Regenerative Agriculture: Global Status, Potential Benefits, and Pathways to Restoration of Soil

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1. Introduction

Climate change, soil degradation, and biodiversity loss are challenging the foundations of global agriculture. In this context, a shift from input-intensive industrial farming toward regenerative practices has become an imperative rather than an option. “Regenerative agriculture” (RA) refers to farming and grazing techniques that restore soil health, enhance ecosystem resilience, and sequester carbon, going beyond mere sustainability to actively improve environmental conditions (Fiorillo, 2023) The stakes are high as healthy soil underpins food security, water supply, and climate stability, yet around 40% of global land is already degraded and 90% of Earth’s topsoil at risk by 2050 (Smith et al., 2024) Thus, rebuilding soil capital is not only an ecological duty but a pragmatic strategy to sustain yields and livelihoods for future generations.

Achieving this transformation at scale requires realigning economic incentives with sustainable outcomes and developing holistic measurement tools to track progress. Traditional metrics focused narrowly on yield or short-term profit fail to capture the long-term value of soil regeneration and ecosystem services. Regenerative agriculture provides the necessary pathway to realize this potential, moving beyond sustainability toward active system restoration. This paper explores how an integrated approach, blending economic alignment with comprehensive metrics, can accelerate the adoption of regenerative agriculture. We draw on recent research, notably the Overall Soil Effectiveness (OSE) framework by Fiorillo et al. (n.d.), which offers an empirical basis for evaluating soil-centered farming performance. By integrating these quantitative insights with qualitative evidence from global assessments and landmark studies (e.g., IPCC, UNFCCC, Fenster et al. (2021)), we outline the current state of knowledge, frame the key challenges to scaling RA practices, and propose targeted solutions focused on farmer engagement, measurement standardization, and dedicated financial models.

2. Literature Review

A robust understanding of the soil crisis requires synthesizing findings on the global status of soil health, the regional manifestation of degradation processes, and the development of modern assessment models to guide sustainable management. The following foundational scientific papers detail this challenge and the required path forward.

2.1 Status of the World’s Soils (Smith et al., 2024)

The comprehensive review by Smith et al. (2024) establishes the critical status of soil resources globally, defining soil health and outlining the main threats that compromise its essential functions. The authors confirm that soil is a non-renewable resource, essential for supporting plant and animal life and performing crucial ecosystem services. Despite its importance, the document confirms that widespread deterioration has occurred, estimating that 33% of soils worldwide are moderately to highly degraded. The major global soil threats identified include soil erosion, the loss of soil organic matter (SOM), nutrient imbalance (depletion or excess), contamination, salinization, and compaction.

The analysis stresses that effective Sustainable Soil Management (SSM) requires implementing Best Management Practices (BMPs) to ensure that the soil’s provisioning, regulating, and cultural services are maintained. For example, BMPs aimed at preventing the loss of SOM require practices that either maintain or increase organic matter inputs or minimize organic matter losses by erosion or mineralization. Regarding soil quality assessment, the paper underscore that effective evaluation requires moving beyond traditional metrics, demanding the integration of non-conventional, biological indicators for monitoring soil health. Recognizing the severity of these threats, the authors highlight legislative measures as paramount, specifically mentioning the EU Soil Strategy for 2030 and the proposed EU Soil Health Law, which aim to provide comprehensive monitoring and management frameworks for soil, legally elevating its status to equal that of air and water.

2.2 Soil Degradation in the European Mediterranean Region (Ferreira et al., 2022)

The systematic review by Ferreira et al. (2022) provides a detailed case study of degradation processes in the European Mediterranean region, demonstrating the complexity of localized threats driven by high human and climate pressures. The authors classify degradation processes into three main categories: physical, chemical, and biological. Physical degradation is severe, encompassing high erosion rates, sealing, and compaction. This manifests as significant economic costs. Severe soil erosion alone led to estimated losses of €1.257 billion in the EU agriculture sector in 2010.

Chemical degradation includes the loss of organic matter, contamination, and salinization, which is a persistent threat often exacerbated by inappropriate irrigation and high mineral fertilization rates. The review highlighted a major knowledge deficiency in the biological degradation category. Processes such as the loss of soil biodiversity remain poorly investigated, suffering from limited and sparse data availability. Furthermore, the authors concluded that a pervasive lack of a continuous, harmonized soil monitoring system at regional scales prevents proper measurement of threats like compaction, thereby hindering effective management and mitigation across the EU.

2.3 Greening The Fields: A Novel Model to Guide Sustainable Agriculture (Fiorillo et al., n.d.)

Acknowledging the pervasive measurement and governance challenges, Fiorillo et al. (n.d.) propose a necessary shift in assessment philosophy through the Overall Soil Effectiveness (OSE) model. The authors argue that conventional sustainability efforts are insufficient because they fail to capture the multifunctional value of soil beyond simple yield maximization. OSE is a novel quantitative framework that adapts performance methodologies from the industrial sector to provide a holistic benchmark score for soil quality.

The OSE model is designed to facilitate a critical conceptual shift: moving from prioritizing the short-term income statement (annual crop yield) to safeguarding the long-term balance sheet, the health and value of the soil asset. OSE merges agroecological and economic perspectives by concurrently quantifying soil utilization, efficiency, and quality based on the provision of multiple ecosystem services, such as carbon sequestration and nutrient cycling. This multifunctional scoring approach was validated in a 10-year Italian experiment comparing Conservation Agriculture (CA) plots with conventional systems. The results showed that CA practices achieved an OSE score up to 80% higher than the control plots, which consistently showed negative carbon sequestration results. This validation confirms that the model successfully provides the quantifiable evidence needed to align agricultural management with the EU's Farm to Fork (F2F) strategy and other sustainability goals.

2.4 Synthesis and the Measurement Imperative

These foundational studies collectively define the necessity of the regenerative transition. The status of global soils is critical, suffering widespread degradation (Smith et al., 2024), intensified by localized threats such as salinization and erosion, leading to immense economic losses (Ferreira et al., 2022). The greatest difficulty in addressing these threats lies in the failure of current assessment systems to capture multifunctional outcomes. A broader review of research confirms that while soil quality literature has entered an explosive growth stage between 2018 and 2022 (Fan et al., 2025), conventional assessment remains dominated by chemical metrics such as SOC/SOM, pH, Nitrogen, Potassium, and Phosphorus (Fan et al., 2025). Therefore, frameworks like OSE are vital for translating abstract functional concepts into quantifiable performance indicators that are necessary for investment and policy-making (Fiorillo et al., n.d.; Fan et al., 2025).

3. Benefits of Healthy Soil

Soil is far more than an inert growth medium; it is a living ecosystem and one of humanity's most vital assets. The shift to regenerative principles delivers superior long-term economic returns and vital ecological outcomes, resolving the perceived conflict between agricultural productivity and environmental health. These benefits extend across climate mitigation, water security, and long-term financial stability.

Healthy soil enhances the farm operation's resilience to weather extremes by drastically improving resource efficiency (Sustainable Food Lab, 2025). This resilience is rooted in the increased soil organic matter (SOM) achieved through regenerative practices, which improves soil structure, stability, and porosity (Ferreira et al., 2022). The improved physical structure allows for greater water handling. A study comparing regenerative and conventional almond orchards found that water infiltration rates were six times faster in the regenerative systems (Fenster et al., 2021). This efficiency is critical for sustaining yields during drought and managing intense rainfall events (Orth & Destouni, 2018, as cited in Ferreira et al., 2022).

Furthermore, enhanced soil function yields direct economic savings by reducing reliance on external inputs. Farms that successfully adopted sustained regenerative practices reported substantial input reductions, showing an average 37% reduction in synthetic fertilizer applications and a 22% reduction in fuel use per acre after five years (Regenerate Outcomes, 2022). These cost reductions translate directly into higher profitability, which is a key driver for farmer adoption (BCG, 2023). This reduction in input dependence is particularly important as it lowers the farmer's exposure to volatile global commodity markets (Fenster et al., 2021).

Regenerative practices transform degraded land into an active climate solution and natural filter by boosting fundamental biological processes (Fenster et al., 2021). Soil biology is the keystone of carbon sequestration, as microbial necromass forms 50-80% of stable soil organic carbon (Buckeridge et al., 2020), meaning farming must actively support microbial growth (Buckeridge et al., 2020). Preventing erosion is equally vital. A global meta-analysis found that protecting the soil surface with cover crops reduced the loss of organic carbon via soil erosion (SOC erosion) by an average of 68% annually (Huang et al., 2025). This erosion reduction provides an additive climate benefit, increasing topsoil SOC stock in the 0-15 cm layer by approximately 14% (Huang et al., 2025). The overall systemic improvement achieved by cover cropping can mitigate the Net Greenhouse Gas Balance (NGHGB) by approximately 2.06 Mg CO - eq ha^{1} year^{1} (Abdalla et al., 2019). Moreover, these methods are critical for clean water supplies, as cover cropping helps capture and cycle excess nutrients, demonstrating a capability to cut nitrate leaching by over 50% on average (Abdalla et al., 2019).

In addition, the financial stability provided by regenerative systems is compelling. While some single-species cover crops might slightly reduce the subsequent crop yield by about 4%, utilizing diverse mixtures of legumes and non-legumes has been found to increase crop yield by approximately 13% on average (Abdalla et al., 2019). The synergy of reduced inputs and stable productivity makes full regenerative systems substantially more profitable; regenerative almond orchards, for instance, were found to be twice as profitable compared to conventional systems (Fenster et al., 2021). Furthermore, these systems support thriving biodiversity, showing significantly greater invertebrate richness and diversity, with increased invertebrate diversity found to be significantly correlated with reduced pest damage (Fenster et al., 2021). This combination of ecological robustness and financial stability translates into a projected long-term 10-year Return on Investment (ROI) of 15-25% for farmers (BCG, 2023).

Overall, these benefits underscore why soil restoration is central to regenerative agriculture’s promise. By healing the soil, we unlock a cascade of positive outcomes for the farm and beyond.

4. Agriculture’s Effect on Climate Change and Vice Versa

Agriculture and climate change are locked in a reciprocal feedback loop. On one hand, conventional agricultural practices are a significant source of greenhouse gases and environmental change. Land clearing and deforestation for agriculture release large amounts of carbon dioxide, while livestock and flooded rice paddies emit methane, and nitrogen fertilizers produce nitrous oxide, a gas with almost 300 times the warming potential of CO . All told, food and land use systems account for roughly a quarter of global anthropogenic greenhouse emissions (IPCC, 2022). Intensive tillage and monocropping have also degraded soil carbon reserves; over decades, many agricultural soils have lost a substantial portion of their native organic carbon to the atmosphere. This not only accelerates climate change but also undermines soil fertility and structure, creating a vicious cycle of diminishing returns.

On the other hand, climate change is increasingly exacting a toll on agriculture. Rising temperatures, shifting rainfall patterns, and more frequent extremes (droughts, floods, heatwaves) are already reducing crop yields and challenging farmers worldwide. Projections indicate that if global warming continues unchecked, some regions will become climatically unsuitable for current staple crops under high-emission scenarios, around 10% of today’s global farmland area may be unable to support its current crops by 2050, expanding to over 30% by 2100 (Hultgren et al., 2025). Even in productive regions, yield variability is expected to increase, with greater risk of harvest failures. In essence, conventional agriculture contributes to climate change, which in turn disrupts agricultural productivity, prompting further expansion or intensification in a maladaptive spiral.

Regenerative agriculture offers a pathway to break this cycle. By redesigning farming systems to work with ecological processes, regenerative practices simultaneously mitigate climate change and build adaptation capacity. On the mitigation side, practices such as cover cropping, agroforestry, reduced tillage, and improved grazing management enhance the land's ability to absorb and store carbon. For example, integrating cover crops into rotations has been estimated to offset on the order of 2 metric tons CO -equivalent per hectare per year through a combination of increased soil carbon and reduced fertilizer emissions. Similarly, agroecological methods that reduce synthetic fertilizer needs (through organic inputs or legumes) can cut nitrous oxide emissions, and well-managed pastures with deep-rooted grasses can sequester carbon while supporting livestock. Perhaps most importantly, regenerative farming prevents further loss of existing soil carbon stocks by keeping soils covered and intact, a critical climate benefit given that existing carbon in soils and biomass is at serious risk under ongoing climate extremes.

On the adaptation side, the same practices improve farm resilience to climate impacts. Healthier, carbon-rich soils act like sponges, retaining moisture during droughts and improving drainage during floods. Enhanced soil structure and vegetative cover reduce erosion and nutrient runoff under heavy rains. Diverse cropping systems and agroforestry can buffer temperature extremes, provide habitat for pollinators and pest predators, and diversify income streams to spread risk. Farmers practicing regenerative methods often report greater yield stability in the face of erratic weather, whereas neighboring conventional fields suffer more. For instance, fields under no-till and cover crops have maintained higher soil moisture and crop vigor during heatwaves that decimated conventionally tilled fields. In aggregate, widespread adoption of regenerative agriculture could make the agricultural landscape a formidable tool for climate mitigation and adaptation. This means that farms would transform from net emitters into net carbon sinks, all while becoming more resilient to the climate disruptions that are already underway.

5. Regenerative Agriculture: Principles, Practices, and Holistic Benefits

Regenerative agriculture (RA) represents a fundamental conceptual shift, moving beyond simple sustainability to emphasize a holistic, system-based approach that actively restores the ecological functions of agricultural land (Fenster et al., 2021). The success of RA relies on bundling multiple context-specific practices to achieve synergistic benefits across the agroecosystem (Fenster et al., 2021). While application is highly localized, regenerative systems follow a core set of ecological principles (Rhodes, 2017, as cited in Fenster et al., 2021):

- Minimize Soil Disturbance: Avoid intensive tillage and plowing (no-till or low-till) to protect soil structure and microbial life.
- Keep Soil Covered: Maintain continuous, year-round living or organic cover (cover crops, mulches, residue retention) to prevent erosion and maximize moisture retention.
- Encourage Plant Diversity: Utilize complex crop rotations and diverse species mixes, including the integration of perennials or agroforestry, to enhance soil biodiversity and break pest/disease cycles.
- Integrate Organic Matter and Livestock: Recycle nutrients through compost, manure, and, where feasible, implement managed rotational grazing to build soil health.
- Reduce Synthetic Inputs: Drastically cut the reliance on synthetic fertilizers, pesticides, and herbicides, emphasizing natural nutrient cycling, biological pest controls, and detailed agronomy (Smith et al., 2024).

5.1 Context-Specific Application

The application of these principles must be highly adaptable to the farm's scale and local context. For large-scale commodity operations, practices often focus on minimizing physical and chemical disturbance to maximize resource efficiency (McKinsey, 2024). This includes the adoption of precision agriculture techniques (Cropin, 2025), implementing reduced tillage or no-till farming (Derpsch et al., 2014; Smith et al., 2024), and utilizing multi-species cover crops (Abdalla et al., 2019). Corporate engagement provides crucial market pull in this sector, as seen with Cargill's RegenConnect program, which offers direct financial incentives to farmers for adopting practices like cover cropping and reduced tillage across its global supply chains (Cargill, 2021).

For smallholder farmers, where capital investment is typically limited, RA practices emphasize maximizing biological diversity and utilizing local resources. This often involves intensive crop diversification, mixed cropping systems, a strong reliance on composting, and local resource use. The use of agroforestry systems, integrating trees and shrubs with crops, is a crucial strategy applicable across all scales, enhancing biodiversity, stabilizing the soil, and diversifying livelihoods (IPCC, 2022). The power of regenerative agriculture lies in the synergistic effect of stacking these practices, as demonstrated in the California almond orchard study where combining permanent ground cover, composts, and avoided synthetic inputs yielded superior performance (Fenster et al., 2021).

5.2 Holistic and Economic Benefits

The benefits of regenerative agriculture are strikingly holistic, delivering both private and public goods that conventional systems often struggle to provide.

Environmentally and agronomically, RA leads to healthier soils with higher organic matter, fertility, and microbial activity. This improved soil structure translates directly to greater water infiltration and water holding capacity, meaning regenerative fields demonstrate significantly greater resilience during climate stresses like drought (Fenster et al., 2021; Revitalizing fields, n.d.). Furthermore, biodiversity on and around farms increases-from soil organisms up to pollinators and birds-creating a more balanced ecosystem that naturally curbs pests and enhances pollination (Revitalizing fields, n.d.). Beyond the farm gate, improved water outcomes mean less downstream flooding and reduced nutrient pollution. Crucially, as discussed previously, carbon sequestration turns farms into active climate solutions.

Economically, RA provides farmers with multiple pathways to enhanced profitability and stability. Farmers can benefit immediately through significant input cost savings, such as using fewer synthetic fertilizers, pesticides, and fuel (BCG, 2023). Moreover, evidence is emerging that regenerative agriculture can be financially rewarding over time. The California almond study found that regenerative orchards achieved equal yields and twice the profit of conventional ones (McKinsey, 2024). Similarly, long-term trials on grain farms have found that after the initial transition, regenerative systems maintain output with lower variable costs, substantially increasing net income. Producers may also obtain price premiums by marketing their products as regeneratively grown or organic, or secure new revenue streams through payments for ecosystem services. By aligning nature’s processes with farm management, regenerative agriculture creates a robust model for truly sustainable food systems, linking environmental health directly to farm economics.

6. Engaging Farmers: Scaling Adoption

Achieving the necessary global adoption of regenerative agriculture depends on a synchronized, multi-stakeholder strategy to reduce the high perceived risk and close the knowledge gaps faced by producers, thereby answering how sustainable practices can be made competitive at scale. Farmers, the protagonists of this transformation, require systemic support across financial, technical, and market dimensions.

6.1 Mitigating the Economic Transition Barrier

The greatest barrier to widespread adoption is the economic uncertainty inherent in the three-to-five-year transition phase (BCG, 2023; Sustainable Food Lab, 2025). During this high-risk period, farmers face potential capital outlays (e.g., up to $200 per acre for new equipment) (McKinsey, 2024) and the threat of temporary profit dips projected to be between 30% and 60% (BCG, 2023). Crucially, farmer motivation is driven by tangible outcomes. Surveyed farmers prioritized reduced input costs and direct soil health benefits (35%) as their primary adoption driver, vastly outweighing revenue from carbon payments (5%) (BCG, 2023).

To overcome this risk, public programs must actively provide financial safety nets. This involves specialized instruments like regenerative crop warranties, transition insurance, or income guarantees to cushion profits during the initial phase. Policy alignment is essential, requiring the reform of existing crop insurance and credit programs to favor resilient farms (BCG, 2023) and the removal of disincentives; for instance, insurance rules that discourage cover cropping. Redirecting agricultural subsidies towards regenerative outcomes, essentially paying farmers to sequester carbon and build soil health, is a critical mechanism for aligning public spending with long-term sustainability goals.

6.2 Knowledge Sharing and Global Smallholder Engagement

Widespread scaling requires engaging the estimated 570 million smallholder farmers worldwide (Zhang et al., 2024) and shifting them away from high-input models (Cropin, 2025). This complex shift necessitates investment in education, technical assistance, and digital solutions.

Governments and NGOs must expand agricultural extension programs focused on regenerative techniques, prioritizing farmer-to-farmer mentoring and peer networks. Seeing a neighbor successfully implement no-till or cover-cropping is often the most effective way to overcome skepticism. The EU Mission “A Soil Deal for Europe,” for instance, is addressing this by funding 100 Living Labs across regions to co-create and test localized regenerative solutions, supporting essential peer learning and technical assistance (EU Mission, n.d.).

Simultaneously, digital transformation is essential for empowerment (Cropin, 2025). Platforms like Cropin Cloud provide necessary advisories in local languages and offer a mechanism to establish a validated production trail (Cropin, 2025). This verifiable data empowers small farmers to bypass exploitative middlemen, secure long-term contracts, and demand higher prices for their sustainably grown produce, fundamentally enhancing their economic resilience (Zhang et al., 2024).

6.3 Corporate Market Pull and Direct Incentives

Corporate engagement provides crucial market pull, as major food and beverage companies recognize that resilient supply chains depend on regenerative farm systems (Klim, 2025). These companies are setting ambitious goals to secure supply chains and reduce scope 3 emissions. Examples include PepsiCo's commitment to implementing regenerative practices on four million hectares by 2030, and General Mills’ goal of one million hectares (Klim, 2025).

Global leaders, including Unilever, Nestlé, and McDonald’s, are driving change through partnerships that share risk and provide direct financial incentives. For instance, Cargill’s RegenConnect program offers explicit financial payments to farmers for adopting key practices like reduced tillage and cover cropping across its global supply chains (Cargill, n.d.; BCG, 2023). By committing to purchase sustainably produced commodities and offering premium prices or long-term contracts, these companies create the reliable market signal necessary to justify the farmer's investment in the regenerative transition

7. Financing and Pricing the Regenerative Transition

Mobilizing the necessary capital is the linchpin for scaling regenerative agriculture globally, requiring the financial system to internalize environmental costs and reward verifiable stewardship. The challenge is immense as the funding required to realize the AFOLU (Agriculture, Forestry, and Other Land Use) sector's full climate mitigation potential is estimated at more than $400 billion per year by 2050 (IPCC, 2022). This need is largely unmet, as dedicated funding for land-based climate mitigation, such as carbon offsets, is critically low, estimated at only about $0.7 billion per year (IPCC, 2022).

Closing this staggering financial gap requires an integrated strategy centered on results-based payments that reward verified environmental outcomes (BCG, 2023) and the realignment of existing financial flows. As the IPCC notes, the estimated funding needed is smaller than what is currently spent on agricultural and forestry subsidies (IPCC, 2022). Redirecting a portion of these existing subsidies toward regenerative practices is perhaps the single most transformative shift available.

7.1 Policy and Systemic Reform

Effective financial mobilization must be underpinned by policy that addresses global market failures, particularly the displacement of environmental costs (Smith et al., 2024). Global agricultural trade is identified as the primary driver of biodiversity loss from recent land-use change (Cabernard et al., 2024). Imports into major consuming regions, such as the United States and Europe, effectively outsource environmental damage to vulnerable tropical biodiversity hotspots (Cabernard et al., 2024). Policy must therefore mandate transparent supply chains and introduce regulatory measures that disincentivize sourcing from vulnerable areas.

The European Union is establishing a crucial global precedent through its EU Soil Strategy for 2030 (Soil Strategy for 2030, 2021), which aims to legally equalize the status of soil to that of air and water (Smith et al., 2024). The associated Farm to Fork strategy includes structural regulatory targets, such as a 20% reduction in fertilizer use by 2030 (Ferreira et al., 2022), providing a systemic financial incentive for RA adoption. The AFOLU sector offers a significant mitigation potential of 0.2 GtCO - eq yr^{1} from crop nutrient management alone (IPCC, 2022), demonstrating that targeted policies are highly effective in leveraging this potential.

7.2 Mobilizing Capital: A Multi-Stakeholder Approach

No single source of funding can bridge the financial gap; rather, a blended approach involving public, private, and market-based solutions is required:

1. Governments and Public Finance

Governments are crucial in the early stages to de-risk the regenerative transition. This includes retooling existing agricultural support programs to promote soil conservation and carbon farming, making subsidies conditional on adopting regenerative practices. Furthermore, public funding must implement specialized financial products:

- Transition Risk Protection: Introducing regenerative crop warranties to protect against yield risk during the initial three-to-five-year transition (BCG, 2023).
- Credit Reform: Reforming crop insurance and credit programs to offer lower interest rates or larger credit lines to resilient farms with verified high Soil Organic Carbon (SOC) levels (BCG, 2023).
- R&D: Expanding agricultural R&D and extension services to provide technical assistance and build knowledge.

2. Private Sector and Supply Chains

Agribusiness, food manufacturers, and retailers have a direct financial incentive to invest in regenerative agriculture to secure long-term, resilient supply chains. Their contribution takes several forms:

- Market Incentives: Offering premium prices or long-term purchase agreements for regeneratively produced crops, providing farmers with market security.
- Financial Products: The financial industry can develop specialized loan products, sometimes called “soil health loans,” with terms that incentivize soil improvements.
- Technical Assistance: Directly funding technical support and inputs at reduced cost for farmers within their supply chains.

3. Carbon and Ecosystem Service Markets

Emerging markets for ecosystem services provide a mechanism to monetize the public goods created by RA.

- Carbon Sequestration: If a farmer can demonstrate that their practices are sequestering verified tons of CO per hectare, they can sell that carbon offset to third parties. While challenges remain in measurement and price stability, these markets can translate the climate value of RA into farm income.
- Water Services: Local governments or water utilities are increasingly recognizing that paying upstream farmers to adopt practices that improve water quality or reduce flood risk is cheaper than building new infrastructure. These payments provide a direct economic return for farmers who regenerate their land.

The future of financing the regenerative revolution lies in blended finance models, where public or philanthropic funds absorb some of the risk or lower the cost of capital, thereby attracting the vast pools of private investment needed for scaling (IPCC, 2022). By realigning existing financial flows with sustainable outcomes, the necessary investment can be unlocked to transform agriculture from a driver of degradation into a force for regeneration.

8. Measuring Progress: The Imperative for Holistic Soil Metrics

To ensure sustained investment and successful implementation of regenerative agriculture, it is critical to determine: How do we measure improvement and make those insights shareable across public and private sectors? Effective measurement must fundamentally prioritize the asset value of soil over short-term yield, capturing the full spectrum of multifunctional regenerative benefits.

The fundamental shift in metrics involves moving the focus from the short-term income statement (annual yield) to the long-term balance sheet, the health and verifiable value of the soil asset (Fiorillo et al., n.d.). This is crucial because regenerative benefits are multi-functional and result from complex ecosystem dynamics (Fiorillo et al., n.d.).

8.1 The Overall Soil Effectiveness (OSE) Framework

As mentioned earlier, the Overall Soil Effectiveness (OSE) model provides the necessary quantitative framework for this shift, adapting industrial performance metrics (like Overall Equipment Effectiveness) to provide a holistic benchmark score for soil quality (Fiorillo et al., n.d.). OSE quantifies utilization, efficiency, and quality by concurrently measuring the provision of multiple ecosystem services, including carbon sequestration, nutrient cycling, and biodiversity enhancement (Fiorillo et al., n.d.).

The OSE framework is built upon three core components:

1. Availability: Measures the fraction of time the soil is biologically active and supporting plant growth. In a regenerative system, high availability means the field is kept covered and productive year- round (e.g., through cover crops), maximizing the effective utilization of the soil resource.
2. Performance: Quantifies the efficiency of crop production relative to the soil’s potential, looking at how well the soil’s productive capacity is translated into actual yield when in use. Improved rooting depth and nutrient availability in healthy soil translate into more efficient growth and higher performance scores.

3. Quality: Goes beyond the market grade of the harvested crop to include indicators of ecosystem health. This component integrates metrics such as the Biological Soil Quality index (which measures soil micro-arthropod diversity) and soil carbon changes, allowing regenerative plots to score over 100%, meaning they exceed the baseline expectations by generating additional ecosystem value.

These three components are combined to yield an overall OSE percentage. Empirical trials have validated its utility, demonstrating that Conservation Agriculture (CA) fields maintained long-term OSE scores around 70-80%, vastly higher than the 7-9% range of comparable conventional fields (Fiorillo et al., 2023). This provides hard, verifiable evidence that regenerative methods make far more effective use of soil as a productive asset.

8.2 Advancing MRV Systems and Standardization

To validate these outcomes and ensure data credibility, Effective Measurement, Reporting, and Verification (MRV) systems must address the historical inadequacy of assessment methods (IPCC, 2022). Historically, soil quality assessment was dominated by frequently utilized chemical indicators (e.g., Soil Organic Matter/Carbon and pH), but this bias must be overcome by mandating the integration of critically underutilized biological indicators, such as Microbial biomass carbon (Fan et al., 2025). The recent evolution of research toward integrated, multifunctional assessments, with 50% of recent papers categorized as "Comprehensive," supports this necessary scientific shift (Fan et al., 2025).

The logistical challenge of high-cost traditional laboratory analysis (Valani et al., 2020, as cited in Fan et al., 2025) must be addressed by leveraging advanced digital tools. The rapid growth of soil quality research supports the potential for integrating artificial intelligence (AI) with multi-source data for rapid, large-scale monitoring (Fan et al., 2025; Smith et al., 2024), alongside remote sensing of key variables (Meng et al., 2023, as cited in Fan et al., 2025).

Finally, policy-backed standardization is required to ensure data harmonization across sectors and borders. The forthcoming EU Soil Health Law is intended to establish the first-ever harmonized framework for tracking physical, chemical, and biological soil indicators across member states (Ferreira et al., 2022; Smith et al., 2024). This provides the verifiable data foundation needed to unlock ecosystem service financing (IPCC, 2022) and make holistic regenerative outcomes as routine to measure as crop yield.

9. Conclusion: The Regenerative Imperative and the Path Forward

The evidence reviewed in this paper confirms that the crisis of global soil degradation requires an immediate and systemic response. The regenerative imperative is clear as we know that agriculture must evolve from merely sustainable to actively restorative, healing the soil, stabilizing the climate, and revitalizing rural economies. This transformation is both scientifically proven and increasingly economically viable, but its widespread global adoption relies entirely on transforming the institutional and financial environment surrounding farming. This necessary shift is achievable through a three-pronged, synchronized global strategy.

9.1 Synthesis of the Strategy

First, Economic Alignment is paramount. The mobilization of capital must urgently address the massive funding gap, moving from the current annual investment of roughly $0.7 billion to the required $400 billion per year to realize the AFOLU sector's full mitigation potential (IPCC, 2022). This requires directing public and private funds toward results-based payments that reward verified environmental outcomes (BCG, 2023) and implementing risk-mitigation tools like regenerative crop warranties. Simultaneously, global policy must tackle the externalized costs of production by mandating transparent supply chains and regulating imports that drive biodiversity loss in vulnerable tropical hotspots (Cabernard et al., 2024).

Second, Universal Engagement must be ensured by systematically addressing the farmer's primary barrier, the financial risk inherent in the transition phase. Incentives must focus on reducing input costs and validating direct soil health benefits (BCG, 2023). Scaling requires empowering the world's 570 million smallholders with accessible digital tools to secure premium markets for their validated, sustainable produce (Cropin, 2025; Zhang et al., 2024). Furthermore, corporate market pull, exemplified by ambitious goals from companies like PepsiCo and financial incentive programs like Cargill's RegenConnect, is crucial for transitioning regenerative practices from pilot projects to standard operating procedures (Klim, n.d.; Cargill, n.d.).

Third, Holistic Measurement must be institutionalized by shifting the focus from short-term yield to the long- term asset value of the soil (Fiorillo et al., n.d.). The adoption of rigorous, quantitative frameworks like the Overall Soil Effectiveness (OSE) model is necessary to benchmark and validate the superior ecological and economic value of regenerative methods. Critically, mandatory and standardized Measurement, Reporting, and Verification (MRV) systems, such as the EU's forthcoming Soil Monitoring Law, are essential to ensuring verifiable outcomes that unlock sustainable finance at scale (Ferreira et al., 2022; Smith et al., 2024).

9.2 The Regenerative Imperative

The time for theoretical proposals is over. This paper demonstrates that scaling sustainable agriculture through economic alignment and holistic measurement is a developing reality, with countless innovators, from farmers and researchers to corporations, already leading the way. While the journey of changing deeply established agricultural systems will be complex, the momentum is undeniable. Every year, more evidence solidifies the case that regenerative agriculture is a win-win for both people and planet.

The regenerative movement invites us to foster a shared vision that farming in harmony with nature is not a nostalgic ideal, but a practical, urgent path forward. By nurturing soil as a living source of renewal, humanity can secure food prosperity and ecological stability for generations to come. If we pay attention to this imperative, we will leave a legacy of abundance, including fertile soils, a stable climate, and thriving communities. The tools are at hand and the time to act is now.

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