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Regenerative Agriculture for Sustainable Farming Systems: Current Status, Challenges and Future Prospects

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ABSTRACT

Regenerative agriculture has emerged as a transformative approach to restoring soil health, enhancing biodiversity, improving water conservation, and mitigating climate change while ensuring sustainable agricultural productivity. This review examines the current status of regenerative farming practices, including conservation tillage, cover cropping, crop diversification, agroforestry, integrated livestock systems, and organic soil management. It highlights key challenges such as limited farmer awareness, economic constraints, policy gaps, and region-specific adaptation issues that hinder widespread adoption. The paper also explores future prospects through technological innovations, supportive policies, carbon farming incentives, and climate-smart practices, emphasizing regenerative agriculture as a resilient pathway toward sustainable farming systems, food security, and environmental sustainability.

Keywords: *Regenerative agriculture; Soil health; Carbon sequestration; Agroecology; Sustainable farming systems.*

INTRODUCTION

The twenty-first-century food system faces the twin task of nourishing a projected population of nearly ten billion by 2050 while operating within safe planetary boundaries. Decades of input-intensive, monoculture-based industrial farming have generated impressive yield gains, yet they have simultaneously degraded roughly 33 per cent of global soils, reduced on-farm biodiversity, accelerated freshwater depletion and contributed close to a quarter of anthropogenic greenhouse-gas (GHG) emissions (FAO, 2019). Against this backdrop, regenerative agriculture (RA) has captured the imagination of farmers, policy makers, corporate value chains and civil society as a farming philosophy that seeks not merely to sustain but to rebuild the natural resource base on which agriculture depends (Rhodes, 2017).

The term "regenerative" was first popularized by the Rodale Institute in the early 1980s, and later refined by practitioners such as Gabe Brown and researchers including LaCanne and Lundgren (2018).

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Newton, Civita, Frankel-Goldwater, Bartel, and Johns (2020) reviewed 229 journal articles and 25 practitioner websites and concluded that RA is defined through some combination of processes (e.g., no-till, cover cropping, diverse rotations, managed grazing, agroforestry) and outcomes (e.g., improved soil health, enhanced biodiversity, climate mitigation, farmer livelihoods). Schreefel, Schulte, de Boer, Schrijver, and van Zanten (2020) similarly proposed that regenerative agriculture should be understood as an approach that uses soil conservation as the entry point to regenerate multiple ecosystem services concurrently.

Six principles are widely cited as the operational core of RA: (i) minimize mechanical and chemical soil disturbance; (ii) keep the soil covered with living plants or residues; (iii) maintain living roots year-round; (iv) maximize plant and biological diversity; (v) integrate livestock through planned grazing; and (vi) reduce reliance on synthetic external inputs (LaCanne & Lundgren, 2018). These principles are visualized in Figure 1. Together they represent a systems-level shift from productivity-only metrics toward multifunctional agroecosystems that support food security, climate resilience and rural livelihoods (Giller, Hijbeek, Andersson, & Sumberg, 2021).

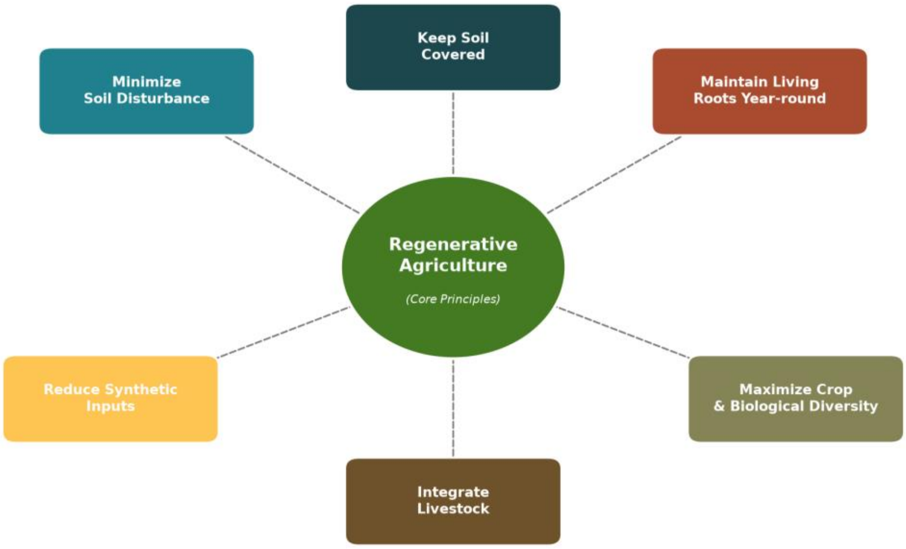

Figure1. Six core principles of regenerative agriculture (adapted from LaCanne & Lundgren, 2018; Rhodes, 2017)

Interest in RA has grown rapidly. According to Project Drawdown (2020), a portfolio of regenerative practices (including managed grazing, silvopasture, tree intercropping and regenerative annual cropping) ranks among the top climate-mitigation solutions globally, with a cumulative CO_2 mitigation potential of 14–22 gigatonnes by 2050. Major food companies, including General Mills, Danone and Unilever, publicly committed between 2019 and 2021 to source ingredients from land under regenerative management (Newton et al., 2020). Simultaneously, national programmes such as India's Zero Budget Natural Farming, the U.S. Department of Agriculture's Soil Health Initiative and the European Union's Farm-to-Fork Strategy have provided institutional backing.

2. Conceptual Foundations and Historical Roots

Regenerative agriculture is not a novel invention; rather, it consolidates knowledge streams that have coexisted with humanity for millennia. Traditional systems such as the Zabo of Nagaland in India, the milpa of Mesoamerica, the shifting cultivation of West Africa and the terraced paddy systems of East Asia embody many regenerative principles including polyculture, closed nutrient cycles and biological pest regulation (Altieri, 1999). Twentieth-century pioneers, notably Albert Howard, Masanobu Fukuoka and J. I. Rodale, articulated similar ideas under labels such as "organic farming", "natural farming" and "biological husbandry" (Rhodes, 2017).

The Rodale Institute's 1983 publication of the term "regenerative organic agriculture" marked the first formal use of the phrase (Rodale, 1983). Regenerative agriculture, unlike sustainability which implies maintaining a status quo, explicitly seeks a net-positive trajectory whereby soil, water, biodiversity and community wellbeing improve over time (Newton et al., 2020). Recent scholarship also aligns RA with agroecology and conservation agriculture, but with a stronger emphasis on soil biology, carbon farming and livestock integration (Schreefel et al., 2020).

The absence of a universally accepted definition remains a critique. Newton et al. (2020) documented at least eight distinct scientific and 21 practitioner-based definitions. This plurality reflects RA's adaptability, but it also complicates certification, policy and comparative research. Giller et al. (2021) cautioned that without measurable indicators, RA risks becoming a marketing slogan rather than a scientific paradigm.

3. Current Status of Regenerative Agriculture (up to 2021)

Global uptake of regenerative practices, while difficult to measure precisely, is best inferred from conservation-agriculture (CA) statistics, since no-till, permanent soil cover and diverse rotation are core CA principles. Kassam, Friedrich, and Derpsch (2019) estimated that 180.4 million hectares (about 12.5 per cent of global cropland) were under CA in the 2015/16 cropping season, up from 106 million hectares in 2008/09. Adoption was highest in South America (69.9 million ha), followed by North America (63.2 million ha), Australia and New Zealand (22.7 million ha), Asia (13.9 million ha), Europe (5.7 million ha) and Africa (1.5 million ha).

In parallel, agroforestry, an inherently regenerative land-use, was practiced on approximately one billion hectares globally, providing more than ten per cent of tree cover on agricultural land (Zomer et al., 2016). Cover-cropped hectares in the United States rose from 4.2 million in 2012 to 6.2 million in 2017, a 50 per cent expansion within five years (USDA NASS, 2019). In India, natural farming initiatives such as Andhra Pradesh Community-Managed Natural Farming reported over 630,000 farmer adopters by 2020 (Khadse & Rosset, 2019).

Corporate procurement targets accelerated during 2018–2021. General Mills announced in 2019 an aim to advance regenerative practices on one million acres by 2030, and Cargill committed to ten million acres in North America by 2030. Certifications also emerged, including the Regenerative Organic Certification launched by the Rodale Institute in 2018 and the Land-to-Market Ecological Outcome Verification programme of the Savory Institute.

4. Ecological and Agronomic Outcomes

4.1 Soil Health and Carbon Sequestration

The strongest and most consistent evidence for RA lies in improvements to soil organic carbon (SOC) and physical soil health. Lal (2004) estimated the technical potential of global cropland to sequester 0.4–1.2 Gt C yr^{-1} through improved management, equivalent to offsetting up to one-third of annual fossil-fuel emissions. Poeplau and Don (2015) meta-analysed 139 plots and reported an average SOC accumulation of 0.32 ± 0.08 Mg C ha^{-1} yr^{-1} under cover cropping. Minasny et al. (2017) explored the "4 per 1000" initiative and argued that a global sequestration rate of 0.4 per cent per year in the top 0.4 m of soil is achievable in many regions through practices such as no-till, cover crops, agroforestry and manure application. Paustian et al. (2016) placed the range for climate-smart soils between 0.5 and 1.0 Mg C ha^{-1} yr^{-1} across diverse regenerative practices. Figure 2 summarises indicative SOC sequestration rates from these syntheses.

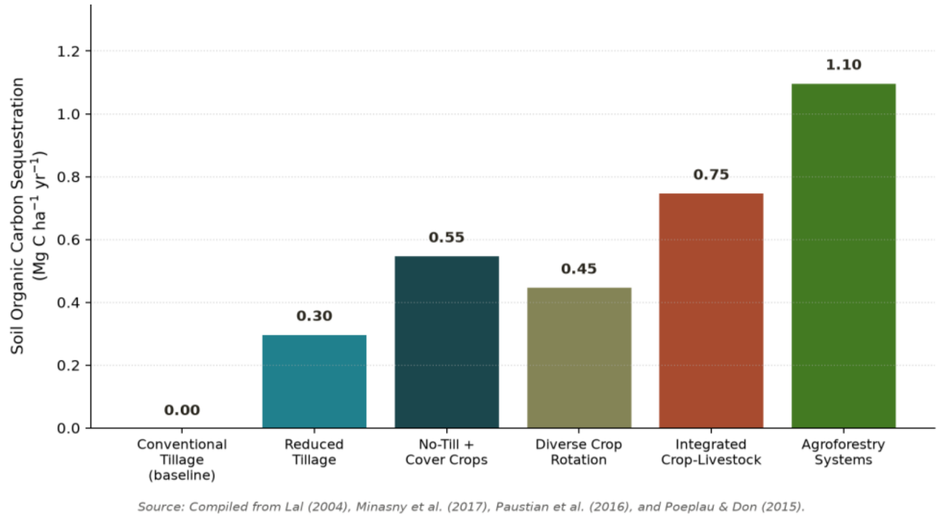

Figure2. Estimated soil organic carbon sequestration potential across regenerative practices (compiled from Lal, 2004; Minasny et al., 2017; Paustian et al., 2016; & Poeplau & Don, 2015)

Beyond carbon, regenerative practices improve water infiltration, aggregate stability and biological activity. Basche and DeLonge (2019) reviewed 89 studies and found that continuous living cover raised infiltration rates by an average of 59 per cent relative to bare-fallow controls. Increased earthworm populations (2–3 fold), higher microbial biomass carbon and greater arbuscular mycorrhizal colonisation have also been documented under long-term no-till and cover-crop systems (Kassam et al., 2019).

4.2 Biodiversity and Ecosystem Services

LaCanne and Lundgren (2018) compared 20 regenerative and conventional maize farms in the U.S. Northern Plains and reported that regenerative fields hosted a tenfold greater abundance of insect pests' predators, resulting in equal or superior pest control without insecticides. Pollinator diversity, bird abundance and above-ground plant diversity have consistently improved under diversified rotations and permanent field margins (Schreefel et al., 2020). Figure 3 provides an indicative synthesis of ecosystem-service gains reported for regenerative versus conventional systems.

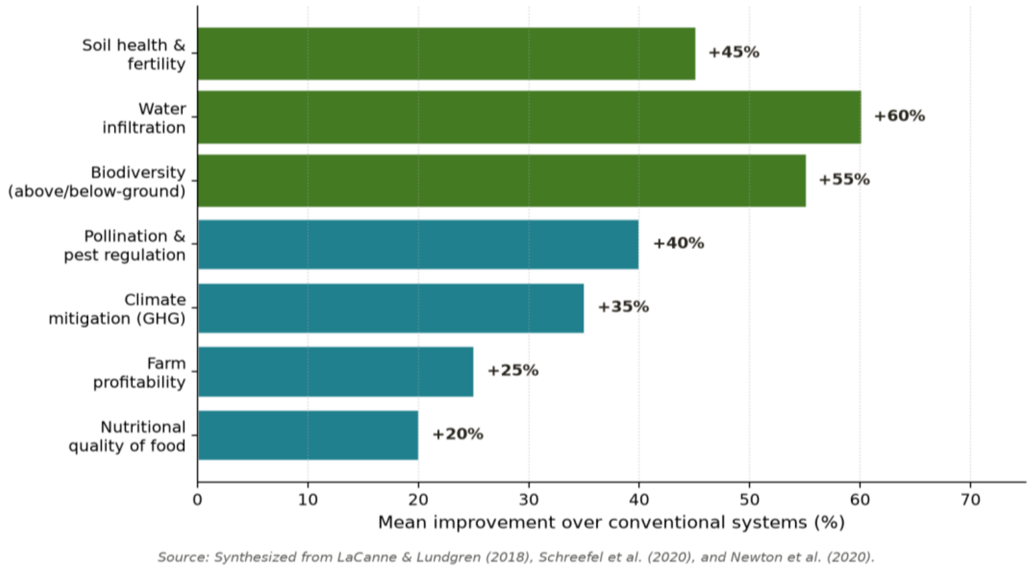

Figure3. Mean ecosystem-service gains reported under regenerative versus conventional farming systems (synthesised from LaCanne & Lundgren, 2018; Newton et al., 2020; & Schreefel et al., 2020)

4.3 Productivity, Profitability and Nutrition

Yield outcomes are context-dependent. Pittelkow et al. (2015), in a meta-analysis of 610 studies, found that no-till alone reduced yields by 5.7 per cent on average, but when combined with residue retention and crop rotation the penalty disappeared and, in dryland systems, yields exceeded conventional tillage by up to 7 per cent. LaCanne and Lundgren (2018) showed that although regenerative maize fields produced 29 per cent lower yields than conventional counterparts, they generated 78 per cent higher profits due to lower input costs and price premiums. Montgomery, Biklé, Archuleta, Brown, and Jordan (2022, drawing on 2019–2021 data) reported that regenerative fields produced grains and vegetables with significantly higher levels of vitamins, phytochemicals and minerals, suggesting an emerging soil-food-nutrition linkage.

5. Socio-Economic Dimensions

Regenerative agriculture reshapes not only fields but also farmer identities, community networks and value chains. Farmer-to-farmer learning platforms such as Understanding Ag and Regeneration International expanded rapidly between 2015 and 2021, with over 300 associated groups worldwide (Newton et al., 2020). Case studies from India's Andhra Pradesh Zero-Budget Natural Farming programme demonstrated that participating farmers reduced input costs by 40–70 per cent and reported improved dietary diversity and lower indebtedness (Khadse & Rosset, 2019). Similar income and welfare improvements were documented in East African push-pull systems and Latin American silvopastoral models (Altieri, 1999).

However, adoption is not without cost. During the transition (typically 3–5 years) farmers may face yield dips, additional knowledge demands and cash-flow uncertainty. Financial risk-sharing mechanisms such as carbon payments, transition credits and outcome-based subsidies are still nascent. Consumer willingness-to-pay premiums, while promising, remain small and geographically uneven (Giller et al., 2021).

6. Challenges to Wider Adoption

Despite compelling evidence, at least six systemic constraints limit the scaling of regenerative agriculture (Figure 4). First, definitional pluralism blocks certification harmonisation, allowing greenwashing and inconsistent metrics (Newton et al., 2020). Second, transition-period yield reductions and cash-flow gaps deter smallholders and heavily indebted farmers (Giller et al., 2021). Third, existing subsidy regimes—crop insurance, minimum-support prices and input subsidies—reward volume and monoculture, thereby penalising diversification (FAO, 2019). Fourth, farmer extension services in many countries still lack agroecological expertise. Fifth, long-term (>10 year) field data remain scarce for many agro-ecological zones, especially in the tropics. Sixth, measurement and verification of soil carbon and biodiversity outcomes are technically demanding and expensive, constraining participation in emerging carbon markets (Paustian et al., 2016).

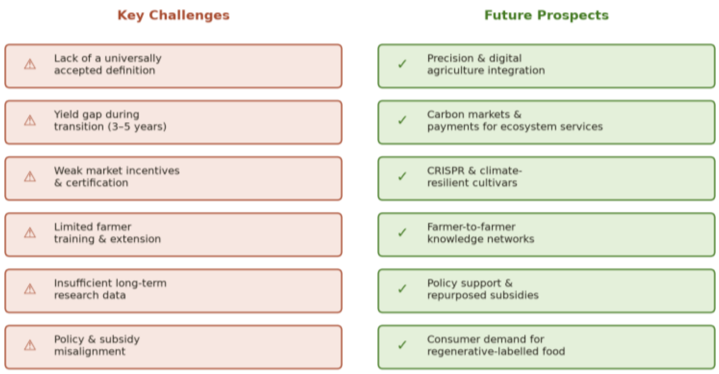

Figure4. Key challenges and future prospects for scaling regenerative agriculture (adapted from Giller et al., 2021; Newton et al., 2020; & Schreefel et al., 2020)

7. Future Prospects

The next decade offers several openings for mainstreaming regenerative agriculture. Precision agriculture and digital tools, ranging from soil-moisture sensors and unmanned aerial vehicles (UAVs) to remote-sensing platforms such as Sentinel-2 and Landsat-8, can radically lower the cost of monitoring cover-crop biomass, soil moisture and carbon stocks (Basso & Antle, 2020). Coupled with machine-learning models, they enable near-real-time verification for outcome-based payments.

Advances in plant breeding, including marker-assisted selection and CRISPR-Cas9 editing, promise cultivars adapted to low-input, diverse rotations and stress-prone regenerative systems (Zaidi et al., 2020). Perennial grains such as Kernza, developed by The Land Institute, illustrate how breeding can synergise with RA by combining deep roots, year-round cover and viable yields. Livestock genomics likewise offers breeds tuned to planned grazing on native pastures.

Policy alignment is another lever. Repurposing even a fraction of the estimated USD 540 billion annual global agricultural support toward outcome-based, ecosystem-service payments could unlock large-scale regenerative transitions (FAO, UNDP, & UNEP, 2021). Voluntary and compliance carbon markets, already valued at over USD 1 billion in 2021, will require robust monitoring, reporting and verification (MRV) protocols. Consumer demand for regenerative labels, particularly among younger and higher-income segments, is projected to grow strongly through 2030 (Rhodes, 2017).

Finally, farmer-to-farmer knowledge platforms, participatory research and Indigenous-led revitalisation of traditional systems are essential to build social capital. Convergence of these technological, policy and social innovations, when aligned with the six core principles of RA, provides a realistic pathway for regenerative agriculture to become the dominant paradigm of sustainable farming systems by mid-century.

CONCLUSION

Regenerative agriculture represents a compelling response to the intertwined crises of soil degradation, biodiversity loss, climate change and rural livelihood insecurity. Evidence accumulated up to 2021 demonstrates that when its six principles—minimise soil disturbance, keep soils covered, maintain living roots, maximise diversity, integrate livestock and reduce synthetic inputs—are applied in an adaptive, systems-based manner, farms can simultaneously sequester carbon, improve water and biodiversity outcomes, produce nutrient-dense food and remain profitable. Yet definitional ambiguity, transition-period yield gaps, weak market signals and misaligned policies still restrain scaling. The path forward requires convergent progress on measurable outcome-based standards, robust carbon and biodiversity MRV systems, precision-agriculture and biotechnology tools, targeted extension and financing, and empowering farmer networks. If these building blocks fall into place, regenerative agriculture can transition from a hopeful movement into the operating system of sustainable farming systems worldwide.

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Author Contribution:
Both author have participated in critically revising of the entire manuscript and approval of the final manuscript.

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