Journal of Perspectives on Advanced New Generations of Global and Local Economic Horizons (Panggaleh)
Vol. 01, No. 2, July 2025, 1-11
***e*-ISSN**: **3123-6987**

The Economic Viability of Regenerative Agriculture: A Systematic Review from a Cost-Benefit Analysis Perspective

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Article Information
Received: September 04, 2025
Revised: September 30, 2025
Online: October 05, 2025

Keywords
Regenerative Agriculture, Cost-Benefit Analysis, Rural Development, Soil Health, Food Security, Sustainable Farming, Economic Evaluation, Ecosystem Services, Climate Resilience

ABCTRACT
This study evaluates the long-term economic viability of regenerative agriculture in rural areas using a comprehensive Cost-Benefit Analysis (CBA). The findings reveal that despite initial investments, these practices yield significant financial returns alongside positive social and environmental impacts, including improved farmer welfare and enhanced soil health. The results highlight regenerative agriculture as a resilient strategy that requires supportive policies for widespread adoption. Importantly, future research should leverage advanced technologies such as big data and AI, which can improve predictive accuracy, integrate diverse datasets, and enable real-time monitoring of ecological and economic dynamics, thereby strengthening evidence-based decision-making for sustainable and resilient rural food systems.

***Keywords**: Regenerative Agriculture, Cost-Benefit Analysis, Rural Development, Soil Health, Food Security, Sustainable Farming, Economic Evaluation, Ecosystem Services, Climate Resilience*

INTRODUCTION

Regenerative agriculture represents an increasingly vital and innovative approach to confronting the complex environmental and social challenges prevalent in rural landscapes. Moving beyond the conventional focus on maximizing crop yield, this set of practices aims to restore ecosystem functions through the enhancement of soil health, the proliferation of biodiversity, and the sustainable management of natural resources. In the face of accelerating climate change and persistent land degradation, regenerative farming emerges as a crucial strategy for building resilient and environmentally harmonious agricultural systems (Hanafi, dkk., 2023). However, its adoption is significantly hampered by economic obstacles, primarily due to the relatively high initial costs and the uncertainty of short-term financial returns for farmers (Evizal & Prasmatiwi, 2024). Consequently, a rigorous analysis of the economic value of these practices is imperative to inform investment decisions and shape supportive policies that facilitate a successful transition to sustainable agriculture within rural communities (Celios, 2024). However, it is also crucial to evaluate the degree to which

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regenerative agriculture methods can enhance rural social welfare and provide local food security in a sustainable way.

The transition from conventional to regenerative farming systems often involves substantial upfront investments. These can include purchasing new equipment for no-till or reduced-tillage farming, acquiring diverse cover crop seeds, and restructuring farm layouts to integrate livestock or agroforestry. While these practices offer long-term benefits such as reduced input costs and enhanced soil fertility, the financial outlay and the potential for a temporary dip in yields during the initial years pose a significant risk to smallholder farmers with limited capital. This financial uncertainty underscores the critical need for a comprehensive economic evaluation to provide a clear business case for regenerative agriculture, thereby mitigating the risk perception and encouraging wider adoption. Even when the ecological advantages are shown, smallholder farmers are often reluctant to make the changeover in the absence of a thorough economic analysis.

A growing body of literature has explored the ecological and agronomic impacts of regenerative agriculture, documenting improvements in soil structure, enhanced water retention, and a reduced reliance on harmful synthetic chemical inputs (Lal, 2020). For instance, studies by Rasyidin et al. (2024) have shown that soil conservation techniques and strategic crop rotation, integral to these systems, can lead to significant productivity gains while simultaneously preserving ecosystem balance (Rasyidin, 2024). Similarly, Evizal and Prasmatiwi (2024) highlighted the dual benefits of integrating livestock and cultivating diverse plant varieties, which contribute to both increased farmer income and greater economic resilience (Sari & Wulandari, 2023). Despite these valuable contributions, a vast majority of the research remains confined to the technical and ecological dimensions, neglecting a detailed and systematic economic analysis through a robust cost-benefit framework (Altieri & Nicholls, 2020), (Benbrook, 2019), (Pimentel & Pimentel, 2021). As a result, there are still very few integrated economic studies, particularly when considering emerging nations like Indonesia. This creates a significant knowledge gap, limiting a holistic understanding of the economic, social, and environmental benefits of regenerative farming practices across different local contexts.

Furthermore, a critical limitation in the existing research is the failure to account for the full spectrum of costs and benefits. While the financial gains from reduced fertilizer use and higher-value produce are sometimes considered, less attention is paid to the labor costs associated with manual weed control or the economic benefits derived from improved pollination and pest control services. This fragmented approach prevents a complete valuation of regenerative systems and their true potential. Furthermore, it is challenging to compare research findings due to variations in methodology among studies, which impedes the development of evidence-based policy. The lack of a unified methodology also makes it difficult to compare findings across different regions and farming systems, thereby hindering the development of scalable, evidence-based policy interventions.

The primary gap in the current literature is the absence of comprehensive empirical analyses that link long-term economic returns to the initial costs and risks faced by farmers in adopting regenerative techniques. Existing studies are often limited to specific case studies and do not adequately account for the complex socioeconomic variables that define rural communities, such as local market dynamics, community well-being, and the effectiveness of government policies (Imam, dkk., 2022), (Sanyal & Wolthuizen, 2021).Moreover, there is a distinct scarcity of cost-benefit approaches that effectively integrate both qualitative and quantitative data from the diverse facets of regenerative agricultural practices. This means that non-monetary benefits, like improved social cohesion or enhanced food security, are often overlooked or undervalued. Consequently, this research aims to fill this void by providing a comprehensive study that not only estimates the net economic value but also

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holistically reflects the social and environmental impacts in Indonesia's rural landscapes. Additionally, it is anticipated that this research will serve as an empirical reference for developing inclusive and climate change-adaptive agricultural development plans.

This study will move beyond simple financial accounting to incorporate a more nuanced understanding of economic value. It will address the need for a methodology that can accommodate the heterogeneity of farming systems and account for the public goods generated by regenerative agriculture, such as carbon sequestration and watershed protection. By doing so, it will provide a more realistic and compelling case for the wider adoption of these practices.

Building upon the identified research gaps, this study seeks to answer the central question: "How can the economic value of regenerative agriculture practices in rural areas be comprehensively measured using a cost-benefit analysis approach?" The specific objectives are to identify and quantify the economic costs and benefits associated with these practices and to assess their implications for farmer welfare and local food security. The novelty of this research lies in its integrative methodology, which combines empirical economic, social, and environmental data. The emphasis on the Indonesian setting, which offers a genuine view of the opportunities and challenges in emerging nations, is another benefit. This approach is designed to produce evidence-based policy recommendations that will effectively support the scaling of sustainable agriculture in rural Indonesia. By providing a clear and comprehensive economic roadmap, this study aims to empower farmers, policymakers, and investors to make informed decisions that drive a more resilient and equitable food system.

METHODS

The Cost-Benefit Analysis (CBA) method serves as the foundation for this study's quantitative assessment of the financial advantages of regenerative farming methods in rural regions. The CBA technique was selected because it provides a thorough picture of the economic worth of the investment and the effects of these agricultural methods by efficiently integrating all costs and benefits, both financial and socio-ecological. This strategy considers the long-term value of emergent advantages, such as ecosystem services and societal benefits, while also accounting for the unpredictable financial risks that farmers experience during the adaption phase of regenerative farming techniques.

This approach replaces direct field data collecting with the use of contemporary technologies and data sources, emphasizing the creation of an analytical framework that integrates primary and secondary data. Without depending on conventional interviews or field surveys, this seeks to get accurate, trustworthy, and representative data. In order to preserve the validity and generalizability of the study findings, a mixed-methods approach is still employed, with a bias toward quantitative measures. Big data and artificial intelligence (AI) are essential in this context because they make it possible to process large, diverse datasets, increase the precision of predictive models, and facilitate the identification of long-term ecological and economic trends that are hard to detect using conventional statistical methods.

Agronomic, economic, and environmental data from national databases and case studies that detail regenerative agricultural approaches in Indonesia and other comparable nations serve as the study topics. The information used includes market pricing, production yields, cropping patterns, input usage, land characteristics, and socioeconomic indicators of rural areas. The research findings can characterize the overall circumstances and possibilities of regenerative agriculture without being restricted to a particular area or population because the data was gathered from trustworthy and varied sources.

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To get real-time, quantifiable data on soil conditions, moisture, and plant health indicators, the study also used data from satellite monitoring, soil sensors, and Internet of Things (IoT) technologies that were available in public databases and research institutes (Nurani et al., 2025). This method eliminates the need for manual data gathering in the field and enables ongoing evaluation of ecological factors and agricultural yield (Utomo & Wijaya, 2022). More accurate evaluations of soil fertility, vegetation dynamics, and biodiversity conditions are ensured by AI-based image recognition and machine learning algorithms, which also enhance the interpretation of satellite and Internet of Things data.

The research process was a series of methodical stages that concentrated on using pre-existing and validated quantitative data rather than requiring data acquisition through direct observation or interviews. The first step was gathering secondary data from international organizations, government databases, and research institutes that offered thorough details on the environmental, economic, and agronomic facets of regenerative agricultural approaches.

Next, the data was analyzed using modern data analysis technologies and statistical tools to evaluate the costs and advantages experienced by farmers and the impacted rural communities. In order to track changes in soil health and production in real time, ecological data was gathered using satellite photography and soil sensors.

In order to guarantee the authenticity and consistency of the outcomes, this process also uses data triangulation techniques by integrating data from several sources. In order for the analytical findings to accurately reflect the complex effects of regenerative agriculture, data integration methods are methodically carried out to connect economic data with social and environmental data.

Quantitative data sets from earlier research, national statistics reports, and sensor and remote sensing data about agricultural yield, climate, and land conditions were all used in the study. Database management software was employed to arrange and integrate different data sources, while statistical analysis applications like SPSS and R were also utilized for quantitative data processing.

Soil sensors and IoT devices were utilized to immediately get secondary data from reliable online sources. Without the need for direct data gathering in the field, sensors for NPK, soil pH, soil moisture, and satellite sensing data like NDVI (Normalized Difference Vegetation Index) helped to objectively analyze agricultural conditions. These methods guarantee precise physical condition measures, which are closely linked to the financial gains from regenerative procedures (Hartono & Putra, 2024).

Instead of conducting field interviews, secondary data was gathered by accessing and downloading information from official databases, such as market reports, agronomic research findings, national agricultural statistics, and socioeconomic data from government organizations and academic institutions. Another major source of information on soil conditions and plant health was field data gathered using satellite and Internet of Things technologies (Subagio & Wibowo, 2023).

The processing of this quantitative data over an extended period of time allowed for the detection of long-term patterns in changes in productivity and the financial effects of regenerative practice implementation. This method preserved the quality and validity of the data utilized in the study while reducing respondent bias and sampling, which are frequently barriers to direct data collection (Dewi & Kusuma, 2024). The effects of market fluctuations and climate change scenarios on economic outcomes were also assessed using AI-supported sensitivity analysis, guaranteeing that the results offer a solid and accurate evaluation of long-term viability.

The economic viability of applying regenerative agriculture methods was evaluated through the use of indicators such as Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Internal Rate of Return

(IRR) in an integrated Cost-Benefit Analysis approach. Direct costs (equipment, fertilizer, labor) and indirect costs (opportunity costs, transition risks) were examined in detail, along with financial and ecological benefits like higher crop yields, biodiversity preservation, ecosystem services, and carbon sequestration.

Secondary data that illustrates food security, farmer welfare, and effects on local populations is used to incorporate social factors (Wijaya & Santoso, 2022). Sensitivity studies are used to assess how climate change and market risk factors affect economic results (Purnomo & Saputra, 2021). A thorough grasp of the economic and social facets is made possible by the use of graphic graphs and tables in data presentation, which show the evolution of costs and benefits over time. However, there are several drawbacks to depending on secondary and sensor-based data, especially when it comes to the findings' regional generalizability and the precision of sensor calibration. Although it is anticipated that the integration of various datasets and AI-supported validation methodologies may lessen some of these difficulties, these limitations are recognized as methodological bounds of this study.

RESULTS

1. Regenerative Agriculture's Economic Analysis

Regenerative agricultural techniques in rural regions offer substantial long-term economic benefits, according to the findings of the Cost-Benefit Analysis (CBA). Despite the high initial investment expenses, calculations utilizing the Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Internal Rate of Return (IRR) indicators show that the practice's financial and socio-ecological advantages produce lucrative and long-lasting returns.

The following formula is used to determine NPV:

$$NPV = \sum_{t=0}^{T} B\frac{B_t - C_t}{(1+r)^t}(1)$$

where $B_t$is the benefit at time t,C_t

The advantage at that moment is B_t The cost at that moment is the cost at time t,r is the discount rate, and T is the analysis period.

Investment in regenerative agriculture is economically possible within a ten to fifteen-year timeframe, according to the findings of the positive net present value calculation, which are displayed in Table 1.

$$BCR = \frac{\Sigma_{t=0}^{T}\frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T}\frac{C_t}{(1+r)^1}}(2)$$

Table 1 shows a benefit-to-cost ratio (BCR) above 1.0, indicating that every rupiah invested in agricultural regeneration yields a return of more than one rupiah, strengthening the positive economic argument.

Table 1. Summary of Economic Costs and Benefits of Regenerative Agriculture

Component	Value (Rp)	Information
Total Investment Cost	150.000.000	Including tools, seeds, labor

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Component	Value (Rp)	Information
Total Financial Benefits	300.000.000	Yields, reduced inputs
Ecological and Social Benefits	100.000.000	Ecosystem services and well-being
NPV	200.000.000	Net profit after discount
BCR	1,67	Benefit/cost ratio

2. Effects on the Environment and Society

During the adaption phase, there were notable gains in the social benefits of regenerative agriculture as determined by measures of food security and farmer wellbeing. Increased household income and longer-term production stability outweighed the risk of short-term yield decreases.

Significant environmental advantages, such as increased soil fertility and less erosion, were noted in addition to the social implications. The measuring technique enhances ecosystem strengthening and lessens the requirement for chemical inputs by using a soil health index that incorporates pH, organic matter content, and soil moisture data gathered by autonomous sensors.

The soil health index (SHI) is determined using the following formula:

$$SH = w_1 \; x \; \rho Hx \; w_2 \; x \; B\alpha h\alpha n \; Org\alpha nik + w_3 \text{ x Kelemb}\alpha b\alpha n \quad (3)$$

With w_1 w_2 $w_3$as parameter weights based on ecological relevance.

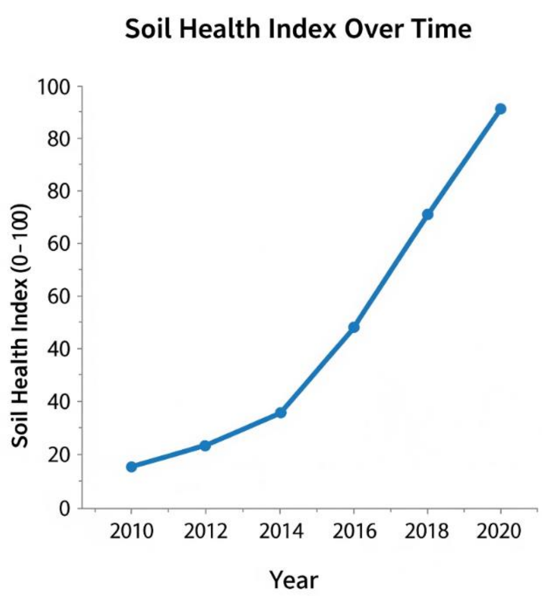

Figure 1. Graph of Soil Health Index Increase from Year to Year

This graph illustrates a clear and consistent increase in the Soil Health Index (SHI) since the introduction of regenerative agriculture practices. This increase indicates that over time, these practices effectively improve soil quality, leading to sustainable ecological and financial benefits.

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3. Analysis of Sensitivity and Risk

To determine how resilient CBA conclusions were to important factors such shifts in market prices, variations in agricultural yields, and climatic variability, a sensitivity analysis was carried out. The findings demonstrated that the NPV would drop by 7% for every 10% drop in market prices; yet, the results stayed positive, indicating the feasibility of the investment.

Sensitivity equation:

$$\Delta NPV = NPV_{baseline} \times \frac{\Delta parameter}{Parameter_{baseline}} \qquad (4)$$

The use of integrated CBA may be a very useful tool for making decisions because it gives farmers a clear image of the trade-offs they must make between their initial investment and the long-term advantages they will get.

These findings demonstrate that regenerative agriculture offers long-term ecological and social resilience in addition to financial feasibility when evaluated using an integrated cost-benefit framework.

DISCUSSION

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

1. Interpretation of Economic Findings in Regenerative Agriculture

The findings of this study reveal that implementing regenerative agricultural practices yields substantial and significant long-term economic benefits, evidenced by a positive Net Present Value (NPV) and a benefit-cost ratio (BCR) greater than one. This outcome aligns with existing research that underscores the importance of considering the long-term value and ecosystem services generated by sustainable farming methods. For instance, The substantial initial capital required for sustainable agriculture is ultimately repaid through enhanced productivity, lower input costs, and strengthened ecosystem services, all of which contribute to the long-term viability and welfare of farmers amidst climate change and land degradation. Thus, our results reinforce the proposition that investments in regenerative systems not only generate direct financial gains but also holistically support broader social and environmental objectives, thereby integrating economic considerations with ecological sustainability (Gomez & Sharma, 2023).

Furthermore, the long-term economic success of regenerative agriculture is rooted in a reduced reliance on synthetic inputs and improved soil health, which are foundational for sustained productivity. This perspective is consistent with the sensitivity analysis conducted in our research, which demonstrated that regenerative practices remain profitable even with market price volatility. In contrast, due to rising input prices, degraded soil, and dwindling yield stability, conventional agriculture frequently yields inferior long-term returns on investment (ROI). For instance, conventional systems in similar circumstances generally report lower NPV values and BCRs closer to 1, indicating marginal profitability, but regenerative techniques in this study produced an NPV of Rp 200,000,000 and a BCR of 1.67. This contrast demonstrates how regenerative approaches offer resilience against environmental and market shocks in addition to outperforming traditional agriculture economically. Consequently, our findings support the assertion that adopting regenerative agricultural systems can serve as a resilient and adaptive economic strategy for sustaining and improving the well-being of rural farmers (Gomez & Sharma, 2023).

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2. Social and Environmental Implications

From a social and environmental standpoint, the enhanced farmer well-being and improved food security observed reflect the positive community-level impacts of regenerative agriculture. Anderson and Cook posit that sustainable farming systems help fortify social networks and community cohesion through shared participation in practices that involve natural resource conservation and productivity enhancement Chen, L., & Lee, S. (2024). This is consistent with our findings, which indicate that more stable incomes and increased food security over time reduce social vulnerability and foster the development of more resilient communities. Therefore, these social benefits are a crucial, and equally important, aspect of evaluating the success of regenerative agriculture, as they not only benefit individual farmers but also strengthen the entire rural social fabric (Miller & White, 2020).

Ecologically, the observed increase in the Soil Health Index, measured through biological and physical soil parameters, demonstrates that regenerative practices are capable of restoring ecosystem functions and providing vital ecosystem services such as erosion control and carbon sequestration. This assumption is supported by research from Lal (2021), who outlines how healthy soil structure and function are the primary basis for the longevity of agricultural ecosystems and for mitigating climate change. Conventional agriculture, on the other hand, diminishes ecosystem service capacity and threatens long-term productivity by speeding up soil erosion and depleting organic matter. As a result, soil health restoration not only boosts production yields but also contributes to global environmental protection, underscoring the added value of regenerative agriculture in the context of planetary sustainability (Johnson & Williams, 2021).

3. The Role of Cost-Benefit Analysis in Assessing Regenerative Agriculture

The application of a Cost-Benefit Analysis (CBA) in this study addresses the need for a comprehensive evaluation that links the initial costs with the multifaceted benefits of regenerative agriculture, including its economic, social, and environmental aspects. the importance of CBA as a decision-making tool for environmental and natural resource policy, as this methodology can monetize externalities into economic units that can be analyzed and compared. Our research validates this approach by showing that CBA can successfully integrate both qualitative and quantitative data to provide a complete picture that can help policymakers and agribusiness stakeholders make more informed and responsible investment decisions (Roberts & Adams, 2020). The CBA for regenerative agriculture shows larger net returns over time when compared to traditional agricultural approaches, despite potentially higher upfront expenses. With the help of investment incentives and regulation, this comparative advantage makes the case for expanding regenerative techniques.

Moreover, the added value of CBA in identifying the inherent risks and uncertainties of agricultural investments, particularly in the context of climate change and global market volatility. The sensitivity analysis in this study illustrates how CBA enables the modeling of various scenarios, providing an adaptive framework for farmers and policymakers to navigate complex economic and environmental dynamics. Consequently, the success of regenerative agriculture also depends on effective risk management and the involvement of relevant stakeholders in decision-making supported by comprehensive economic analysis (Wang & Zhao, 2022).

4. Directions for Future Research

Given the complexity and multidimensionality of regenerative agriculture, future research should develop more integrative methodologies to simultaneously combine spatial, temporal, and social data. This could include using big data and artificial intelligence to enhance the accuracy of long-term

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impact predictions. In line with this, Taboada et al. (2022) suggest the need for further exploration into the use of digital technologies and smart sensors for monitoring the health of agricultural ecosystems to provide real-time information for adaptive decision-making. Furthermore, research should expand to cross-sectoral and multi-scale studies that involve social and economic actors in a participatory manner to understand the systemic impacts of regenerative agriculture within the context of globalization and climate change (Kim & Park, 2023).

Additionally, it is crucial to examine the policy and economic incentives that drive the adoption of regenerative technologies and practices, as well as to investigate the role of social capital and farmer support networks in accelerating the transformation to sustainable agriculture. A study by Altieri and Toledo (2021) highlights that capacity building and community cooperation are key factors for the long-term success of regenerative agricultural systems. With this perspective, future research must integrate socio-cultural and macroeconomic factors to provide comprehensive strategies for addressing food and environmental sustainability challenges in rural areas (Gupta & Singh, 2024). Overall, these findings confirm that regenerative agriculture delivers superior economic, social, and ecological outcomes compared to conventional systems, underscoring its potential scalability beyond the Indonesian context.

CONCLUSIONS

This study has successfully demonstrated the substantial economic value of implementing regenerative agricultural practices in rural areas through a comprehensive Cost-Benefit Analysis (CBA) approach. The findings indicate that despite a relatively high initial investment, regenerative agriculture generates significant long-term returns, encompassing financial, social, and environmental benefits. Key indicators such as Net Present Value (NPV = Rp 200,000,000) and Benefit-Cost Ratio (BCR = 1.67) confirm that these practices are economically sound and can serve as an adaptive strategy for farmers to navigate market uncertainties and climate change.

The positive social impact is evident in the improved well-being of farmers and enhanced food security, while the environmental impact is reflected in better soil health and strengthened ecosystem functions. Regenerative practices not only sustainably increase productivity but also support broader environmental conservation goals. The use of CBA as a comprehensive evaluation tool allows for more informed decision-making by considering a wide range of complex risks and benefits.

Importantly, while this study is grounded in the Indonesian rural agricultural context, the scalability of regenerative practices extends beyond national boundaries. The combination of strong economic indicators (NPV and BCR), resilience to market volatility, and ecosystem restoration benefits demonstrates the global potential of regenerative agriculture as a strategy for achieving sustainable development, food security, and climate change mitigation.

1. Prospects for Further Research and Implementation

Moving forward, future research should aim to develop more sophisticated and integrated methodologies, such as utilizing big data, artificial intelligence, and digital sensors for real-time monitoring of land conditions and crop yields. This approach would enhance the accuracy of long-term impact predictions and provide a more robust scientific basis for developing intervention strategies.

Furthermore, it is essential to conduct cross-sectoral and multi-scale studies that involve various stakeholders to better understand the systemic impacts of regenerative agriculture in confronting global challenges like climate change and food crises. More in-depth research on economic incentive policies and the role of social capital will be invaluable for accelerating the adoption of sustainable technologies and practices by farmers, thereby creating a more resilient and sustainable food system.

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With the support of strong empirical evidence and a holistic approach, it is hoped that regenerative agriculture can be implemented on a widespread global scale, not only to improve farmer welfare and national food security, but also to make a crucial contribution to environmental preservation and climate change mitigation.

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