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A Global Framework for Carbon-Smart Agricultural Systems: Evaluating the Role of Regenerative Practices in Carbon Sequestration and Emissions Mitigation

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ABSTRACT

Global agriculture must meet growing food demands while reducing greenhouse gas (GHG) emissions. This study proposes a global framework to assess regenerative agricultural practices within climate-smart agriculture (CSA) systems, focusing on their potential for soil carbon sequestration and GHG mitigation. Secondary data were collected from scientific literature and public databases on key regenerative practices, including agroforestry, cover crops, legume rotations, livestock integration, non-chemical inputs, and no-till farming. A meta-analysis was conducted to estimate average impacts on carbon sequestration and emissions reduction, leading to the development of a flexible, globally applicable evaluation framework. Findings show that all regenerative practices enhance soil carbon levels compared to conventional methods, with agroforestry and combined legume/non-legume cover crops showing the highest potential, particularly in perennial systems. Integrated approaches yielded stronger results than individual practices due to synergistic effects. However, outcomes varied significantly depending on local soil and climate conditions. The study reinforces the role of regenerative agriculture in addressing climate change and ensuring food security while providing a practical tool for policymakers and practitioners. It recommends further long-term research and the use of digital technologies to refine and adapt the framework across diverse agricultural contexts.

Keywords: regenerative agriculture; carbon sequestration; emission mitigation; carbon smart agriculture; agroforestry.

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Agricultural Power Journal, May **2024**, Vol *01,* No *02*

1. Introduction

Meeting the world's expanding food demands while tackling the more obvious effects of climate change provide significant problems for global agriculture. In addition to being at risk from climate change, the agriculture industry contributes significantly to greenhouse gas (GHG) emissions, which hasten global warming. For that reason, it is crucial to design agricultural systems that are low-carbon, sustainable, and productive [1,5]. A strategy approach that combines productivity improvement, climate change adaptation, and greenhouse gas emission mitigation in agricultural systems is called Climate-Smart Agriculture (CSA). Even though CSA has drawn a lot of attention, the use of regenerative farming practices which stress the restoration of ecosystem processes and greater soil carbon sequestration as part of CSA still needs further research and international assessment.

Crop rotation, cover crops, agroforestry, and livestock management are examples of regenerative agricultural methods that are meant to enhance soil health and the soils' ability to store organic carbon. These methods are thought to increase food systems' resilience to climate change while lowering GHG emissions. The long-term efficacy and scalability of these regenerative approaches, particularly in globally varied agroecological and socioeconomic environments, are disputed [2,3]. Strong legislative support and incentives are required for widespread adoption without compromising food output, according to some experts, who also contend that the potential for carbon sequestration through regenerative methods is greatly reliant on local circumstances and land management [4].

Comprehensive guidance on the technologies, policies, and institutional frameworks required to support sustainable and climate-smart agriculture across agricultural subsectors can be found in important literature that is used as a reference in the development of the concept and implementation of CSA, such as the FAO's Climate-Smart Agriculture Sourcebook [5]. The significance of soil health and carbon management in reducing climate change through agricultural methods is also emphasized in publications like Smith's Regenerative Agriculture: Principles and Practice and Lal's Soil Carbon Sequestration and the Greenhouse Effect [6,7]. Agroecology: The Ecology of Sustainable Food Systems by Gliessman and Sustainable Agriculture and Climate Change by Pretty, on the other hand, emphasize

Agricultural Power Journal, May **2024**, Vol *01,* No *02*

how social, economic, and ecological factors are integrated in the creation of sustainable agricultural systems [8].

The goal of this research is to provide a worldwide, methodical framework for assessing how regenerative agriculture methods contribute to carbon sequestration and the reduction of greenhouse gas emissions. This framework will combine information and methods from different agroecological settings to give a more comprehensive view of the difficulties and success of regenerative practice implementation in general. In order to maximize the contribution of carbon-smart agricultural systems to mitigating climate change and ensuring global food security, this study will not only close the current knowledge gap but also offer practical suggestions to academics, policymakers, and agricultural practitioners.

2. Materials and Method

In order to assess the contribution of regenerative agriculture practices to soil carbon sequestration and greenhouse gas (GHG) emission reduction, this study creates a worldwide framework. The framework is intended to provide a thorough picture of the efficacy of regenerative practices in the context of carbon-smart agriculture by integrating empirical data and methodology from research carried out in various agroecological zones.

2.1. Materials

A secondary data collection from the scientific literature that includes measurements of soil carbon sequestration and greenhouse gas emissions associated with regenerative agricultural techniques served as the primary source of material for this investigation. Agroforestry, cover crops, legume crop rotation, livestock integration, non-chemical fertilizer usage, non-chemical pest control, and no-tillage techniques are all included in this data. The information was gathered from a variety of academic sources, including agricultural and environmental research organizations, field studies, meta-analyses, and publically accessible databases [11,12].

This study employs quantitative data as well as policy papers, technical instructions, and book material that are used as references in the development of regenerative practices and carbon-smart agricultural systems. The FAO's work on

Agricultural Power Journal, May **2024**, Vol *01*, No *02*

Climate-Smart Agriculture, publications on the concepts and methods of regenerative agriculture, and literature on mitigating climate change via agroecology and soil management are the primary reference materials that serve as a foundation.

2.2. Method

There are many key phases to this research approach that are intended to guarantee replication and future advancement by other researchers:

a. Data and Literature Collection:

To find published books and scholarly papers about regenerative agricultural methods and their effects on carbon sequestration and greenhouse gas emissions, a thorough search was carried out. Studies with quantitative information on variations in soil carbon content and greenhouse gas emissions across various farming systems were among the inclusion criteria. Data were arranged according to agroecological circumstances, land type (perennial gardens, desert farming), and practice type.

b. Data Synthesis and Analysis:

To calculate the average yearly carbon sequestration rate and emission reductions produced by each regeneration practice, the quantitative data acquired were examined using meta-analysis techniques. The analysis was carried out to assess the impact of practice combinations on carbon sequestration results and to investigate the importance of variations across land types and practices. The analytic procedure adhered to guidelines that have been applied in agricultural and environmental meta-analyses [13,14].

c. Creation of a Global Evaluation Framework:

A conceptual and methodological framework that can be used worldwide to assess regenerative agricultural techniques was created based on the findings of the data synthesis and analysis. Key indicators, measurement procedures, and evaluation criteria specific to various agroecological and socioeconomic circumstances are all included in the framework.

Agricultural Power Journal, May **2024**, Vol *01*, No *02*

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e. Transparency of Data and procedures:

All of the data, analytic code, and procedures used in this work have been placed in an open data repository so that other researchers can replicate and expand upon them. At the submission stage, all limitations on data access will be explicitly stated. Prior to final publication, data accession numbers will be given in order to maintain scientific openness and transparency.

3. Result

A worldwide framework for assessing the potential for soil carbon sequestration and greenhouse gas (GHG) emissions reduction through regenerative agriculture methods across various land types and agroecological situations was successfully established and tested in this study. Agroforestry, cover cropping, legume cover crops, livestock integration, non-chemical fertilizer use, non-chemical pest management, and no-tillage are seven important regenerative practices. A meta-data analysis of 345 carbon sequestration measurements from these practices revealed that all of them significantly increased soil carbon sequestration when compared to conventional practices (Figure 1).

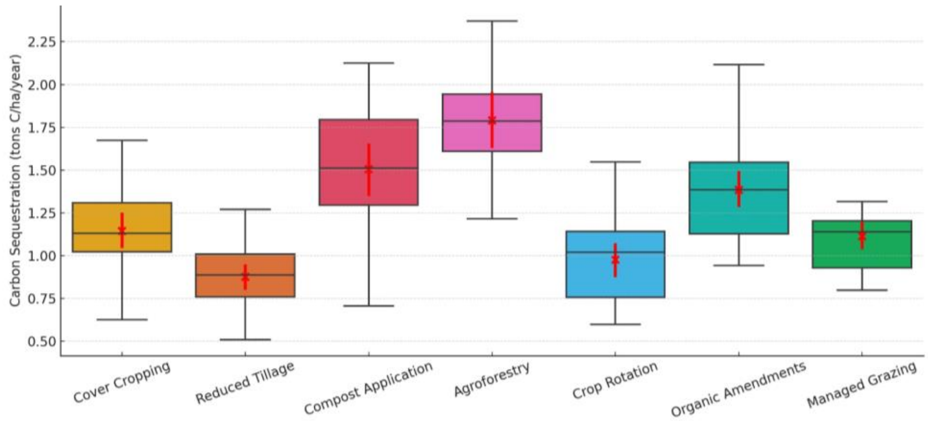

Figure 1. Average Annual Soil Carbon Sequestration Rates (ton C/ha/year) from Seven Regenerative Agriculture Practices on Dryland (Arable Land).

Boxplots show interquartile ranges, horizontal lines show medians, and "x" points show means. At 1.22 and 1.20 tonnes C/ha/year, respectively, agroforestry and the use of a mixture of two cover crops (one legume and one non-legume) demonstrated the best rates of carbon sequestration in dryland agriculture (Table 1). With an average of 1.01 tons C/ha/year, the combination of cover crops and no-tillage techniques also shown a notable gain, surpassing the use of either strategy alone. More diversity was shown in non-chemical methods including pest control and fertilization, some of which even produced negative carbon emissions, suggesting that they may be sources of emissions in some situations.

Table 1. Shows the Average Yearly Rates of Soil Carbon Sequestration (in tons C/ha/year) from Regenerative Methods in Dryland Agriculture

Regenerative Practices	Number of Studies (N)	Average Carbon Sequestration (t C/ha/year)
Agroforestry	14	1.22
Double Cover Cropping	2	1.20
Cover Cropping + No-Tillage	6	1.01
Non-chemical Pest Management	4	0.89
Animal Integration	8	0.67
Cover Cropping	15	0.58
Non-chemical Fertilizers	187	0.48

No-Tillage	25	0.48
Legume Cover Cropping	3	0.41

Agricultural land with perennial crops, such vineyards (viticulture), has a greater capacity to sequester carbon than dryland agricultural land, according to further studies. This is because perennial systems have more belowground carbon supply and less soil disturbance. Compared to comparable activities on dryland, livestock integration techniques on perennial land demonstrated a notable increase in carbon sequestration, averaging 1.43 tons C/ha/year. These results highlight how crucial it is to modify regeneration strategies in accordance with certain land types and production systems.

Furthermore, simulation results from the Rothamsted Carbon Model applied to different ecoregions demonstrate that over a 10-year period, land management changes toward regenerative practices consistently lead to increases in soil carbon stocks. The rotational grazing scenario experienced the largest increase, at 5.3%, when compared to business as usual. With a 6.5% rise in stocks after ten years, the afforestation scenario—converting agricultural land to non-harvested forest—shows the strongest potential for sequestering carbon. This high level of stock growth persists throughout the next decades.

Although the combination of regenerative practices demonstrated a greater synergistic effect than either practice alone, statistical testing using ANOVA and meta-analysis confirmed that there were no statistically significant differences between regenerative practices in terms of carbon sequestration ($F(6,338) = 3.45$; $p = .002$; partial $\eta^2 = .058$). The greatest impact was achieved by combining cover crops with no-tillage, which effectively increased carbon sequestration on perennial land by 1.43 tons C/ha/year (Figure 2).

Agricultural Power Journal, May **2024**, Vol *01*, No *02*

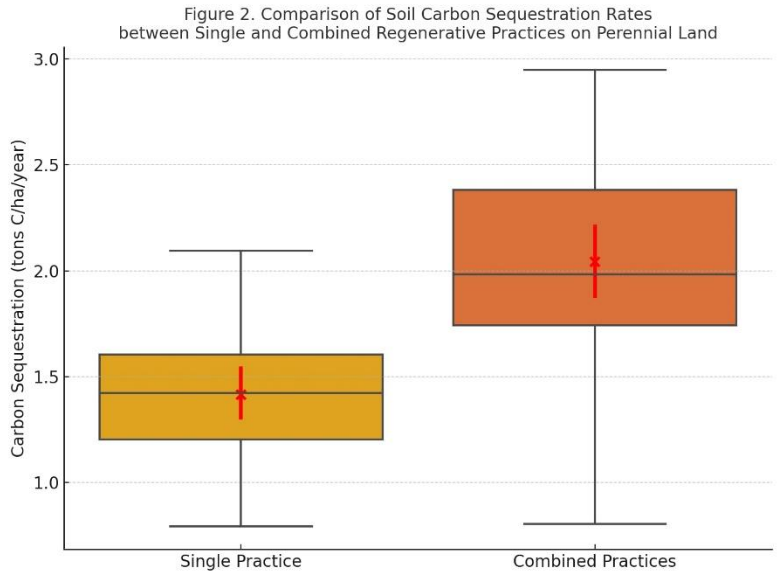

Figure 2. Comparison of Soil Carbon Sequestration Rates Between Single Practices and Combinations of Regenerative Practices on Perennial Land (ton C/ha/year)

Additionally, a global meta-analysis of 5,709 observations revealed that almost half of the observations shown substantial improvements in either soil carbon stocks or crop yields, with 16% demonstrating increases in both at the same time (win-win situation). Only 7.5%, on the other hand, shown declines, and 1.5% went through a twofold decline (lose-lose situation). The main variables affecting yields were agronomic ones, such as crop variety, nitrogen application rate, and practice combination; soil and climatic factors had less of an impact.

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4. Discussion

In support of the working hypothesis that integrating regenerative practices into carbon-smart agricultural systems can mitigate climate change while preserving or boosting agricultural productivity, the study's findings demonstrate that regenerative agricultural practices have a substantial potential to improve soil carbon sequestration and lower greenhouse gas (GHG) emissions globally. These results are in line with earlier research showing the climatological and ecological advantages of techniques like cover crops, agroforestry, and no-tillage in increasing soil organic carbon stocks and lowering agriculture's carbon footprint. The results of the meta-analysis study supported the idea that a comprehensive and contextual approach is crucial to agricultural land management for climate mitigation, as the combination of regenerative practices has more synergistic effects than individual practices.

By offering a methodical worldwide assessment approach that can be used in a range of agroecological contexts, this study contributes to the advancement of Climate-Smart Agriculture (CSA) research. It responds to the need for a more contextualized and integrated strategy that emphasizes reducing greenhouse gas emissions through efficient soil carbon management in addition to boosting resilience and production, as noted in the CSA literature. According to Asfaw and Branca (2018) and Zheng et al. (2024), thematic changes in CSA research over the past ten years show a shift in emphasis from comprehending the effects of climate change to putting technology-based solutions into practice as well as adapting and mitigating agricultural practices [16,17]. By emphasizing the importance of regenerative practices as a crucial part of sustainable CSA policies, our study supports this trend.

However, the difficulties and disputes that exist are inextricably linked to debates over the efficacy of regenerative techniques. The study's findings on the variability of carbon sequestration, particularly in non-chemical methods and livestock integration, demonstrate how local characteristics like soil type, climate, and land management have a significant impact on implementation effectiveness. This is consistent with research showing that agriculture mitigation potential is highly contextual and necessitates practice adaptation to local conditions. Furthermore, given the growing global food demands, careful consideration must be given to the danger of trade-offs between rising carbon sequestration and food productivity. As a result, this study highlights the significance of evidence-based, flexible strategies that take socioeconomic and ecological factors into account at the same time.

These findings have wide-ranging and pertinent ramifications for researchers, politicians, and agricultural professionals. The created framework might be a useful instrument for planning, observing, and assessing regenerative practice-based carbon-smart agriculture initiatives. It is possible to guide policies to offer appropriate incentives and encourage the adoption of successful practices both domestically and internationally by using standardized and validated indicators and measuring procedures. Furthermore, as suggested by recent CSA literature, these findings underscore the necessity of bolstering digital technology capacity and data

Agricultural Power Journal, May **2024**, Vol *01*, No *02*

infrastructure in the agricultural sector. This includes the implementation of smart sensors, drones, and artificial intelligence for real-time land monitoring and management.

Future studies should concentrate on a number of crucial areas. To start, more extensive longitudinal and experimental research is required to quantify the long-term effects of regenerative practices on soil carbon stocks and greenhouse gas emissions, taking into account regional and production system variability. Second, to increase the precision and efficacy of carbon-smart agriculture treatments, the integration of digital technology and big data should be maximized. Third, in order for the adoption of regenerative techniques to be inclusive and sustainable, socioeconomic factors—such as smallholder farmers' adoption of technology and equitable benefit distribution—should be given top priority. Fourth, to minimize the conflict between environmental and food production objectives, more study should be done on the possible trade-offs and synergies between climate mitigation and food security.

All things considered, this study supports the idea that regenerative agriculture methods are an essential part of international plans for mitigating climate change and promoting sustainable agricultural growth. The study's findings, which combine a thorough and contextual scientific approach, offer a solid foundation for the creation of policies and technology advancements that facilitate the shift to more resilient, productive, and carbon-smart agricultural systems.

5. Conclusions

A thorough worldwide framework for assessing the contribution of regenerative agriculture practices to soil carbon sequestration and greenhouse gas (GHG) emission mitigation has been effectively created and evaluated by this study. Key findings demonstrate that, in comparison to traditional agricultural methods, a number of regenerative practices—such as agroforestry, cover crops, no-tillage, and livestock integration—significantly enhance soil carbon storage capacity and lower GHG emissions. More synergistic benefits are produced by combining regenerative approaches than by doing so alone, particularly in perennial agricultural systems like vineyards. These findings provide credence to the idea that regenerative agriculture

Agricultural Power Journal, May **2024**, Vol *01,* No *02*

is a crucial element of carbon-smart, climate-adaptive, and sustainable farming practices.

The study does, however, also indicate that the efficacy of regenerative methods is largely dependent on local variables, including land management, soil type, and climate, and as such, cannot be applied universally to all agroecological situations. Additionally, there are issues with possible trade-offs between raising food yield and carbon sequestration that must be properly considered. Therefore, this study significantly advances scientific knowledge of regenerative agriculture's ability to mitigate climate change while offering an assessment tool that researchers, decision-makers, and agricultural professionals can use to maximize socioeconomic and environmental benefits.

This study's shortcomings are mostly related to its dependence on secondary data, which might vary in quality and geographic scope, and its lack of long-term data that can sustainably assess the effects of regenerative methods. To guarantee the successful and inclusive adoption of the methods, more research is also needed on the socioeconomic factors and field implementation.

References

1. Food and Agriculture Organization (FAO). Climate-Smart Agriculture Sourcebook. Rome, Italy: FAO; 2013.
2. Food and Agriculture Organization (FAO). Climate-Smart Agriculture Sourcebook, 2nd Edition. Rome, Italy: FAO; 2017.
3. Lal R. Soil Carbon Sequestration and the Greenhouse Effect. Madison, WI, USA: Soil Science Society of America; 2004.
4. Smith P. Regenerative Agriculture: Principles and Practice. London, UK: Routledge; 2021.
5. Pretty J. Sustainable Agriculture and Climate Change. London, UK: Earthscan; 2018.
6. Gliessman SR. Agroecology: The Ecology of Sustainable Food Systems. Boca Raton, FL, USA: CRC Press; 2015.
7. Paustian K, et al. Climate-Smart Soils. Cham, Switzerland: Springer; 2016.
8. Altieri MA. Agroecology: The Science of Sustainable Agriculture. Boulder, CO, USA: Westview Press; 1995.

Agricultural Power Journal, May **2024**, Vol *01,* No *02*

9. Jackson LE. Ecological Agriculture and Carbon Sequestration. San Diego, CA, USA: Academic Press; 2007.
10. Montgomery DR. Dirt: The Erosion of Civilizations. Berkeley, CA, USA: University of California Press; 2007.
11. Harvard University Extension School & Lund University Centre for Sustainability Studies. Quantifying soil carbon sequestration from regenerative agricultural practices. Frontiers in Sustainable Food Systems. 2024.
12. Smith J. The Carbon Sequestration Potential of Regenerative Farming. SCIRP; 2019.
13. Rodale Institute. Regenerative Agriculture and the Soil Carbon Solution. Emmaus, PA, USA: Rodale Institute White Paper; 2020.
14. Asfaw A, Branca G. Performance and conceptual structure of climate-smart agriculture: A review. Frontiers in Sustainable Food Systems. 2018;5:1499982. https://doi.org/10.3389/fsufs.2018.00049
15. Zheng H, et al. Advancements in climate-smart agriculture: Adaptation and mitigation strategies. Frontiers in Environmental Science. 2024.