AGRICULTURAL POWER JOURNAL
Vol. 3 No. 4, November 2026
Page 27 – 43 | e-ISSN: 3062-8563

Carbon-Smart Agriculture and Farm Profitability: A Systematic Literature Review of Economic and Environmental Trade-offs

Riyanti [1]*, Anita Ninasari [2], Nyahu Rumbang [3], Agus Suprapto [4] and Sevindrajuta [5]
[1] Universitas Amir Hamzah, Indonesia, [2] Universitas Khairun Ternate, Indonesia, [3] Universitas Palangkaraya, Indonesia, [4] Universitas Tidar, Indonesia,
[5] Universitas Muhammadiyah Sumatera Barat, Indonesia
* Correspondence: riyantihasim@gmail.com

ABSTRACT

Carbon-smart agriculture is promoted as a way to reduce greenhouse gas emissions while sustaining farm income, yet evidence on when this dual benefit materializes remains fragmented. This study synthesizes the conditions under which carbon-smart practices are profitable or unprofitable and the economic–environmental trade-offs involved. A Systematic Literature Review (SLR) of 15 publications (2021–2026) was analyzed using thematic content analysis and a synthesis matrix; quantitative results are reported in their original units. Adoption studies reported higher farm income, for example 20.3% higher income per hectare in southern Ethiopia and about 40% in drought-prone India. Modeling studies indicated that regional emissions from irrigated cropping in Australia could fall by up to 50% without reducing total gross margins, and that carbon sequestration on farmland could generate up to USD 375 billion in additional producer revenue at USD 160 per tCO_2e. These benefits are conditional on input-use efficiency, practice combinations, transition and verification costs, farm characteristics, and credible carbon payment systems, and capital-intensive practices tend to be viable only with incentives. Economic and environmental benefits should be assessed jointly rather than assumed to coincide. The evidence is dominated by observational studies of climate-smart agriculture in general, and carbon-specific farm-level cost data remain scarce.

Keywords: carbon-smart agriculture; carbon farming; farm profitability; systematic literature review; economic–environmental trade-offs

Article Information
Received: October 12, 2026
Revised: November 10, 2026
Online: November 23, 2026

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Agricultural Power Journal, November **2026**, Vol 3, No 4

1. Introduction

Agriculture plays an important role in supporting food security, rural livelihoods, and economic development. However, agricultural activities are also closely associated with environmental degradation and greenhouse gas (GHG) emissions. The use of synthetic fertilizers, intensive soil cultivation, livestock production, land-use changes, and inefficient resource management can contribute to GHG emissions and reduce the long-term sustainability of agricultural systems. At the same time, farmers face increasing pressure to maintain productivity and profitability under changing climatic and economic conditions. Agricultural practices that integrate economic efficiency and environmental protection are therefore increasingly necessary to support sustainable agricultural development [1,2].

Three related concepts are used in this literature, and this article adopts the following working distinction. Climate-smart agriculture (CSA) is the broadest: it seeks to increase agricultural productivity and incomes, strengthen resilience to climate change, and reduce or remove GHG emissions where possible [3], and its economic benefits for farm households have been examined empirically [4]. Carbon farming focuses on increasing carbon stocks in soils and biomass, or reducing emissions, in ways that may generate carbon credits or payments for environmental services [5–7]. Carbon-smart agriculture sits between the two: it retains the profit objective of CSA but places greater emphasis on reducing the carbon intensity of agricultural production, improving carbon sequestration, and increasing the efficiency of resource use [1]. Typical practices include improved soil management, conservation agriculture [8], agroforestry, optimized fertilizer application, and residue management. Its distinguishing characteristic is that economic and carbon outcomes are evaluated together, at the farm or regional level, rather than in isolation.

Previous research reports mostly positive but variable outcomes. Studies of climate-smart practices associate adoption with higher farm income, productivity, and resilience in Ethiopia, India, and elsewhere [9–11]. Carbon farming has been discussed as a framework for augmenting carbon sinks while maintaining agricultural production [12], but its financial attractiveness depends on implementation costs, carbon prices, and measurement and verification requirements, and the suitability of soil carbon certificates as a mitigation tool has itself been examined [13]. Research on the adoption of multiple climate-smart technologies shows that adoption can affect both productivity and net farm income [14], and a recent systematic review reports substantial heterogeneity in the economic performance of carbon farming practices [15]. Results are therefore not additive: the economic outcomes of conservation-oriented practices, for example, are not consistent across farming systems because farm size, soil conditions, input prices, crop types, and management influence profitability [8].

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Existing syntheses leave several gaps. Reviews of climate-smart agriculture cover productivity, income, resilience, and emission outcomes across a broad set of practices [2], whereas a recent systematic review of carbon farming concentrates on the economic trade-offs of carbon farming practices [15]. Primary studies, in turn, tend to examine either environmental outcomes (GHG mitigation and carbon sequestration) or economic outcomes (farm income, productivity, and adoption behavior), and rarely both. Although various studies have examined climate-smart agriculture, carbon farming, and conservation agriculture, the evidence on the conditions under which carbon-smart practices yield economic and environmental benefits simultaneously remains fragmented. In particular, the relationships among input-use efficiency, transition costs, productivity changes, and carbon-related income have not been synthesized within a single analytical framework. This matters for policy, because policies that focus only on emission reduction may achieve limited adoption if they do not address farmers' economic incentives and constraints [4].

This study therefore synthesizes recent evidence to answer three research questions. RQ1: through which mechanisms does carbon-smart agriculture affect farm profitability, and under what conditions is it profitable or unprofitable? RQ2: what environmental outcomes does it deliver, and what trade-offs exist between economic and environmental outcomes? RQ3: which barriers and enabling factors determine the feasibility of adoption by farmers? The article contributes to the literature in three ways. First, it distinguishes four profitability mechanisms (lower input costs, higher yields, reduced risk of production loss, and carbon-related revenue) and shows that they do not necessarily occur together. Second, it compiles quantitative results from the reviewed studies in a synthesis matrix with their original units and study designs, separating observational, modeling, and review evidence. Third, it identifies the conditions and institutional factors that determine whether environmental benefits translate into economic value for farmers, and it derives a research agenda from the gaps identified.

2. Materials and Method

This study employed a qualitative approach using a Systematic Literature Review (SLR) to examine the role of carbon-smart agriculture in improving farm profitability and environmental sustainability. The SLR design was selected to identify, screen, and synthesize relevant scientific literature on the economic and environmental contributions of carbon-smart agricultural practices in a structured and transparent way. The review proceeded in four stages: identification of records in academic databases, screening against the inclusion and exclusion criteria, full-text eligibility assessment, and data extraction and synthesis.

The search covered peer-reviewed journal articles published between 2022 and 2026. Relevant articles were identified through academic databases, including ScienceDirect,

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SpringerLink, Wiley Online Library, Taylor & Francis Online, Frontiers, MDPI, and Google Scholar. The search combined three keyword groups with Boolean operators: concept terms ("carbon-smart agriculture," "carbon farming," "climate-smart agriculture"), economic terms ("farm profitability," "farm income"), and environmental terms ("carbon sequestration," "greenhouse gas emissions," "environmental sustainability"). These keywords were used to identify publications addressing the relationship between agricultural practices, economic performance, and environmental outcomes.

Inclusion criteria were peer-reviewed journal articles published within the search window that address at least one of three research dimensions: carbon-smart agricultural practices, farm profitability or income, and environmental sustainability. Exclusion criteria were studies unrelated to agricultural production, studies that did not discuss economic or environmental outcomes, and publications that were not peer-reviewed. One earlier study published in 2021 was retained deliberately as a foundational source because it introduces the carbon-smart agriculture concept [1]. The final corpus therefore consists of 15 publications: 14 articles published between 2023 and 2026 and one foundational study from 2021. The reference list contains exactly these 15 items, and no article published in 2022 met the criteria. The corpus is deliberately focused. It is intended to support an in-depth thematic synthesis of a narrowly defined topic, namely carbon-smart practices evaluated jointly for economic and environmental outcomes, rather than an exhaustive census of the climate-smart agriculture literature. The implications of its size are discussed in Section 4.5.

Data were extracted into a synthesis matrix recording, for each study, the practice or focus, setting and design, economic indicators, environmental indicators, key findings, and limitations (Table 1). The selected literature was then analyzed using thematic content analysis in four steps. First, each study was read in full and its findings were coded. Second, the codes were grouped according to their relevance to the research questions into three main themes: (1) carbon-smart agricultural practices and farm profitability, (2) carbon-smart agriculture and environmental sustainability, and (3) barriers and enabling factors affecting adoption. Third, within each theme the findings were compared across studies to identify common patterns, differences in findings, and the conditions under which results diverged. Fourth, the themes were integrated to examine the relationship between economic and environmental outcomes. Quantitative results are reported in their original units and were not pooled, because outcome definitions, units, and study designs differ too widely for a meta-analysis. No formal risk-of-bias scoring was applied; instead, the study design is reported alongside each finding so that the strength of the evidence can be judged.

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3. Results

Table 1 summarizes the 15 reviewed studies. The corpus combines household and farm surveys, a field experiment, modeling studies, and review articles, covering Asia, Africa, Europe, Australia, the United States, and global assessments. Explicit quantitative economic results come mainly from studies of climate-smart agriculture adoption [4,9,10], while carbon-related economic and environmental results come mainly from modeling studies [1,5,6].

Table 1. Synthesis matrix of the 15 reviewed studies (results are given in the units reported by each study).

Ref.	Practice / focus; setting	Design	Economic indicators and key results	Environmental indicators and key results	Limitations noted
[1]	Integrated regional use of land and water in irrigated cropping; Australia	Regional trade-off (optimization) model	Total gross margin: up to 50% lower GHG emissions at regional level without reducing total gross margins	GHG emissions; surplus land and water available for environmental planting; further cuts need a higher carbon price or water markets that value water more	Model-based; single regional test case
[2]	Climate-smart practices; global literature 2013–2023	Comprehensive review	Productivity, income, and efficiency improved in many instances	GHG emissions reduced; soil quality improved	Secondary evidence on CSA in general; benefits not universal
[3]	CSA adoption and impacts; overview of a 19-paper special issue	Overview / synthesis	Adoption linked to higher yields, farm income, and economic diversification	Improved resilience and GHG mitigation	Summarizes other studies; no independent estimate
[4]	Seven CSA practices; 1,785 grain households, China	Household survey; 2SRI and IV-quantile regression	Per additional adoption level: +4.12 (household income) and +4.30 (net farm income) thousand yuan per capita (sample means 16.84 and 7.03); income diversity +0.04 (weak)	Not assessed	Cross-sectional; no environmental outcome
[5]	Carbon sequestration options on agricultural land; global	Economic land-use (scenario) model	Up to USD 375 billion additional producer revenue at USD 160/tCO_2e; net-zero in agriculture, forestry and other land use by 2050 at about USD 80–120/tCO_2e; GDP +0.6%	Mitigation potential comparable to afforestation by 2050, mostly in the Global South	Global scenarios; needs efficient institutions and monitoring within about five years

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Ref.	Practice / focus; setting	Design	Economic indicators and key results	Environmental indicators and key results	Limitations noted
[6]	Cover crops and no-till under carbon payment schemes; USA	Economic scenario analysis	Profitable for farmers but with strong geographic variability; depends on payment type, payment level relative to out-of-pocket costs, and sequestration information	Annual sequestration of 17–75 $MtCO_2e$	US-specific; scenario assumptions
[7]	Soil-based carbon farming; collaboration opportunities	Qualitative / institutional analysis	Institutional and collaborative arrangements shape feasibility; no quantitative indicator extracted	Soil carbon	Not quantified
[8]	Conservation agriculture vs. conventional tillage; Northern Italy	Field experiment; data envelopment analysis	Profitability compared with conventional practice; best management practice identified; context-dependent	Soil organic carbon sequestration and its timing	One experiment; context-specific
[9]	CSA practices; southern Ethiopia	Household survey; propensity score matching	Adopters: 20.3% higher annual farm income per hectare; food consumption score 6.27–8.15 points higher	Not assessed	Observational; single region
[10]	Climate-resilient technologies and advisories; drought-prone Karnataka, India	Village survey (60 farmers per group); difference-in-differences	Farm income about 40% higher; Rs 54,717 higher in a drought year	Not assessed	Small sample; one intervention and one comparison village
[11]	CSA practices under a state program targeting +25% productivity and +20% income; semi-arid Karnataka, India	Impact evaluation of farmer income	Income effect of adoption assessed against program targets	Not assessed	Regional; results not extracted here
[12]	Carbon farming as a circular framework to augment CO_2 sinks	Review / conceptual framework	No economic indicator extracted	Carbon sinks; soil fertility, water retention, nutrient cycling	Conceptual
[13]	Soil carbon certificates in carbon farming	Review / assessment	Measurement and verification costs affect participation, especially of smaller farms	Soil carbon mitigation	Focus on certification

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Ref.	Practice / focus; setting	Design	Economic indicators and key results	Environmental indicators and key results	Limitations noted
[14]	Zero tillage, row planting, drought-resistant seed (combinations); 3,197 maize farmers, Ghana	Survey; multinomial endogenous switching regression	Row planting + zero tillage: largest net farm income effect; all three together: largest maize yield effect	Not assessed	Observational; one crop
[15]	Economic trade-offs of carbon farming practices; global literature	Systematic literature review (46 studies)	Substantial heterogeneity in economic performance; capital-intensive practices viable only with incentives or well-structured carbon markets	None extracted	Review of economic dimension only

3.1. Carbon-Smart Agriculture and Farm Profitability

The literature review indicates that carbon-smart agriculture can contribute to farm profitability through improvements in resource-use efficiency, productivity, and production cost management. Practices such as optimized fertilizer application, conservation agriculture, improved soil management, and integrated farming systems can reduce inefficient input use while maintaining or improving agricultural productivity [2]. The economic benefits, however, vary depending on farm characteristics, production systems, and farmers' access to technology and supporting resources [3].

Quantitative income evidence is concentrated in observational studies of climate-smart practices (Figure 1a). In southern Ethiopia, adopters earned 20.3% higher average annual farm income per hectare than non-adopters (propensity score matching) and had food consumption scores 6.27–8.15 points higher [9]. In drought-prone villages of Karnataka, India, farm income in the intervention village was about 40% higher than in a comparable village, and treated households earned Rs 54,717 more than the control group during a drought year (difference-in-differences; 60 farmers per group) [10]. In China, among 1,785 grain-farming households, each additional level of adoption intensity was associated with 4.12 thousand yuan higher per-capita household income and 4.30 thousand yuan higher per-capita net farm income, against sample means of 16.84 and 7.03 thousand yuan [4]. In Ghana, among 3,197 maize farmers, adopting all three technologies together had the largest effect on maize yields, whereas the combination of row planting and zero tillage had the largest effect on net farm income [14].

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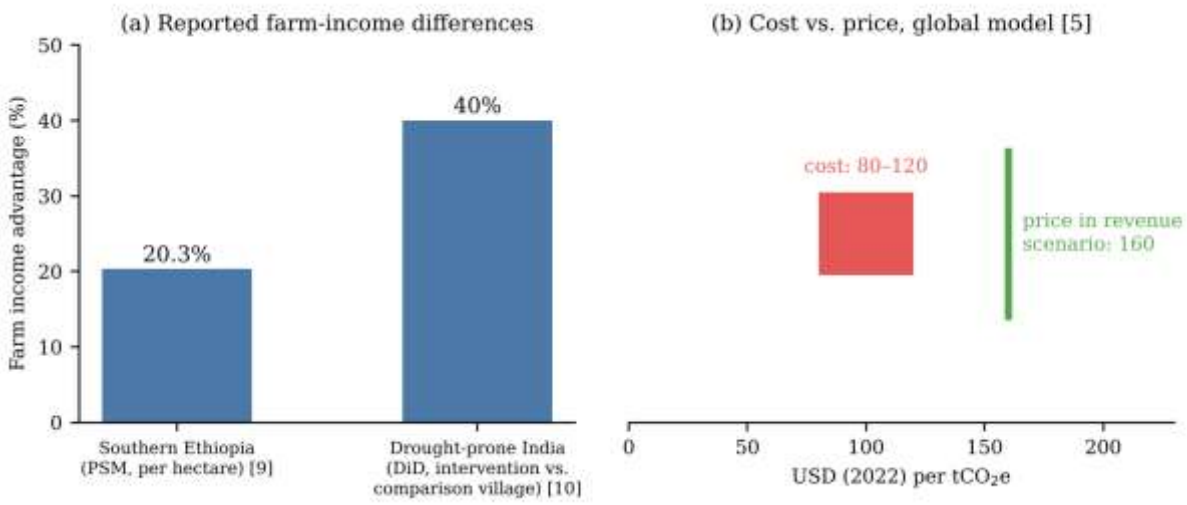

Figure 1. Quantitative economic results extracted from the reviewed studies: (a) reported farm-income differences between adopters (or treated villages) and comparison groups [9,10]; (b) mitigation cost and carbon price in the global scenario analysis [5]. Values are as reported by the original studies, are not directly comparable, and cost data in comparable units were rarely available.

Carbon-smart agriculture can also improve profitability by reducing farmers' dependence on inefficient or excessive input use. Better soil management can improve nutrient utilization and water retention, potentially reducing production costs over time. Conservation agriculture, for example, can provide both economic and environmental benefits through improved resource efficiency and reduced environmental pressure [8]. However, the transition toward carbon-smart practices may require initial investment, additional labor, or changes in established production methods, which can limit short-term financial benefits. Therefore, the contribution of carbon-smart agriculture to farm profitability should be considered from both short-term and long-term perspectives. Although implementation may initially increase production expenses, improvements in input efficiency, soil conditions, and agricultural productivity may provide economic benefits over time.

3.2. Carbon Sequestration and Environmental Sustainability

The reviewed literature shows that carbon-smart agriculture contributes to environmental sustainability primarily through carbon sequestration and greenhouse gas emission reduction. Agricultural practices that increase soil organic carbon, improve soil management, and maintain vegetation cover can strengthen the capacity of agricultural land to function as a carbon sink [5]. Carbon farming therefore provides an opportunity to connect agricultural production with climate change mitigation.

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Soil-based carbon management also provides environmental benefits beyond carbon storage. Improved soil organic matter can contribute to soil fertility, water retention, nutrient cycling, and ecosystem functioning. Carbon farming has consequently been proposed as a broader framework for increasing carbon sinks while maintaining productive agricultural systems [12]. These environmental improvements can support the long-term productive capacity of agricultural land. This indicates that soil carbon management has an important role in maintaining the ecological conditions required for sustainable agricultural production. Improvements in soil quality can support the availability of natural resources while reducing the environmental pressures associated with agricultural activities.

Conservation agriculture provides another important pathway for improving environmental performance. Reduced soil disturbance, improved soil cover, and more efficient resource management can contribute to lower environmental impacts while maintaining agricultural productivity [8]. The findings indicate that environmental sustainability is not limited to emission reduction but also includes the preservation of soil quality and agricultural resources. The combination of carbon sequestration, soil conservation, and efficient resource utilization demonstrates that carbon-smart agriculture can contribute to broader environmental improvements. These practices support the maintenance of agricultural ecosystems while strengthening their capacity to sustain production in the long term.

Quantitative environmental results come mainly from modeling studies. A regional optimization of land and water use for irrigated crops in Australia indicated that GHG emissions could fall by up to 50% without reducing total gross margins, while surplus land and water became available for environmental planting [1]. At global scale, enhanced carbon sequestration on agricultural land was projected to reach a cumulative mitigation potential comparable to afforestation by 2050 at USD 160 per tCO_2e, with most of the potential located in the Global South [5]. In the United States, annual sequestration from cover crops and no-till under carbon payment schemes was estimated at 17–75 million tCO_2e [6]. Experimental evidence is more limited: one field experiment in Northern Italy assessed the timing of soil organic carbon sequestration together with the profitability of conservation agriculture [8].

3.3. Economic and Environmental Benefits of Carbon Farming

The literature suggests that carbon farming can create a connection between environmental improvements and additional economic opportunities. Increasing carbon sequestration may allow farmers to participate in carbon markets or environmental service programs, potentially generating supplementary income [5]. However, the realization of these benefits depends on the availability of credible carbon measurement, reporting, verification, and payment mechanisms.

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The economic scale of these opportunities is large in global scenarios but uncertain at farm level. At a carbon price of USD 160 per tCO_2e, producers worldwide could earn up to USD 375 billion in additional revenue, and net-zero emissions in agriculture, forestry and other land use by 2050 would cost about USD 80–120 per tCO_2e [5]. In the United States, agricultural carbon markets could be profitable for farmers, but with substantial geographic variability that depends on payment design, payment levels relative to out-of-pocket costs, and the availability of sequestration information [6].

The business feasibility of carbon farming is influenced by the balance between implementation costs and potential carbon-related revenues. Farmers may incur costs associated with changing production practices, monitoring carbon outcomes, obtaining certification, and participating in carbon markets [6]. Consequently, carbon farming does not automatically increase profitability, particularly when transaction costs and verification requirements are high. This finding highlights that the potential financial benefits of carbon farming depend not only on the amount of carbon sequestered but also on the economic feasibility of participating in carbon-related programs. When implementation and verification costs exceed the potential financial returns, farmers may have limited incentives to adopt these practices.

The reviewed studies indicate that economic incentives can play an important role in encouraging farmers to adopt carbon-smart practices. Financial support, technical assistance, carbon payments, and access to appropriate markets can reduce adoption barriers and increase the economic attractiveness of sustainable agricultural practices [4]. This indicates that institutional support is an important component in translating environmental benefits into tangible economic outcomes for farmers. Accordingly, the integration of environmental objectives with appropriate financial incentives can strengthen the relationship between carbon farming and farm profitability. Accessible carbon markets and effective support mechanisms are particularly important in ensuring that farmers can obtain economic value from their contributions to environmental sustainability.

3.4. Carbon-Smart Agriculture and Farm Resilience

Another important finding is the contribution of carbon-smart and climate-smart practices to farm resilience. Farmers operating under drought, changing rainfall patterns, or other climatic pressures may experience unstable production and income. The adoption of climate-smart practices can help reduce vulnerability by improving resource efficiency and strengthening the capacity of farming systems to withstand environmental shocks [10].

Improved farm resilience can indirectly support profitability because more resilient production systems may reduce the risk of substantial production losses. Studies on climate-

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smart agriculture indicate that income and food security outcomes can improve when farmers have sufficient access to technology, knowledge, and productive resources [9]. Therefore, the economic contribution of carbon-smart agriculture can extend beyond immediate increases in farm income to include greater stability of agricultural production. The findings suggest that farm resilience is an important factor connecting environmental sustainability with economic performance. Agricultural systems that are better able to manage climatic pressures may experience more stable production conditions, helping farmers maintain their income and reduce potential economic losses.

3.5. Barriers to Adoption

Despite the potential benefits, the literature identifies several barriers to the adoption of carbon-smart agriculture. The most common barriers include high initial investment, limited access to technology and information, insufficient technical knowledge, uncertain financial returns, and inadequate institutional support [3]. These constraints are particularly relevant for farmers with limited financial and technological capacity.

The costs associated with carbon measurement and verification can also create challenges for participation in carbon markets. Carbon farming requires reliable systems for measuring changes in carbon stocks and demonstrating environmental outcomes. Without accessible and affordable mechanisms, smaller farms may have difficulty participating in carbon-related programs [13]. These conditions can create differences in adoption opportunities between farmers with sufficient financial and technological resources and those with more limited capacities. Consequently, the availability of affordable measurement and verification systems is important for expanding farmers' participation in carbon farming initiatives.

In addition, farmers may be reluctant to adopt new practices when the economic benefits are uncertain or occur over a longer period. The literature on carbon farming emphasizes the importance of evaluating economic trade-offs between implementation costs, productivity effects, and potential carbon-related revenues [15]. Consequently, policies designed to promote carbon-smart agriculture need to consider both environmental objectives and farmers' financial realities. The findings demonstrate that the adoption of carbon-smart agriculture is influenced not only by its environmental advantages but also by the certainty of economic returns. Therefore, reducing financial risks, improving access to information, and providing technical assistance are important measures to encourage farmers to implement sustainable agricultural practices.

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3.6. Integrated Results

Overall, the literature indicates that carbon-smart agriculture can contribute to both farm profitability and environmental sustainability, but the relationship depends on the conditions under which practices are implemented. The main economic pathways include improved resource-use efficiency, productivity gains, lower long-term production costs, increased resilience, and potential additional income from carbon-related markets [5].

From the environmental perspective, the main outcomes include increased carbon sequestration, reduced greenhouse gas emissions, improved soil quality, better resource conservation, and greater resilience of agricultural ecosystems [12]. However, these benefits can be constrained by adoption costs, technological limitations, market uncertainty, and insufficient institutional support.

Table 2 summarizes the conditions that favor or limit profitability across the reviewed studies.

Table 2. Conditions under which carbon-smart practices tend to be profitable or unprofitable, as identified in the reviewed studies.

Dimension	Conditions favoring profitability	Conditions limiting profitability	Refs.
Input and resource efficiency	Reduced inefficient input use; optimized use of land and water	Gains vary with farm size, soil conditions, input prices, crop types, and management	[1,8]
Practice combinations	Combinations of complementary technologies; higher adoption intensity	Single practices or low adoption intensity; limited market access and resources	[4,14]
Transition costs and timing	Long-term savings and soil improvement that accumulate over time	Initial investment, additional labor, and transition periods before benefits appear	[7,8,15]
Carbon revenue	Credible measurement and verification; payments that exceed out-of-pocket costs; high enough carbon prices	High transaction and verification costs; uncertain carbon prices; capital-intensive practices without incentives	[5,6,13,15]
Farm characteristics	Adequate knowledge, resources, and technology access	Limited technology, financing, and knowledge, particularly among small and medium-scale farmers; unequal gains across income levels	[4,7]
Institutional support	Extension services, farmer organizations, credit, information, and efficient monitoring institutions	Weak institutions and absent support services	[3,5,9,14]

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4. Discussion

4.1. Mechanisms for Generating Profitability

The reviewed studies point to four mechanisms through which carbon-smart practices can raise profit, and these need to be distinguished because they do not necessarily occur together. The first is lower input cost: improved fertilizer management, conservation agriculture, and optimized use of land and water reduce inefficient input use while maintaining productivity [1,8]. The second is higher yield or productivity, which is documented mainly in adoption studies and is strongest when practices are combined [9,14]. The third is a reduced risk of production loss: climate-smart interventions were associated with higher farm income in a drought year [10], so profitability is partly a matter of income stability rather than average income alone. The fourth is additional revenue from carbon markets and payments for environmental services, which depends on measurement, verification, and payment systems [5,6]. The farm-level adoption studies in the corpus report effects on yield and income [4,9,10,14] and, on the evidence extracted for this review, do not isolate carbon revenue; the fourth mechanism is supported mainly by modeling and scenario analyses [5,6]. A practice can therefore improve profit through one mechanism, for example, lower fertilizer cost, while remaining unprofitable on the others, and any claim that carbon-smart agriculture is profitable should specify which mechanism is at work.

4.2. Economic and Environmental Trade-offs

Environmentally beneficial practices can require initial investment, equipment, additional labor, or a transition period before benefits appear [7,15]. Long-term benefits can offset these costs when improvements in soil health, resource efficiency, and productivity accumulate [8], when carbon payments cover out-of-pocket costs [6], or when carbon prices are high enough, as in the global scenario in which sequestration generates large producer revenue at USD 160 per tCO_2e while net-zero emissions in agriculture, forestry and other land use cost about USD 80–120 per tCO_2e [5]. The regional Australian analysis shows that emission reductions of up to 50% were achievable without lowering total gross margins, but further reductions without trade-offs required a higher carbon price or water markets that ensure higher-value water use [1]. Conversely, capital-intensive practices were viable only with appropriate incentives or well-structured carbon markets [15]. The reviewed evidence does not allow a general threshold to be stated: whether long-term benefits offset transition costs depends on the practice, the payment design, and local costs.

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4.3. Dependence on Farm-Level Context

Outcomes vary with crop type, farm size, soil conditions, climate, production system, and market access, and findings from one region should not be generalized to all agricultural systems. The profitability of conservation agriculture differs with farm size, soil conditions, input prices, crop types, and management [8]. The magnitude of income effects differs across settings, from 20.3% higher income per hectare in southern Ethiopia [9] to about 40% in drought-prone villages in India [10], and effects are not distributed evenly within a setting: in China, the effect of adoption intensity on household income increased across the income distribution, whereas its effect on net farm income decreased across the net-farm-income distribution [4]. Carbon revenue also varies geographically, as US carbon markets were profitable for farmers but with substantial geographic variability [6]. In addition, the studies differ in what they measure (income per hectare, per capita, or per household; single practices or bundles), which limits direct comparison.

4.4. Institutional Aspects and Adoption Feasibility

Whether environmental benefits translate into economic value depends on institutions. Extension services, training, membership in farmer organizations, land tenure security, access to information, and access to credit consistently support the adoption of climate-smart practices [3], and farmer-organization membership and education influenced technology adoption in Ghana [14]. Effective extension services, accurate climate information, and sound policy support were identified as requirements for scaling up climate-smart practices in southern Ethiopia [9]. For carbon farming, the costs of measurement, reporting, and verification, together with payment design, determine whether smaller farms can participate [6,13]. At global scale, realizing the revenue and mitigation potential of agricultural carbon sinks was found to require efficient institutions and monitoring systems [5]. Policies that focus only on emission targets without addressing farmers' economic constraints risk low participation [4].

4.5. Limitations of the Review

Four limitations qualify these findings. First, a corpus of 15 publications is small for a systematic review; it supports an in-depth synthesis of a narrowly defined topic but not exhaustive coverage, and additional studies could change the balance of the evidence. Second, the corpus is heterogeneous, mixing household surveys, modeling studies, a field experiment, and reviews, so outcomes are not comparable in units and were not pooled. Third, most income evidence concerns climate-smart agriculture in general rather than practices explicitly designed as carbon-smart, and it is observational and cross-sectional, which limits causal interpretation; carbon revenue is supported mainly by modeling studies. Fourth, no formal quality appraisal

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was applied, and publication bias toward positive results cannot be excluded. Compared with earlier reviews [2,15], the contribution of this study lies in the joint, condition-based reading of economic and environmental evidence rather than in greater coverage.

5. Conclusions

This study set out to establish how, and under what conditions, carbon-smart agriculture supports farm profitability and environmental sustainability. Across the 15 reviewed publications, the economic mechanisms identified are lower input cost through efficient resource use, higher yields or productivity, reduced exposure to production losses, and additional carbon-related revenue, the last of which is supported mainly by modeling studies. Adoption studies report farm income gains of about 20% per hectare in southern Ethiopia [9] and about 40% in drought-prone India [10], while modeling suggests that regional emissions from irrigated cropping can fall by up to 50% without lowering total gross margins [1].

These benefits are conditional. They are facilitated by adopting complementary practices rather than single ones, by gains in input-use efficiency, by carbon payments that exceed out-of-pocket costs, and by credible measurement and verification. They are constrained by initial investment, additional labor and transition periods, high transaction and verification costs, uncertain carbon prices, and farm characteristics, and capital-intensive practices tend to be viable only with incentives [15].

The feasibility of adoption by farmers depends on education, membership in farmer organizations, and access to extension services, information, credit, technology, and markets, as well as on the certainty of economic returns [3,9,14]. Smaller farms are particularly exposed to the costs of carbon measurement and verification [13].

For policy, support should combine extension, finance, and affordable measurement and verification with carbon payments designed around farmers' costs, because emission targets alone may not secure participation [4]. Future research should estimate the profitability and carbon outcomes of specific carbon-smart practices jointly using farm-level data, report costs in comparable units, compare crops, farm sizes, and regions, and examine the long-term financial feasibility of carbon farming and the role of carbon-market incentives in farmer participation. Studies that apply a common economic and carbon accounting framework would allow the quantitative synthesis that was not possible here.

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References

1. Maraseni, T.; An-Vo, D.-A.; Mushtaq, S.; Reardon-Smith, K. Carbon smart agriculture: An integrated regional approach offers significant potential to increase profit and resource use efficiency, and reduce emissions. *J. Clean. Prod.* 2021, 282, 124555. https://doi.org/10.1016/j.jclepro.2020.124555
2. Zheng, H.; Ma, W.; He, Q. Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: A comprehensive review. *Mitig. Adapt. Strateg. Glob. Change* 2024, 29, 28. https://doi.org/10.1007/s11027-024-10124-6
3. Ma, W.; Rahut, D.B. Climate-smart agriculture: Adoption, impacts, and implications for sustainable development. *Mitig. Adapt. Strateg. Glob. Change* 2024, 29, 44. https://doi.org/10.1007/s11027-024-10139-z
4. Sang, X.; Chen, C.; Hu, D.; Rahut, D.B. Economic benefits of climate-smart agricultural practices: Empirical investigations and policy implications. *Mitig. Adapt. Strateg. Glob. Change* 2024, 29, 9. https://doi.org/10.1007/s11027-024-10104-w
5. Frank, S.; Augustynczik, A.L.D.; Havlík, P.; et al. Enhanced agricultural carbon sinks provide benefits for farmers and the climate. *Nat. Food* 2024, 5, 742–753. https://doi.org/10.1038/s43016-024-01039-1
6. Plastina, A.; Jo, H.; Wongpiyabovorn, O. The business case for carbon farming in the USA. *Carbon Balance Manag.* 2024, 19, 7. https://doi.org/10.1186/s13021-024-00253-5
7. Baumber, A.; Cross, R.; Ampt, P.; et al. Soil-based carbon farming: Opportunities for collaboration. *J. Rural Stud.* 2024, 108, 103268. https://doi.org/10.1016/j.jrurstud.2024.103268
8. Lorenzetti, L.A.; Fiorini, A. Conservation agriculture impacts on economic profitability and environmental performance of agroecosystems. *Environ. Manag.* 2024, 73, 532–545. https://doi.org/10.1007/s00267-023-01874-1
9. Belay, A.; Mirzabaev, A.; Recha, J.W.; et al. Does climate-smart agriculture improve household income and food security? Evidence from Southern Ethiopia. *Environ. Dev. Sustain.* 2024, 26, 16711–16738. https://doi.org/10.1007/s10668-023-03307-9
10. Samuel, J.S.; Rama Rao, C.A.; Pushpanjali; et al. Enhancing farm income resilience through climate smart agriculture in drought-prone regions of India. *Front. Water* 2024, 6, 1327651. https://doi.org/10.3389/frwa.2024.1327651
11. Kapoor, S.; Pal, B.D. Impact of adoption of climate smart agriculture practices on farmer's income in semi-arid regions of Karnataka. *Agric. Syst.* 2024, 221, 104135. https://doi.org/10.1016/j.agsy.2024.104135

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12. Singh, S.; Kiran, B.R.; Mohan, S.V. Carbon farming: A circular framework to augment CO_2 sinks and to combat climate change. *Environ. Sci. Adv.* 2024, 3, 522–542. https://doi.org/10.1039/D3VA00296A
13. Paul, C.; et al. Carbon farming: Are soil carbon certificates a suitable tool for climate change mitigation? *J. Environ. Manag.* 2023, 330, 117142. https://doi.org/10.1016/j.jenvman.2022.117142
14. Asante, A.; Ma, W.; Prah, S.; et al. Farmers' adoption of multiple climate-smart agricultural technologies in Ghana: Determinants and impacts on maize yields and net farm income. *Mitig. Adapt. Strateg. Glob. Change* 2024, 29, 16. https://doi.org/10.1007/s11027-024-10114-8
15. Maggio, V.; Tulone, A.; Laudicina, V.A.; Paliaga, S.; Biondo, A.; Galati, A. Exploring the economic trade-offs of carbon farming practices: A systematic literature review. *Ecosyst. Serv.* 2026, 79, 101868. https://doi.org/10.1016/j.ecoser.2026.101868