes, 2017). The phrase regenerative organic agriculture was originally coined by the late Robert Rodale, founder of the Rodale Institute. The Rodale Institute, founded in the 1930s, has been at the forefront of organic and regenerative agriculture research for decades (LaSalle *et al.*, 2008). Their Farming Systems Trial, established in 1981, is the longest-running comparison of organic and conventional farming practices in the United States (Moyer, 2013). This research has demonstrated that organic systems can match conventional yields while improving soil health, reducing energy consumption, and lowering greenhouse gas emissions (Moyer, 2013). Regenerative agriculture aims to enhance soil organic matter, carbon sequestration, and biodiversity while producing nutritious food profitably (Hatt *et al.*, 2024). It integrates multiple practices to deliver ecosystem services and achieve desirable socio-ecological outcomes at the farm level (Hatt *et al.*, 2024). Robert Rodale, a key figure in promoting regenerative agriculture, played a significant role in advancing alternative agricultural research and education policies (Hassebrook, 1990). His work continues to influence both alternative and conventional agricultural communities worldwide. His regenerative practices demonstrated the potential to increase organic matter in soil, thereby enhancing natural carbon sequestration from the atmosphere (Rhodes, 2017). Regenerative agriculture encompasses a broad spectrum of farming practices aimed at transferring carbon from the atmosphere into the soil, enhancing biodiversity, improving the water cycle, and increasing soil organic matter to improve soil health and mitigate climate change (Yadav *et al.*, 2023). Despite growing global interest, a standardized definition of regenerative agriculture remains absent (Newton *et al.*, 2020; Schreefel *et al.*, 2020). Existing definitions vary—some emphasize specific practices such as cover cropping and livestock integration, while others focus on outcomes

Table 2: Different outcomes of using reduced tillage.

Findings	Researcher
Reduced and minimum tillage systems cause less soil displacement and erosion compared to conventional tillage in dryland agriculture.	**Kouselou *et al.*, (2018)**
Minimum tillage and residue retention increase soil microbial population size and diversity compared to conventional tillage.	**Li *et al.*, (2020)**
No-tillage and minimum-tillage can reduce greenhouse gas emissions compared to conventional ploughing.	**Alskaf *et al.*, (2021)**
Reducing tillage intensity increases soil organic carbon sequestration and aggregate stability through enhanced fungal biomass and microbial necromass.	**Sae-Tun *et al.*, (2022)**

Table 3: Research findings related to use of cover cropping.

Findings	Researcher
Cover cropping significantly increases soil microbial abundance, activity, and diversity compared to bare fallow.	**Kim *et al.*, (2020)**
Including cover crops in agricultural rotations significantly increases soil organic carbon, with the greatest increases in fine-textured soils and temperate climates.	**Jian *et al.*, (2020)**
Cover cropping enhances soil microbial biomass and affects microbial community structure compared to no cover crop.	**Muhammad, *et al.*, (2021)**
Cover crops can provide ecosystem services like soil water conservation and nutrient supply, but may also reduce subsequent crop yields in drylands, with a "break-even" point of ~700 mm annual precipitation.	**Garba, *et al.*, (2022)**
Cover crops can improve soil health and crop performance by enhancing physical, chemical, and biological soil properties and optimizing nutrient use efficiency.	**Scavo *et al.*, (2022)**

Table 4: Outcomes related to Diversified farming approach.

Findings	Researcher
Agricultural diversification enhances multiple ecosystem services without compromising crop yields.	**Tamburini *et al.*, (2020)**
Crop-rotation diversification increases agricultural resilience to adverse growing conditions without sacrificing yields.	**Bowles *et al.*, (2020)**
Maximizing crop functional diversity in agroforestry systems can drive multiple ecosystem functions like weed suppression, soil protection, and crop yield.	**dos Santos *et al.*, (2021)**
Diversified crop rotation improves soil condition, boosts system productivity, and contributes to sustainable crop production.	**Shah *et al.*, (2021)**
Increasing plant diversity at multiple scales can enhance ecosystem services and contribute to ecologically intensive and sustainable crop production.	**Brooker, R. *et al.*, (2023)**

like enhanced soil health and carbon sequestration, or a combination of both (Newton *et al.*, 2020). Nonetheless, most definitions converge on the goal of improving both environmental and socio-economic dimensions of agriculture (Schreefel *et al.*, 2020).

According to (Schreefel *et al.*, 2020), soil conservation is frequently regarded as the foundational step toward regenerative agriculture. Researchers increasingly advocate for operational definitions that incorporate local knowledge and socio-economic outcomes (Jayasinghe *et al.*, 2023). A selection of definitions proposed by researchers is presented in Table 1. The lack of a precise and unified definition may create ambiguity in policy implementation and communication (Newton *et al.*, 2020). Among various agricultural systems, regenerative agriculture (RA) stands out for its combined benefits of biodiversity conservation and landscape restoration (Khangura *et al.*, 2023). It includes a suite of techniques aimed at improving soil health, enhancing biodiversity, and sequestering atmospheric carbon. Recently, RA has been acknowledged as a comprehensive approach for promoting soil and environmental health, boosting biodiversity, and fostering productive farms, a healthy society, and a thriving agricultural community (TASS, 2021).

Basic principles of regenerative agriculture:

A collection of generally acknowledged guidelines known as "regenerative agriculture" consists of the following: 1) minimising soil disturbance; 2) maintaining (as much as possible) a continuous vegetative cover on the soil; 3) increasing the amount and variety of organic residues reverted to the soil; and 4) optimising plant nutrient and water use efficiency (Paustian *et al.*, 2020). The protection of water resources, economic sustainability, soil restoration, and climate mitigation are the main tenets of the RA system (Al-Kaisi & Lal, 2020). This holistic approach to farming or ranching is based on six core principles for restoring agroecosystems: understanding the specific context of the farm or ranch, minimizing soil and ecological disturbances (such as tillage, pesticides, and synthetic fertilizers), maintaining the soil covered, keeping the living roots in the soil for as much of the year as possible, maximizing diversity, and integrating livestock (Eckberg *et al.*, 2020). Regenerative agriculture (RA) is a food production approach aimed at improving soil health, enhancing biodiversity and sequestering carbon (Newton *et al.*, 2020). Key practices include reducing soil disturbance, maintaining soil cover, protecting living roots, increasing species diversity, integrating livestock, and minimizing synthetic inputs (Khangura *et al.*, 2023). Despite these guidelines, the absence of a universal definition and limited empirical evidence on long-term benefits and profitability have hindered broader adoption (Newton *et al.*, 2020; Khangura *et al.*, 2023).

Recognising Context:

This principle emphasizes on the concept of uniqueness or individuality of each farm. While considering individual farm a number of variables are involved, including the local resources, vegetation, soil type, and climate. To get better result in the individual

Table 5: Research findings related to continuous living cover.

Findings	Researcher
Agricultural diversification enhances multiple ecosystem services without compromising crop yields.	**Tamburini *et al.*, (2020)**
Crop-rotation diversification increases agricultural resilience to adverse growing conditions without sacrificing yields.	**Bowles *et al.*, (2020)**
Maximizing crop functional diversity in agroforestry systems can drive multiple ecosystem functions like weed suppression, soil protection, and crop yield.	**dos Santos *et al.*, (2021)**
Diversified crop rotation improves soil condition, boosts system productivity, and contributes to sustainable crop production.	**Shah *et al.*, (2021)**
Increasing plant diversity at multiple scales can enhance ecosystem services and contribute to ecologically intensive and sustainable crop production.	**Brooker *et al.*, (2023)**

farmers place farmer should give high priority to understand uniqueness of their farm and develop package of practices that work best for their land. Although RA techniques like residue retention, cover crops, and minimum tillage can raise crop yields and soil carbon under specific circumstances, the advantages may differ for different agroecosystems and conditions. (Khangura *et al.*, 2023).

Reduce Soil disturbance:

Traditional farming methods include frequent intensive tilling, which ruins beneficial microorganisms, causes structural disturbances in the soil, and accelerate erosion. Regenerative agricultures this principle reduce soil disturbance which strongly emphasis on no-till or low-tillage techniques. This practice results into better microbial population, encouraging water infiltration and preservation of soil aggregates (Table 2).

Preserve Soil Surface:

In the natural world, soil is rarely left exposed. Cover crops, or living plants, cover the soil's surface, while mulch made from plant leftovers is maintained by regenerative farmers. This controls soil temperature, reduces wind- and rain-induced erosion, and aids in moisture retention (Table 3).

Enhancing Diversity:

Growing a single crop year-round, or monoculture, depletes soil nutrients and attracts pests. The utilisation of a range of crops, cover plants, and beneficial insects in regenerative agriculture fosters diversity. In addition to lowering the need for pesticides, this improves ecological balance and attracts pollinators like butterflies and bees (Table 4).

Table 6: Reviews related to livestock integration.

Findings	Researcher
Livestock integration in organic farming provides benefits such as nutrient cycling and soil fertility restoration.	**Nandhini *et al.*, (2018)**
Integrated crop-livestock systems with cover cropping and no-till can provide benefits for animal production and soil characteristics through diversification and complex agroecosystem functions.	**Carvalho *et al.*, (2018)**
Integrated crop-livestock systems can provide sustainable intensification of food production while benefiting producer income, soil, and the environment.	**Kumar *et al.*, (2019)**
Integrating livestock into oil palm plantations can provide environmental and socioeconomic benefits to achieve sustainable development goals.	**Azhar *et al.*, (2021)**
Livestock integration in agriculture provides benefits through organic fertilizer, waste utilization, and land conservation.	**Said *et al.*, (2022)**

Keep living roots in the soil throughout the year:

Regenerative techniques such as multi- and cover-cropping guarantee the presence of live roots all year round. This encourages the cycling of nutrients, feeds soil microbes, and increases soil organic matter(Table 5).

Integrate Livestock:

In regenerative agriculture, integration of livestock can be quite beneficial. Grazing animals can help in seed distribution and weed control. Their manure can be composted and used as a natural fertiliser to increase soil fertility and microbial activity. Integrating animals necessitates careful management to avoid overgrazing, but when done correctly, it can significantly improve the health of the land. crops, or living plants, cover the soil's surface, while mulch made from plant leftovers is maintained by regenerative farmers. This controls soil temperature, reduces wind- and rain-induced erosion, and aids in moisture retention (Table 6).

Regenerative agriculture Practices

Regenerative agriculture encompasses a variety of farming practices, and growers can opt to employ different combinations of practices based on their topography, geography, soil type, climate, and the availability and constraints of natural resources. The goals of regenerative agriculture (RA) practices are to increase soil health, boost biodiversity, and increase soil organic carbon (SOC)

Table 7: Benefits of regenerative agriculture, associated practices, and mechanisms as reported in literature.

Category	Benefits	Mechanisms/Practices	Key References
Climate Change Mitigation	• Enhances carbon sequestration via soil organic carbon buildup • Reduces greenhouse gas emissions (CO_2, N_2O) • Improves ecosystem carbon balance and soil as carbon sink	Cover cropping, reduced tillage, compost application, perennial systems, agroforestry, rotational grazing	Schreefel *et al*., (2020); Newton *et al*., (2020); Teague *et al*., (2016); Rhodes (2017); Lal (2020); Khangura *et al*., (2023); Jayasinghe *et al*., (2023)
Soil Health Improvement	• Improves soil structure, aggregation, and water-holding capacity • Increases soil organic matter, nutrient cycling, and cation exchange capacity • Enhances microbial diversity and enzymatic activity • Reduces erosion, compaction, and nutrient leaching	Reduced tillage, cover crops, crop diversification, compost/organic amendments, managed grazing, maintaining living roots	Lal (2020); Rhodes (2017); Schreefel *et al*., (2020); LaCanne & Lundgren (2018); Newton *et al*.,(2020); Jayasinghe *et al*., (2023); White *et al*., (2020); Singh *et al*., (2023); Saho *et al*., (2020)
Biodiversity Enhancement	• Promotes above and below ground biodiversity • Supports pollinators, natural predators, soil fauna, and microorganisms • Suppresses soil-borne pathogens and enhances resilience • Builds ecologically balanced systems	Intercropping, agroforestry, cover crops, rotational grazing, reduced agrochemical inputs, crop–livestock integration	LaCanne & Lundgren (2018); Kremen & Miles (2012); Schreefel *et al*., (2020); Giller *et al*., (2021); Jayasinghe *et al*., (2023)
Socio-Economic Benefits	• Reduces dependence on synthetic inputs and lowers production costs • Enhances farm profitability and resilience under climate change • Strengthens rural livelihoods and food security • Supports eco-certification, carbon credits, and farmer innovation networks	Diversified cropping systems, local resource use, farmer-to-farmer learning, eco-certification and carbon markets	LaCanne & Lundgren (2018); Giller *et al*., (2021); Schreefel *et al*., (2020); Khatri-Chhetri *et al*., (2021); Jayasinghe *et al*., (2023)
Environmental Resilience	• Enhances water retention, infiltration, and erosion control • Buffers against drought, floods, and climate variability • Strengthens ecosystem services (pollination, pest regulation, nutrient cycling) • Builds adaptive capacity of agroecosystems	Cover crops, reduced tillage, agroforestry, organic amendments, crop–livestock integration	Giller *et al*., (2021); Newton *et al*., (2020); LaCanne & Lundgren (2018); Schreefel *et al*., (2020); TASS (2021)
Other Ecosystem Services	• Improves water quality by reducing runoff and eutrophication • Promotes carbon-neutral or carbon-negative farming • Integrates traditional knowledge and farmer autonomy • Reduces exposure to agrochemicals and enhances community health-Aligns with UN SDGs (Zero Hunger, Climate Action, Life on Land)	Sustainable nutrient management, low-input farming, ecosystem-based practices	Basche & Edelson (2017); Gosnell *et al*., (2020); FAO (2021); Giller *et al*., (2021)

Table 8: Case studies demonstrating the outcomes and challenges of regenerative agriculture across different regions.

	Location & Crop System	Regenerative Practices	Duration of Study	Observed Benefits	Challenges/Limitations	Reference
1	Lakhipara Tea Estate in Dooars, West Bengal, India,	Inhana Rational Farming (IRF), Novcom composting, reducing chemical fertilizers by 20-30%, reducing pesticides and herbicides, and using plant health management.	3 years	Increased crop productivity by 78 kg/ha/year, a 52-77% reduction in pesticide toxicity potential, an 8% increase in the Soil Fertility Index, and a 6% increase in the Soil Quality Index after three years.	Initial adoption resistance, need for training and monitoring	Bera *et al.* (2024)
2	South Carolina, USA (Multiple crop systems on 9 farms))	Multispecies cover cropping, reduced tillage, reduced fertilizer and chemical inputs	2–4 years	Increase Soil organic matter (0.11%–0.55%), Increase Carbon sequestration (425–1584 lbs C/ac/year), improved soil health, crop yield benefits (e.g., better wheat and soybean yields), effective across various soil textures	No conventionally managed control plots; only top 6.2-inch soil tested; no measurement of soil inorganic carbon; cultural barriers like farmer apprehension to climate-focused research	Kenne & Kloot, (2019)
3	Rainfed almond farms in Southeast Spain (Granada, Almeria, Murcia).	Reduced tillage with green manure and/or organic amendments, and no-tillage with permanent natural covers and organic amendments.	Two consecutive years (2018-2019).	Improved soil quality (physical, chemical, biological) without compromising crop nutrition. No-tillage with covers and amendments showed the best results.	Slow adoption due to lack of evidence, slow soil response in drylands, and socioeconomic constraints. Difficult to assess yield impact due to climate variability.	Soto *et al.* (2021)
4	Gotland, Sweden	Reduced or no tillage, application of organic matter, livestock integration, crop diversity, and use of legumes and perennials.	0 to 30 years	Application of organic matter improved soil carbon, aggregate stability, and infiltration rate. Reduced tillage and perennials positively impacted root abundance, depth, and vegetation density. The "crop-high-org-input" cluster had the highest total organic carbon, C:N levels, infiltration rate, and earthworm abundance.	no uniform definition of regenerative agriculture and few comprehensive scientific studies on "real-life" farms	Daverkosen *et al.*, (2022)
5	Almond orchards in California	Perennial ground covers, compost/compost tea, livestock integration, non-crop habitat, reduced/no synthetic agrichemicals.	2 years (2018-2019).	Higher soil carbon, organic matter, and nitrogen; 6x faster water infiltration; greater invertebrate richness and earthworm abundance; similar yields and pest populations; double the profit.	No single practice was responsible; success was due to a combination of practices.	Fenster *et al.*, (2021)
6.	Arable farms in the Hoeksche Waard region, Netherlands.	Minimum tillage, cover cropping, and organic amendments (compost and solid manure).	3 years	Significant increase in soil organic matter (+0.30 percentage points), improved aggregate stability, deeper rooting potential (critical depth at 48 cm), and enhanced water retention, soil life, and crop quality.	Reduced soil workability in wet conditions, higher upfront costs, limited statistical significance for some parameters, and the need for a long-term commitment.	Dik *et al.*, (2023)

(Rehberger *et al.*, 2023; Khangura *et al.*, 2023). Reduced tillage, cover crops, crop rotation, and integrated crop-livestock systems are examples of common RA practices (Rehberger *et al.*, 2023). These practices have demonstrated varying degrees of effectiveness in increasing soil organic carbon (SOC), with potential increases ranging from nonsignificant to 3 Mg C/ha/year (Rehberger *et al.*, 2023). A meta-analysis found statistically significant increases in SOC for ley-arable rotations and reduced tillage, but no effect for cover crops (Jordon *et al.*, 2022). While RA practices can improve soil carbon sequestration, they do not always result in higher crop yields (Jordon *et al.*, 2022; Villat & Nicholas, 2024). Different agroecosystems may respond differently to RA practices, which emphasises the need for long-term, regionally focused research to produce evidence-based recommendations for farmers and policymakers (Khangura *et al.*, 2023). Reduced or no till, cover crops, crop rotation, employing farm-sourced organic inputs rather than synthetic ones, an increased use of agroforestry and perennials, integrated crop-livestock systems, and managed grazing are examples of common practices (Rehberger *et al.*, 2023).

Benefits of Regenerative agriculture

Regenerative agriculture is a way of thinking and a collection of methods that enhances ecological and financial resilience, supports biodiversity, preserves watersheds, and restores and maintains soil health and fertility (White, 2020). Regenerative agriculture has various beneficial aspects which are summarized in Table 7. The table outlines the multiple dimensions of regenerative practices, including their contributions to climate change mitigation, soil health improvement, biodiversity enhancement, socio-economic benefits, environmental resilience, and the provision of other ecosystem services. In addition, selected case studies that demonstrate both the benefits and challenges of

Table 9: Challenges in the Transition to Regenerative Agriculture in the Indian Context. (TASS, 2021).

Challenges to transition to regenerative agriculture in India	
1.	Lack of Awareness, knowledge gaps, trusted technical assistance
2.	willingness to change,
3.	clear accessible entry points for transitioning
4.	A disconnect between scientific validation, broad principles and top-down expert led dissemination of RA from actual farmer-led experience and practice
5.	Lack of an operationalizable method to design RA systems across a wide range of contexts and to scale-up the process of scientific learning and validation.

regenerative agriculture are presented in Table 8, providing empirical evidence of its practical application across different agroecological contexts.

Challenges in regenerative agriculture implementation

Regenerative agriculture (RA) emerges as a crucial approach to address environmental challenges posed by conventional agriculture, including climate change, biodiversity loss, and soil degradation (Day & Cramer, 2021; Al-Kaisi & Lal, 2020). RA practices, such as no-till farming, have shown potential in reducing greenhouse gas emissions and enhancing soil organic carbon storage (Al-Kaisi & Lal, 2020). The transition to RA systems requires a shift from open, resource-intensive methods to more closed, regenerative systems that prioritize soil health, biodiversity, and water management (Pearson, 2007; Vamshi *et al.*, 2024). Implementation challenges include higher labour costs and the need for supportive policies and economic incentives (Pearson, 2007; Vamshi *et al.*, 2024). However, RA offers opportunities for improved farm resilience, ecological balance, and economic viability, particularly for smallholder farms (Al-Kaisi & Lal, 2020; Vamshi *et al.*, 2024). Successful adoption of RA practices necessitates community engagement, knowledge dissemination, and alignment of science with policy frameworks (Day & Cramer, 2021; Vamshi *et al.*, 2024). Transition periods, upfront costs, yield variability, risk management, economic viability, unclear standards, and the requirement for farmers to pick up new skills can all be obstacles to implementing RA, despite its potential benefits (Sands *et al.*, 2023; O'donoghue *et al.*, 2022). Diverse definitions, disagreements over indicators and models, a lack of baseline data, a lack of digital integration, and a lack of locally pertinent information and evidence are some of the obstacles to adopting RA (Jayasinghe *et al.*, 2023). Challenges in the Transition to Regenerative Agriculture in the Indian Context given in the Table 9.

Future thrust

Regenerative agricultures potential extends to developing countries, where it can help small-scale farmers improve resource use efficiency and reduce reliance on expensive inputs (Francis *et al.*, 1986). However, the concept's broad application across different contexts has led to some confusion and debate within the agricultural community (Giller *et al.*, 2021). Despite having obstacles Regenerative agriculture is viewed as a viable strategy for developing sustainable food production systems that can satisfy the demands of an expanding global population while protecting the environment (Sahu & Das, 2020; Rhodes, 2017). Federal laws, certification, knowledge-sharing, infrastructure diversification, farmer support, and research funding are all necessary to things for advancement of RA (Jayasinghe *et al.*, 2023). It is vital to reconsider and develop a new set of policies to advance RA systems in order to slow down the effects of climate extremes and soil degradation. (Al-Kaisi & Lal, 2020). Regenerative agricultural techniques have the biophysical potential to considerably improve soil health and mitigate the effects of climate change, according to the science (Paustian *et al.*, 2020) Rethinking and formulating a new set of policies is desperately needed to advance RA systems and slow down the effects of climate extremes and soil degradation. (Al-Kaisi & Lal, 2020).

Conclusion

Regenerative agriculture is gaining prominence as a holistic approach to address soil degradation, biodiversity loss, and climate instability. Unlike conventional methods that prioritize short-term yields, regenerative systems restore soil function through practices like minimal tillage, cover cropping, organic amendments, and integrated livestock management. This outcome-based, context-specific framework aligns with ecological principles by enhancing soil organic carbon, improving biodiversity, and increasing water retention. While benefits vary by region, global case studies confirm consistent improvements in soil structure, microbial activity, climate resilience, and farmer livelihoods. Despite its promise, widespread adoption is hindered by policy gaps, economic constraints, and limited technical knowledge. Advancing regenerative agriculture requires coordinated global efforts—tailored frameworks, farmer education, supportive policies, and participatory research. Ultimately, regenerative agriculture represents a paradigm shift that reconnects food systems with ecological integrity, offering a resilient and sustainable path for future land management.

References

Al Kaisi, M.M. and Lal R. (2020). Aligning science and policy of regenerative agriculture. *Soil Science Society of America Journal*, **84(6)**, 1808-1820.

Alskaf, K., Mooney S.J., Sparkes D.L., Wilson P. and Sjögersten S. (2021). Short-term impacts of different tillage practices and plant residue retention on soil physical properties and greenhouse gas emissions. *Soil and Tillage Research*, **206**, 104803.

Azhar, B., Tohiran K.A., Nobilly F., Zulkifli R., Syakir M.I., Ishak Z. and Maxwell T.M. (2021). Time to revisit oil palm-livestock integration in the wake of United Nations sustainable development goals (SDGs). *Frontiers in Sustainable FoodSystems*, **5**, 640285.

Basche, A.D. and Edelson O.F. (2017). Improving water resilience with more perennially based agriculture. *Agroecology and Sustainable Food Systems*, **41(7)**, 799-824.

Basche, A. and DeLonge M. (2017). The impact of continuous living cover on soil hydrologic properties: A meta analysis. *Soil Science Society of AmericaJournal*, **81(5)**, 1179-1190.

Bera, R., Datta A, Bose S., B.A., Asthana A. and Seal A. (2024). Development of Regenerative Tea Cultivation Models through Dual Approach of Soil and Plant Health Management towards Crop Sustainability, Soil Quality Development, Pesticide Reduction and Climate Change Mitigation: A Case Study from Lakhipara Tea Estate, Dooars, West Bengal, India (PART-I). *International Journal of Environment and Climate Change*, **14(4)**, 494–512. https://doi.org/10.9734/ijecc/2024/v14i44135

Bowles, T.M., Mooshammer M., Socolar Y., Calderón F., Cavigelli M.A., Culman S.W. and Grandy A.S. (2020). Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. *One Earth*, **2(3)**, 284-293.

Brooker, R.W., Hawes C., Iannetta P.P., Karley A.J. and Renard D. (2023). Plant diversity and ecological intensification in crop production systems. *Journal ofPlant Ecology*, **16(6)**, rtad015.

Carvalho, P.C.D.F., Peterson C.A., Nunes P.A.D.A., Martins A.P., de Souza Filho W., Bertolazi V.T. and Anghinoni I. (2018). Animal production and soil characteristics from integrated crop-livestock systems: toward sustainable intensification. *Journal of animal science*, **96(8)**, 3513-3525.

Crews, T.E. and Rumsey B.E. (2017). What agriculture can learn from native ecosystems in building soil organic matter: a review. *Sustainability*, **9(4)**, 578.

Daverkosen, L., Holzknecht A., Friedel J.K., Keller T., Strobel B.W., Wendeberg A. and Jordan S. (2022). The potential of regenerative agriculture to improve soil health on Gotland, Sweden. *Journal of Plant Nutrition and Soil Science*, **185(6)**, 901-914.

Day, C. and Cramer S. (2022). Transforming to a regenerative US agriculture: the role of policy, process, and education. *Sustainability Science*, **17(2)**, 585-601.

Dik, P.E., Walvoort D., Teuling K. and Knotters M. (2023). *A case study on the efficacy of regenerative agriculture: A comparative study in the Hoekse Waard, the Netherlands*. (Report / Wageningen Environmental Research; No. 3300). Wageningen Environmental Research. https://doi.org/10.18174/641804

dos Santos, D., Joner F., Shipley B., Teleginski M., Lucas R.R. and Siddique I. (2021). Crop functional diversity drives multiple ecosystem functions during early agroforestry succession. *Journal of Applied Ecology*, **58(8)**, 1718-1727.

Eckberg, J.O. and Rosenzweig S.T. (2020). Regenerative agriculture: a farmer-led initiative to build resiliency in food systems. *Cereal Foods World*, **65(6)**.

Elevitch, C.R., Mazaroli D.N. and Ragone D. (2018). Agroforestry standards for Regenerative agriculture. *Sustain*, **10**, 1–21. https://doi.org/10.3390/su10093337

FAO and ITPS (2015). Status of the World's Soil Resources.; Rome: s.n., https://www.fao.org/3/i5199e/i5199e.pdf

FAO (2021). Scaling up Agroecology to achieve the SDGs. Rome: Food and Agriculture Organization of the United NationsProceedings of the second FAO international symposium. Rome. 412. Licence: CC BY-NC-SA 3.0 IGO.

Fenster, T.L., Oikawa P.Y. and Lundgren J.G. (2021). Regenerative almond production systems improve soil health, biodiversity, and profit. *Frontiers in Sustainable Food Systems*, **5**, 664359.

Garba, I.I., Bell L.W. and Williams A. (2022). Cover crop legacy impacts on soil water and nitrogen dynamics, and on subsequent crop yields in drylands: a metaanalysis. *Agronomy for Sustainable Development*, **42(3)**, 34.

Giller, K.E., Hijbeek R., Andersson J.A. and Sumberg J. (2021). Regenerative agriculture: an agronomic perspective. *Outlook on agriculture*, **50(1)**, 13-25.

Gosnell, H., Charnley S. and Stanley P. (2020). Climate change mitigation as a co-benefit of regenerative ranching: insights from Australia and the United States. *Interface Focus*, **10**, 20200027. http://dx.doi.org/10.1098/rsfs.2020.0027

Griffiths, M., Delory B.M., Jawahir V., Wong K.M., Bagnall G.C., Dowd T.G. and Topp C.N. (2022). Optimisation of root traits to provide enhanced ecosystem services in agricultural systems: A focus on cover crops. *Plant, Cell &Environment*, **45(3)**, 751-770.

GSP (2017). Global Soil Partnership Endorses Guidelines on Sustainable Soil Management http://www.fao.org/global-soil partnership/resources/highlights/detail/en/c/416516/ (2017).

Hassebrook, C. (1990). Developing a socially sustainable agriculture. *American Journal of Alternative Agriculture*, **5(2)**, 50-50.

Hatt, S., Armbrecht I., Lundgren J.G. and Wyckhuys K.A. (2024). Breathing new life into farming: illuminating the socio-ecological benefits of regenerative agriculture. *Frontiers in Sustainable Food Systems*, **8**, 1515184.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2019a). *Global Assessment Report on Biodiversity and EcosystemServices*. Bonn, Germany: IPBE

Jayasinghe, S.L., Thomas D.T., Anderson J.P., Chen C. and Macdonald B.C.T. (2023). Global Application of Regenerative Agriculture: A Review of Definitions and Assessment Approaches. *Sustainability*, **15(22)**, 15941. https://doi.org/10.3390/su152215941

Jian, J., Du X., Reiter M.S. and Stewart R.D. (2020). A meta-analysis of global cropland soil carbon changes due to cover cropping. *Soil Biology and Biochemistry*, **143**, 107735.

Jordon, M.W., Willis K.J., Bürkner P.C., Haddaway N.R., Smith P. and Petrokofsky G. (2022). Temperate Regenerative Agriculture practices increase soil carbon but not crop yield—a meta-analysis. *Environmental Research Letters*, **17(9)**, 093001.

Kenne, G.J. and Kloot R.W. (2019). The carbon sequestration potential of regenerative farming practices in South Carolina, USA. *American Journal of Climate Change*, **8(02)**, 157.

Khangura, R., Ferris D., Wagg C. and Bowyer J. (2023). Regenerative Agriculture—A Literature Review on the Practices and Mechanisms Used to Improve Soil Health. In *Sustainability* (*Switzerland*) **(Vol. 15, Issue 3)**. https://doi.org/10.3390/su15032338.

Khatri-Chhetri, A., Aggarwal P.K., Joshi P.K. and Vyas S. (2016). Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural Systems*, **151**, 184–191. https://doi.org/10.1016/j.agsy.2016.10.005

Kim, N., Zabaloy M.C., Guan K. and Villamil M.B. (2020). Do cover crops benefit soil microbiome? A meta-analysis of current research. *Soil Biology & Biochemistry*, **142**, 107701.

Kouselou, M., Hashemi S., Eskandari I., McKenzie B.M., Karimi E., Rezaei A. and Rahmati M. (2018). Quantifying soil displacement and tillage erosion rate by different tillage systems in dryland northwestern Iran. *Soil Use and Management*, **34(1)**, 48-59.

Kremen, C. and Miles A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. *Ecology and Society*, **17(4)**. https://doi.org/10.5751/ES-05035-170440

Kumar, S., Sieverding H., Lai L., Thandiwe N., Wienhold B., Redfearn D. and Jin V. (2019). Facilitating crop–livestock reintegration in the Northern Great Plains. *Agronomy Journal*, **111(5)**, 2141-2156.

LaCanne, C.E. and Lundgren J.G. (2018). Regenerative agriculture: merging farming and natural resource conservation profitably. *Peer. J.*, **6**, e4428.

Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of soil and water conservation*, **75(5)**, 123A-124A.

LaSalle, T., Hepperly P. and Diop A. (2008). The organic green revolution. *Rodale Institute*.

Li, Y., Zhang Q., Cai Y., Yang Q. and Chang S.X. (2020). Minimum tillage and residue retention increase soil microbial population size and diversity: Implications for conservation tillage. *Science of the Total Environment*, **716**, 137164.

Malik, P. and Verma M. (2014). Organic agricultural crop nutrient. *Res. J. Chem. Sci.*, **4**, 94– 98.

Montgomery, D.R. (2012). Dirt: The Erosion of Civilizations, with a New Preface. University of California press.

Moyer, J. (2013). Perspective on Rodale Institute's Farming Systems Trial.

Muhammad, I., Wang J., Sainju U.M., Zhang S., Zhao F. and Khan A. (2021). Cover cropping enhances soil microbial biomass and affects microbial community structure: A meta-analysis. *Geoderma*, **381**, 114696.

Nandhini, D. and Suganthi S. (2018). Livestock importance in organic farming. Approaches in Poverty,. *Dairy and Veterinary Sciences*, **5(1)**.

Newton, P., Civita N., Frankel-Goldwater L., Bartel K. and Johns C. (2020). What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. In *Frontiers in Sustainable Food Systems* (**Vol. 4**). Frontiers Media S.A. https://doi.org/10.3389/fsufs.2020.577723

O'donoghue, T., Minasny B. and McBratney A. (2022). Regenerative agriculture and its potential to improve farmscape function. *Sustainability*, **14(10)**, 5815.

O'donoghue, T., Minasny B. and McBratney A. (2022). Regenerative agriculture and its potential to improve farmscape function. *Sustainability*, **14(10)**, 5815.

Paustian, K., Chenu C., Conant R., Cotrufo F., Lal R., Smith P. and Soussana J.F. (2020). Climate mitigation potential of regenerative agriculture is significant. Princeton University [accessed 2024Mar16].

Pearson, C.J. (2007). Regenerative, semiclosed systems: a priority for twenty-firstcentury agriculture. *Bioscience*, **57(5)**, 409-418.

Prescott, C.E. and Grayston S.J. (2023). TAMM review: Continuous root forestry Living roots sustain the belowground ecosystem and soil carbon in managed forests. *Forest ecology and management*, **532**, 120848.

Pretty, J. (2008) Agricultural Sustainability: Concepts, Principles and Evidence. Philosophical Transactions of the Royal Society of London B: *Biological Sciences*, **363**, 447-465. https://doi.org/10.1098/rstb.2007.2163

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)**, 052001.

Rhodes, C.J. (2017). The imperative for regenerative agriculture.

In *Science Progress* (**Vol. 100, Issue 1**). https://doi.org/10.3184/003685017X14876775256165

Sae-Tun, O., Bodner G., Rosinger C., Zechmeister-Boltenstern S., Mentler A. and Keiblinger K. (2022). Fungal biomass and microbial necromass facilitate soil carbon sequestration and aggregate stability under different soil tillage intensities. *Applied Soil Ecology*, **179**, 104599.

Sahu, G. and Das S. (2020). Regenerative agriculture: Future of sustainable food production. *Biotica research today*, **2(8)**, 745-748.

Said, M.I. (2022). The role of the livestock farming industry in supporting the global agricultural industry. *Agricultural Development in Asia-Potential Use of Nano-Materials and Nano-Technology*, **1**, 13.

Sands, B., Machado M.R., White A., Zent E. and Gould R. (2023). Moving towards an anti-colonial definition for regenerative agriculture. *Agriculture and Human Values*, **40(4)**, 1697-1716.

Scavo, A., Fontanazza S., Restuccia A., Pesce G.R., Abbate C. and Mauromicale G. (2022). The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, **42(5)**, 93.

Schreefel, L., Schulte R.P.O., de Boer I.J.M., Schrijver A.P. and van Zanten H.HE. (2020). Regenerative agriculture – the soil is the base. *Global Food Security*, **26**. https://doi.org/10.1016/j.gfs.2020.100404

Shah, K.K., Modi B., Pandey H.P., Subedi A., Aryal G., Pandey M. and Shrestha J. (2021). Diversified crop rotation: an approach for sustainable agriculture production. *Advances in Agriculture*, **2021(1)**, 8924087.

Singh, I., Hussain M., Manjunath G., Chandra N. and Ravikanth G. (2023). Regenerative agriculture augments bacterial community structure for a healthier soil and agriculture. *Frontiers in Agronomy*, **5**, 1134514.

Sokol, N.W., Kuebbing S.E., Karlsen Ayala E. and Bradford M.A. (2019). Evidence for the primacy of living root inputs, not root or shoot litter, in forming soil organic carbon. *New Phytologist*, **221(1)**, 233-246.

Soto, R.L., Martínez-Mena M., Padilla M.C. and de Vente J. (2021). Restoring soil quality of woody agroecosystems in Mediterranean drylands through regenerative agriculture. *Agriculture, Ecosystems & Environment*, **306**, 107191.

TAAS (2021). Regenerative Agriculture for Soil Health, Food and Environmental Security: Proceedings and Recommendations. Trust for Advancement of Agricultural Sciences (TAAS), Avenue II, Pusa Campus, New Delhi. vii+30 p

Tamburini, G., Bommarco R., Wanger T.C., Kremen C., Van Der Heijden M.G., Liebman M. and Hallin S. (2020). Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science advances*, **6(45)**, eaba1715.

Teague, W.R., Apfelbaum S., Lal R., Kreuter U.P., Rowntree J., Davies C.A. and Byck P. (2016). The role of ruminants in reducing agriculture's carbon footprint in North America. *Journal of Soil and Water Conservation*, **71(2)**, 156-164.

Vamshi, M., Jagadeesan R., Lamani H.D., Rout S., Vijay Kumar R., Jagadesh M. and Sachan K. (2024). The Revolutionary Impact of Regenerative Agriculture on Ecosystem Restoration and Land Vitality: A Review. *Journal of Geography, Environment and Earth Science International*, **28(4)**, 1-14.

Villat, J. and Nicholas K.A. (2024). Quantifying soil carbon sequestration from regenerative agricultural practices in crops and vineyards. *Frontiers in Sustainable Food Systems*, **7**, 1234108.

White, C. (2020). Why regenerative agriculture? *American Journal of Economics and Sociology*, **79(3)**, 799-812.

Yadav, A., Prajapati J., Kumar R. and Upadhyay A. (2023). Regenerative Agriculture- A Review. *Vigyan Varta*, **4(1)**, 107-109.