Climate-Smart Agriculture Legal Strategies for Enhancing Environmental Sustainability in Farming Production

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Abstract. Climate change poses significant challenges to global food security and agricultural sustainability. In response, climate-smart agriculture (CSA) has emerged as a framework to enhance the resilience of farming practices to climate variability and mitigate greenhouse gas emissions. This paper explores the legal strategies aimed at promoting CSA and enhancing environmental sustainability in agricultural practices. It examines key regulatory frameworks at international, national, and local levels that support the adoption of CSA techniques, such as conservation agriculture, agroforestry, and precision farming. The analysis highlights the role of legal instruments in incentivizing climate-resilient farming practices, promoting sustainable land management, and fostering innovation in agricultural technologies. Additionally, the paper discusses the challenges and opportunities associated with implementing CSA legal frameworks, including the need for policy coherence, stakeholder engagement, and capacity building. By integrating legal strategies into agricultural policies, countries can effectively address climate change impacts while promoting sustainable and resilient food systems.

1 Introduction

The compounding effects of climate change, including frequent flooding, extreme heat, and unpredictable precipitation patterns, pose significant challenges to crop production and agricultural development. Numerous studies have highlighted the detrimental impact of climate change on global crop production. For instance, research indicates a reduction in farm productivity due to climate change. Furthermore, the COVID-19 pandemic and the growing global population have intensified food demand, exacerbating food insecurity. Addressing the well-being of the global population without hunger necessitates a substantial increase in agrifood output while adhering to sustainable development principles.

Given these challenges, farmers are urged to adopt climate-smart agricultural (CSA) practices, which aim to mitigate climate-induced challenges. Numerous studies have explored the effects of CSA practices, such as row planting and soil, water, and nutrient

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management, on agricultural productivity and resilience. However, the outcomes of these studies may vary across different locations and contexts.

CSA involves innovations aligned with three goals: sustainable increase in agricultural productivity and incomes, adaptation and resilience building to climate change, and reduction or avoidance of greenhouse gas emissions. Despite some studies synthesizing the literature on CSA adoption and its impact on these goals, further research is needed to comprehensively understand the effectiveness of CSA interventions across diverse contexts.

2 Research methodology

The reviews mentioned above help enrich our understanding of the economic and environmental effects of CSA adoption and underscore the site-specific nature of climate change impacts on agricultural production. However, findings from selected practices or regions in those literature review studies lack generalizability. In addition, we cannot conclude a one-fit-all CSA (either row planting or adjusting crop calendars) for achieving the goal for other countries and regions. Thus, a comprehensive review of literature detailing CSA practices is imperative to discern effective CSA approaches for diverse crops and regions. Besides, achieving the three CSA objectives could result in synergies or trade-offs. Yet, delineating effective CSA strategies for each goal is pivotal due to regional variations in prioritizing these goals. This distinction equips policymakers to craft targeted strategies and interventions aligned with their primary objectives.

The objective of the present study is to review a body of collected literature and summarize their findings on the effects of CSA adoption on farm productivity and incomes, resilience, and greenhouse gas emissions, covering the three goals of climate-smart agriculture. Our contributions to the existing literature encompass three aspects. Firstly, our review discerns the effects of CSA adoption based on the three goals intrinsic to climate-smart agriculture. This makes our study stand as one of the limited systematic syntheses of CSA-related literature. Secondly, we comprehensively delineate multiple dimensions to chart CSA adoption's impacts within each goal. Specifically, our analysis delves into the literature regarding the effects of CSA adoption on farm productivity and incomes, focusing on crop yields and productivity, incomes, and technical and resource use efficiency – all aligning with CSA goal 1. In addition, we categorize the impacts of CSA adoption on resilience into food consumption, dietary diversity, and food security, and production risk and vulnerability, which align with goal 2 of climate-smart agriculture. In the context of goal 3, we examine impacts on greenhouse gas emissions and soil quality.

3 Results and Discussions

We collected 27 papers exploring CSA adoption’s impact on income-related indicators. Some studies exclusively focused on one or two CSAs. The examined indicators comprise (1) crop income or gross revenue, (2) farm income, (3) household income, (4) net returns, net income, or profit, (5) net household income, and (6) other indicators like net present values and farm assets. Although crop income or household income provide insights, they do not encompass production costs or household expenditures. Therefore, incorporating net returns or net household income is valuable for a comprehensive assessment of the income-enhancing impact of CSA adoption.

Findings in this category also underscore the importance of utilizing indicators like net returns or net household income. When crop income, farm income, or household income are employed as outcome variables, prevailing studies consistently reveal that adopting

various CSA combinations yields a positive and statistically significant impact on these variables, suggesting the economic viability of CSA adoption. Nevertheless, the efficacy of CSA adoption is contingent upon considering production costs or household expenditures. For example, net returns or net farm income is the disparity between crop/farm gross revenue and production costs. Net household income is derived from the contrast between total household income and expenditure. Several studies revealed that CSA adoption contributes to an increase in net returns, net farm income, or household net income. However, Song et al. (2018) exhibited that engineering-type measures have negligible influence on crop net profit in China, while Quddoos et al. (2022) emphasized that effective climate change adaptation measures could still lead to a 4.4% profit reduction for farms in Austria.

Both grain crops (such as wheat and rice) and cash crops (like cotton and fruit) contribute to increased household income, with the latter often playing a more substantial role due to its commercialization. As such, the literature analyzing the relationship between CSA adoption and income-related indicators encompasses both grain and cash crops, differing slightly from the literature assessing the impact of CSA adoption on crop yields and productivity in the preceding subsection. For example, this subsection examines crops like wheat, rice, tef, and grain, simultaneously concentrating on cash crops like cotton, cocoa, and mango. Drawing definitive policy implications about the overall effectiveness of CSA adoption requires careful consideration. Firstly, our review highlights that the positive impact of CSA adoption on these goals is context-dependent. Acknowledging this context specificity, policymakers are urged to adopt an approach that tailors CSA strategies to each region's unique socio-economic, environmental, and geographic conditions. In addition, it is imperative to recognize that no one-size-fits-all CSA strategy guarantees universal success. Policymakers should prioritize flexibility in policy frameworks, allowing for adaptation to the distinct characteristics of various agricultural landscapes. This flexibility will enable the effective customization of CSA practices, ensuring their alignment with the specific challenges and opportunities faced by farmers in diverse regions.

Secondly, it is essential to note that the published literature does not always yield consistent findings regarding the positive effects of CSA adoption. In some instances, we observe cases where CSA adoption has not proven to be effective. In addition, the tendency to publish studies with positive results while neglecting those with negative or inconclusive outcomes can introduce a bias in the overall literature. This selective reporting can skew our understanding of a particular phenomenon and lead to an incomplete or distorted view of the research landscape. Policymakers must be aware of this potential bias. Encouraging researchers to disseminate comprehensive findings, regardless of the direction of outcomes, is essential for mitigating the risk of skewed perspectives in formulating evidence-based policies.

4 Conclusions

This study aims to comprehensively understand how adopting CSA affects farm productivity and incomes, resilience, and greenhouse gas emissions. Our thorough review includes examining 107 scholarly papers. We have categorized the existing literature into three categories corresponding to the three CSA goals. This categorization of the literature based on CSA objectives serves as an analytical framework, enabling the identification of effective strategies and approaches tailored to specific CSA goals.

The study's results offer valuable insights into the impact of CSA adoption. Regarding the first CSA goal to sustainably increase agricultural productivity and incomes, our analysis reveals that CSA adoption enhances farm productivity and incomes through increased crop yields and productivity, income, and technical and resource use efficiency.

Addressing the second CSA goal of fostering resilience in people and agrifood systems against climate change, our findings demonstrate that CSA adoption bolsters individuals' resilience by boosting food consumption, dietary diversity, and food security. Moreover, at the system level, CSA adoption enhances agrifood system resilience by mitigating production risks and decreasing vulnerability. Concerning the third CSA goal of lowering GHG emissions, our review establishes that CSA adoption contributes to reducing emissions, including CO2, N2O, and CH4. In addition, CSA adoption promotes carbon sequestration in soils and biomass, thereby improving soil quality.

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