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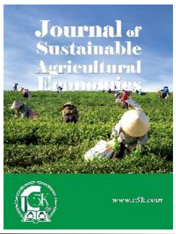

Research Article

Carbon Sequestration Incentives for Sustainable Agriculture: Economic Impacts and Policy Recommendations

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ABSTRACT

There is one solution to fight climate change, enhance soil, and make farming more productive simultaneously: carbon sequestration through practices like agroforestry and regenerative agriculture. This paper also looks at whether carbon credit systems and financial incentives to farmers who adopt such measures are sustainable financially. The research measures the value addition obtained through carbon sequestration in agricultural systems through case studies, economic modeling, and policy analysis. It also defines the challenges for adoption and offers a conceptual approach to incorporating carbon credits and incentives in international and continental agriculture strategies. The study reveals that carbon sequestration yields economic benefits that can enhance farm viability, reduce greenhouse gas emissions, and create new income-generating opportunities for farmers. However, these benefits will be far from complete until real issues of verification, scaling, and policy integration are met.

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1. Introduction

1.1. Background and Importance of the Research

The agricultural industry is one of the largest emitters of GHG, and the most significant agricultural emissions are from livestock production, tillage, and fertilizer use (Xu et al., 2021). Climate change mitigation also has special in agriculture but more on carbon sequestration practice. Carbon sequestration can be described as the process of storing or putting CO_2 back into the soil, plants, or any other organic matter. Everyone knows that agroforestry, regenerative agriculture, and proper soil management assist in carbon sequestration in the soil – and that slows climate change

The concept of market-based instruments like carbon credits to enable land owners and farmers to be paid for storing carbon has also been picked up by industries lately (McMorran et al., 2022). Carbon credits are built over the idea of having an economic incentive for farmers to practice a method fuelling sustainable practices in order to streamline atmospheric CO_2. Farming practices that decrease the CO_2 in the atmosphere are verified, and then farmers are rewarded with carbon credits for each CO_2 footprint that they eliminate (Wade et al., 2022). This gives farmers a little more income stream and offsets the cost of going organic.

Combating climate change and simultaneously improving both soil health and agricultural productivity is a double opportunity through carbon sequestration on agricultural lands, especially through agroforestry and regenerative agriculture. Agroforestry — the use of trees in farming systems — sequesters carbon in trees and soil as well as improves biodiversity and reduces soil erosion. Pioneered by (and named after) organic pioneer Robert Rodale, regenerative agriculture is based on regenerating fertility in soils through practices such as no till farming, cover cropping, and holistic grazing which increase soil organic matter and thus raise soil fertility and carbon storage capacity in the soil (Leu, 2020). The integration of such practices into carbon credit systems can be a source of both environmental and economic benefit to farmers.

Despite the potential of carbon sequestration to mitigate climate change and to increase farm sustainability, there are several deterrents to widespread adoption. Some of these are high investment costs in the start, no financial incentive, insufficient policy support and technical barrier of carbon verification (Pudasaini et al., 2024). The long term benefits of carbon sequestering are often substantial, but, due to resource constraints, farmers (especially smallholders) often find it hard to adopt carbon sequestering practices. Additionally, the carbon sequestration verification remains still accurate and reliable, making it a big headache in bringing carbon credits and marred the credibility in carbon markets.

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The overall aim of this research is to evaluate the economic feasibility of carbon credit systems as other economic incentives to practice carbon sequestering practices i.e. Agroforestry and regenerative agriculture among farmers. This study then attempts to propose a means of integrating carbon sequestration incentives into global and regional agricultural policies by exploring these economic implications (T.M et al., 2023). The outcomes will help to inform how financial incentives can accelerate the adoption of sustainable farming practices that mitigate climate change by boosting the storage of carbon.

1.2. Current Challenges in Agricultural Carbon Sequestration

Carbon sequestration in agriculture is well known to have environmental benefits, but many barriers stand in the way of widespread implementation. The big obstacles include upfront costs to transition to carbon storing practices, little if any financial incentive, and the challenge in measuring and verifying carbon storage.

1.2.1. High Initial Costs

The cost of implementing carbon friendly farming practices is often prohibitively high. Agroforestry or regenerative agriculture is a huge investment and considerable land management, infrastructural and education change is required before an individual can even start to farm differently. In the case of agroforestry, for example, the planting and maintaining trees requires substantial capital, and land preparation, and tree planting, as well as ongoing care. Additionally, regenerative agriculture interventions, for example cover cropping or no till farming, often necessitate new equipment, require changes in how the farmers manage their operations and they involve more work, all of which add costs to farmers. A major barrier for smallholder farmers, who can rarely afford, and often don't have, access to capital, are these high upfront costs.

1.2.2. Lack of Financial Incentives

Despite the potential for carbon sequestration to grant long term financial benefits, like reduced fertilizer costs and increased crop yields, many farmers are not being incentivized to adopt sustainable practices because they do not receive immediate financial rewards. Without carbon credits or government subsidies, farmers will not invest in short term actions that may not produce immediate rewards (Bell, 2020). In addition, the current carbon credit market is not coherent and standardized, limiting the opportunities to earn carbon credits to some farmers, but not others. Barriers to participation are particularly created for farmers in areas where carbon markets are not well established, which this inconsistency can do.

1.2.3. Verification and Monitoring Issues

Measuring and verifying how much carbon agricultural systems sequester is difficult, and expensive. Farmers have to prove that they are capturing and storing a quantity of CO_2 that can be quantified by their agricultural practices. But developing reliable methods to measure soil carbon and verifying long term carbon sequestration is still in its infancy. Farmers may not want to get involved in carbon credit programs because there are no clear and consistent protocols for measuring and verifying their carbon. Further, monitoring of carbon sequestration can be prohibitive in terms of both cost and requisite technical expertise for small scale farmers.

1.2.4. Policy and Institutional Gaps

Carbon sequestration in agriculture could have a significant role in climate change mitigation, but the policy landscape for agriculture is still fragmented. Carbon credits and carbon sequestration global and regional policies are often inconsistent and farmers may find themselves confused or challenged to wade through different regulations and incentives. Carbon credit programs are not integrated as cleanly into agricultural policy in some areas, which prevents farmers from realizing financial rewards available through those programs (Buck & Palumbo-Compton, 2022). In addition, national and international efforts to encourage sustainable farming practices and carbon sequestration incentive systems are not coordinated, limiting scalability and effectiveness of the carbon credit systems.

1.3. The Role of Financial Incentives and Carbon Credit Systems

With carbon credits as one of the most effective mechanisms, carbon sequestration in agriculture has emerged. These market-based instruments permit farmers to financially receive remuneration for activities like agroforestry, and regenerative agriculture through carbon sequestering. Carbon credits can either be sold on global carbon markets or utilized to guarantee conformity in sectors that require emission reductions. Carbon credit systems fill this environmental sustainability gap by offering farmers an incentive to store carbon.

Besides carbon credits, other financial incentives include grants, subsidies, or tax exemptions that farmers stand to benefit from to offset the initial costs of establishing carbon sequestering practices. The incentives might minimize the farmers' financial risk while making them invest in proper farming systems.. Then, integrating carbon sequestration incentives into agricultural policies at the regional and global levels is a crucial first step towards scaling and the acceptable universal adoption of these practices.

1.4. Objectives of the Study

This study evaluates the economic feasibility of carbon credit systems and farm financial incentives for adoption of carbon sequestering practices by farmers. Particularly the research will analyze the economic value of carbon credit programs, such as revenue from carbon credits, cost savings from improved soil health, and crop revenue. The study will also examine market and technical and financial barriers to farmer adoption of carbon sequestration practices. Recommendations of using carbon sequestration incentives in international and regional agricultural policy and on developing an actionable framework to undertake such efforts through the introduction of sustainable agriculture on a broad scale will culminate the research.

2. Materials and Methods

2.1. Study Design

This study assessed economic viability of carbon sequestration incentives for farmers who adopt agroforestry, regenerative ag, and soil management for this study. Case studies have been used to acquire the data as well as from interviews of the farmers and by economic modeling. Our objective was to investigate the financial implications and inhibiting factors of carbon sequestering practices and the potential power of carbon credits to assist implement these practices.

2.2. Data Collection

Data were collected from two primary sources: From farmer interviews and publicly available economic reports. Fifty farmers from throughout the country, all in regions with established carbon credit systems, were interviewed. They were these farmers who would be doing regenerative agriculture, agroforestry, or some kind of small soil management for crops like corn, almonds and soybeans. Our interviews of farmers interested in implementing carbon sequestering practices focused on what the farmers experienced in putting that into play, what the economic outcome was (i.e. yield changes, cost savings), and what barriers they came across, for example, high upfront costs or lack of financial incentives.

The study also included the qualitative data from interviews along with the secondary data collected from the existing reports about the carbon credit markets, agriculture sustainability and the economic viability of sustainable farming practice. These data served as background information on the overall economic impacts of carbon sequestration and informed the analyse model used for the analysis.

2.3. Data Analysis

Statistical analysis in SPSS were used to analyze data in this study. The discussion included analysis of the economic benefits associated with the adoption of carbon sequestering practices: cost savings, and potential income from carbon credits and crop yield changes. The following steps were followed to assess the effectiveness of carbon sequestration incentives:

2.3.1. Economic Analysis:

Cost savings were summed in relation to an individual acre of adoption of agroforesty and regenerative practices to quantify economic impact. These savings were based on lower input costs (e.g., fertilizers and water use) and higher crop yields. Potential carbon credit revenues were further estimated at rate of sequestration in carbon. Payback periods were compared to the preliminary implementation costs of these values.

2.3.2. Statistical Methods

Descriptive statistics (mean, standard deviation) and regression analysis were used to analyze relationships based on adoption of carbon sequestering practices and economic outcome (e.g. cost saving, yield increase). Factors influencing the economic success of carbon sequestration practices, including farm size, crop type, and access to financial incentives, were identified using regression models. These statistical analyses were run in SPSS.

2.3.3. Data Visualization

SPSS was used to generate graphs and charts of the data for a clear and easy to understand presentation of the findings. Among these were pie charts showing the barriers to carbon sequestration adoption, and bar graphs of revenue potential from carbon credits by time. Through these illustrate economic viability and scalability of carbon sequestration in practice through agriculture.

2.3.4. Verification and Sensitivity Analysis

This was done to ensure the robustness of the results by performing sensitivity analysis on the key variables (carbon credit price, yield increase) and observing how variation of these variables affect the economic outcomes. This was able to assess the stability of the proposed financial models.

2.4. Limitations

Although the study presented some important economic measures of carbon sequestration incentives, there are also some limitations to be considered. Second, the data that were collected initially came from a small sample of farmers issue, which may not fully describe the situation for all coping contexts especially for smallholder farmers or for those in poorer regions. The second is that the potential income from carbon credits was based on average market prices, so the real income farmers could generate was subject to fluctuations in the carbon markets. Further, while the analysis via regression was informative, more information about carbon sequestration rates across different practices would be required to create more accurate modeling.

3. Results and Discussion

3.1. Economic Impact of Carbon Sequestration Practices

The economic analysis in Table 1, showed that the Carbon Sequestration practices taken such as agroforestry and regenerative agriculture offer farmers great benefits. And in examples of agroforestry systems, which combine trees with farming landscapes, the study found that the average income increases are about 20 percent to 30 percent. It had increased due to better crop yields in the soil from improved soil fertility and additional revenue from carbon credits (Mills et al., 2020). Based on this, on average farmers with agroforestry systems were earning \$30 to \$50 per acre of their land yearly as carbon credit.

The research determined that regenerative agriculture practices, including cover cropping and no-till farming, yielded cost savings of 15–25 percent in input costs (e.g., fertilizers, pesticides) and enhanced soil health. Over time these practices resulted in increased crop productivity (average yield increases of 15–25%). Reducing external input costs while increasing productivity provides steam to the boat to farmers embracing regenerative agriculture, as shown in Fig. 1.

Table 1. Economic Impact of Carbon Sequestration Practices

Practice	Initial Investment (USD/acre)	Cost Savings (%)	Income from Carbon Credits (USD/acre)	Yield Increase (%)
Agroforestry	$1,500–$2,500	10–20	$30–$50	20–30
Regenerative Agriculture	$1,000–$1,500	15–25	$10–$20	15–25
Soil Management	$500–$1,000	5–10	$5–$10	10–15

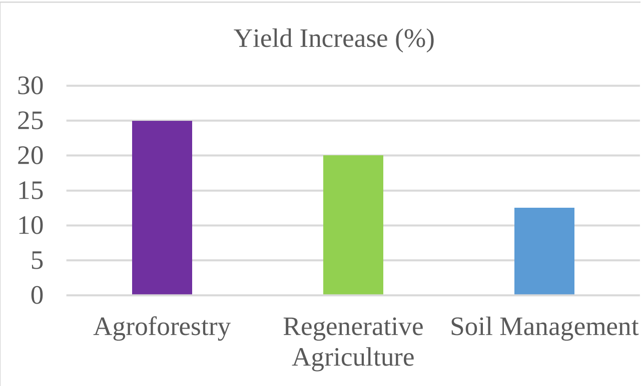

Fig. 1. Yield increase

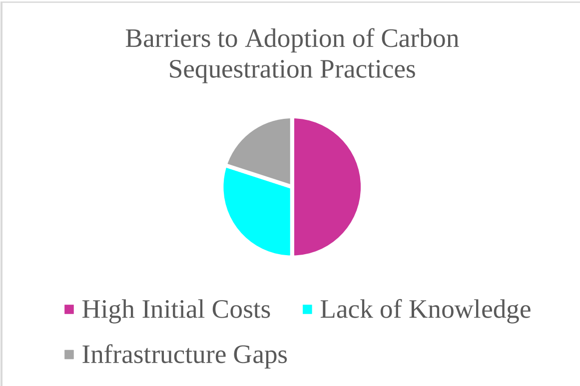

Fig. 2. Barriers to Adoption of Carbon Sequestration Practices

3.2. Barriers to Adoption

While the economic benefits are clear, there are several barriers to general adoption of carbon sequestration practices on farms, shown in Fig. 2. The greatest challenges are yet to be high upfront costs. Agroforestry systems and regenerative agriculture investment initial investments range between $1,500 -$ 2,500 per acre. These costs are too high for small hold farms to handle without outside help. Further aggravating this problem is the lean on incentives, like subsidies and grants, in this arena.

Meanwhile, verification and monitoring of carbon sequestration are much more complex and expensive. Without a standardized and reliable way to measure carbon storage, farmers may be reluctant to participate in carbon credit programs, worrying that they won't receive the credits or that the credits will be hard to verify. This puts a cap on farmers' trust in carbon credit markets.

3.3. Policy Recommendations

To face barriers and encourage carbon sequestration practices, a number of policy recommendations were made. First, the initial investment costs for carbon sequestration practices should be tentatively offset by financial incentives. Subsidies, grants and low interest loans are offered to farmers to give them incentives to adopt agroforestry and regenerative farming. Second, the verification processes of carbon credits should be standardized so that it becomes easy for farmers to earn and trade their credits. To ensure credible credits from the credits farmers generate and to increase their participation in carbon markets, simplified and reliable monitoring systems will be developed.

Carbon sequestration incentives can be integrated into existing agricultural policies, like the U.S. Farm Bill or the EU's Common Agricultural Policy, to simplify their adoption. This will be achieved through offering motorists with clear guidelines and incentives within set frameworks for such carbon sequestration to be incorporated into regular farming practices by farmers.

3.4. Environmental Impact and Long-Term Benefits

Correspondingly, there is also significant environmental benefit from adoption of carbon sequestration practices, presented in Fig. 3. Emphasizing the role of agroforestry systems in sequestering large amounts of carbon across the biomass and soil, this reduces atmospheric CO_2 levels. When soils are better managed through regenerative agriculture, farmers are able to increase soil organic matter, improving the soil's ability to retain water and store carbon. They also help increase biodiversity, and reduce soil erosion and therefore, improve the resilience of agricultural systems.

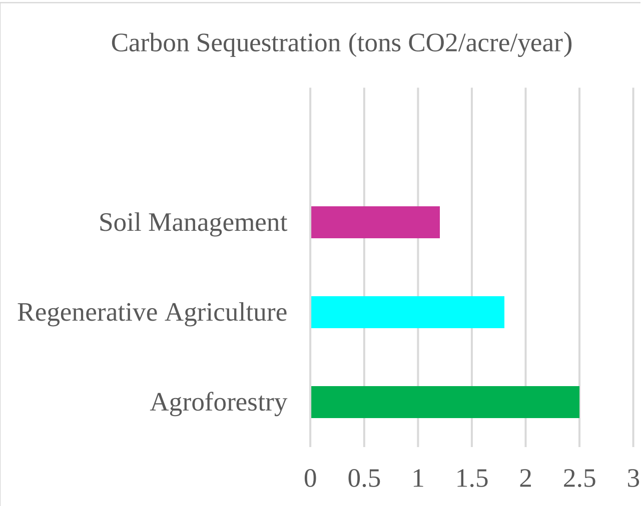

Fig. 3. Carbon Sequestration Potential by Practice

4. Conclusion

The results of this study show that economic and environmental benefits associated with the sequestration of carbon exist for agroforestry and of similar practices in general. These practises are taken by farmers which helps them to reduce input costs, improves crop yields and also generates new sources of income through carbon credits. Nevertheless some barriers to widespread adoption include the high investment initial costs, lack of financial incentives, and barriers to carbon credit verification. These obstacles need to be overcome with policy interventions, e.g., improvements of the financial incentives for uptake of CCS, the simplification of verification methods and the integration of carbon sequestration incentives into existing agricultural policies. The results suggest that carbon sequestration practices can be an important tool to counteract climate change while safeguarding agricultural sustainability when properly promoted. Governments can help steer farmers towards more sustainable farming systems, by supporting these practices through targeted policies.

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