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Climate-Smart Agriculture Adoption: *Key Drivers and Impacts on Food Security*

1) Introduction

- **Understanding Food Security**

Food security is the assurance that every person has reliable access to enough safe and nutritious food to maintain a healthy life. Traditionally, this is built upon four pillars: availability (adequate supply), access (ability to obtain food), utilization (nutritional value and proper use), and stability (consistent access over time, even during shocks). In recent years, our understanding has evolved to include agency—the power of communities to make their own food decisions and sustainability, which protects the resources needed for future generations. Together, these six dimensions offer a holistic perspective, shifting the focus from mere production to a more equitable, resilient, and long-term approach to feeding the world.

- **Impact of Climate Change on Food Security**

Climate change is a profound threat to global food security, disrupting crop productivity, destabilizing food systems, and undermining both incomes and nutrition. Smallholder farmers in developing nations are on the front lines, facing rising temperatures and unpredictable rainfall that degrade vital soil and water resources. These extreme weather events directly threaten the availability and stability of food, as traditional farming systems often lack the tools to withstand such volatility.

In response, Climate-Smart Agriculture (CSA) has emerged as a vital strategy to build resilience. By integrating three core objectives sustainable productivity, climate adaptation, and mitigation CSA offers a pathway forward. Practical innovations such as drip irrigation, crop rotation, and the use of drought-resistant varieties are not just farming techniques; they are essential tools that improve resource efficiency and protect the livelihoods of those most vulnerable to a changing climate.

- **Climate Smart Agriculture (CSA)**

Climate-Smart Agriculture (CSA) practices are generally categorized into two streams: water and soil management (WSA), involving high-cost, long-term investments, and conservation practices (CP)—such as no-tillage and crop rotation—which offer lower costs and immediate yield impacts. By merging traditional wisdom with modern, data-driven techniques, CSA boosts productivity and resilience far more effectively than traditional farming, which remains vulnerable to climate shifts.

However, CSA is not a universal solution; its success depends on tailoring strategies to local contexts. To build truly resilient food systems, adoption must be anchored by supportive policies, institutional frameworks, and sustained investment.

- **Factors Influencing CSA Adoption**

Adoption of Climate-Smart Agriculture (CSA) is driven by a complex interplay of socioeconomic, institutional, and environmental factors. Socioeconomic influences include household demographics, income, labor availability, and environmental awareness. Equally vital are institutional dimensions, such as access to extension services, credit, government support, and market connectivity.

Furthermore, environmental conditions—including climate variability, social networks, and the integration of traditional and modern knowledge—shape a farmer's decision to adapt. Collectively, these factors reveal that CSA adoption is a multidimensional process occurring at the intersection of personal, organizational, and ecological contexts. This highlights the urgent need for integrated, context-specific strategies to ensure the effective and sustained uptake of climate-resilient practices.

- **Climate-Smart Agriculture in Sri Lanka**

In Sri Lanka, Climate-Smart Agriculture (CSA) is a cornerstone of national policy, driving initiatives like agroforestry, water conservation, and the cultivation of resilient rice varieties. A primary driver of this transition is the Climate Smart Irrigated Agriculture Project (CSIAP), which targets Dry Zone districts by upgrading irrigation infrastructure, introducing hardy crops, and providing vital climate advisories.

However, despite these strategic efforts, widespread adoption remains hampered by various systemic barriers. This study examines the specific socio-economic and institutional factors that influence whether a farmer chooses to embrace these resilient practices, aiming to bridge the gap between policy intent and field-level implementation.

2) Case study

The study area, located in Sri Lanka's intermediate agro-ecological zone, was selected due to the implementation of the Climate-Smart Irrigated Agriculture Project (CSIAP) since 2019, making it a suitable setting to examine the impacts of CSA. Field evidence demonstrates significant agricultural transformations, including the adoption of drip irrigation systems, the installation of solar-powered water pumps, improved road connectivity, and capacity-building programs focused on climate-resilient practices. Farmers in the area primarily cultivate red onions but have recently diversified into Cavendish banana production for export markets (Fig 01– Fig 04). The community was chosen because of its high level of CSA adoption, the coexistence of adopters and non-adopters within a concentrated area, and the availability of first-hand insights from farming households. Moreover, Koskotagolla farming community in the Kurunegala district reflects broader challenges commonly faced by Sri Lankan smallholders, such as climate variability, pest outbreaks, market constraints, and shifting labor dynamics, providing a relevant context to analyze CSA's effects on household food security as well as the social, institutional, and environmental factors influencing farm-level decision-making.

3) Methodology

The study uses a mixed-methods research design, combining qualitative and quantitative approaches to understand CSA adoption determinants and their contribution to food security among the Koskotagolla farming communities. Quantitatively, an ordered survey of 35 farmers (20 adopters and 15 non-adopters) was conducted to assess socio-demographic, economic, and institutional factors such as age, gender, education, access to credit, and extension services. Data were analyzed using

Figure 1: Drip Irrigation Systems

Figure 2: Solar Panels

Figure 3: Pest Nets

Figure 4: Cavendish Banana

descriptive statistics, Spearman's rank correlation, chi-square tests, cross-tabulation, and regression analysis to identify key drivers of CSA adoption. A semi-structured questionnaire, the primary quantitative tool, collected information on farmer demographics, farm characteristics, CSA practices (e.g., drip irrigation, drought-tolerant crops), and household-level food security (availability, self-sufficiency, and supply stability). Most questions were closed-ended for statistical analysis, while selected open-ended items captured personal insights. Key adoption factors such as social networks and market access were operationalized into measurable indicators and coded for analysis. The data provided both CSA adoption drivers and baseline food security metrics.

To understand perceptions, challenges, and motivations for CSA adoption, two focus group discussions (FGDs) were held with adopters and non-adopters, providing insights into peer influence, group dynamics, and contextual factors. Key informant interviews were conducted with institutional experts involved in CSA implementation and monitoring in Kurunegala District, including project directors, agricultural officers, and capacity-building staff. These interviews explored institutional support, implementation challenges, adoption barriers, and CSA's role in food security. Among surveyed farmers, 54% adopted CSA practices. Most were male with secondary education, owned land, and had long farming experience (average age 54 years; 30 years' experience). About half engaged in CSA networks, cooperatives, and support services, while 60% farmed full-time. The average farm size was 2 acres, with a monthly income of LKR 73,529. Most had well-based water access, and none perceived CSA as risky.

4) Results and discussion

The analysis reveals that CSA adoption is primarily driven by external "enabling environments" rather than individual farmer characteristics. The perfect positive correlation ($r = 1.000$, $p < 0.01$) for market access and government support indicates that adoption is a demand-driven process. When farmers are guaranteed a buyer (market access) and have their financial risk mitigated (85% CSIAP subsidy), the resistance to shifting toward CSA becomes negligible.

Interestingly, while institutional support like extension services ($r = 0.850$) is vital, the qualitative data suggests a nuance in social capital. Peer-to-peer interactions emerged as a more potent influencer than formal group memberships. This implies that in rural Sri Lanka, demonstration effects seeing a neighbor succeed carry more weight than classroom-style training. This refines the findings of Diallo et al. (2019) by suggesting that social "contagion" is a key mechanism for scaling CSA.

Despite high motivation and market linkages, a clear "adoption ceiling" was identified regarding physical assets. The drop in correlation from market access ($r = 1.000$) to water reliability ($r = 0.656$) highlights a resource gap. Even with an 85% subsidy, the 45.7% of farmers without agro-wells remained excluded from high-value CSA practices. This suggests that financial subsidies alone cannot overcome fundamental hydro-geological constraints.

The study confirms that CSA is not merely an environmental strategy but a food security intervention ($p < 0.05$). The shift from monocropping to diversification stabilized caloric availability during climate shocks. However, the "utility" pillar of food security saw the most significant gain, as the introduction of crops like Cavendish bananas improved diversity.

5) Conclusion

This study concludes that the transition to Climate-Smart Agriculture (CSA) in Sri Lanka's Dry Zone is driven by a supportive ecosystem rather than the personal backgrounds of farmers. Research indicates that individual traits like age and education are not barriers to change; instead, adoption is an economically rational response to the removal of risk. When the government provides substantial infrastructure subsidies and guarantees access to stable markets, farmers are highly willing to embrace sustainable practices. However, a significant "adoption ceiling" remains due to physical constraints. Even when motivation is high, many smallholders are excluded from high-value CSA practices because they lack reliable water sources, such as personal agro-wells. Socially, the study finds that peer-to-peer interaction is the most powerful catalyst for change, as farmers trust the visible success of their neighbors more than formal classroom training. Ultimately, shifting to CSA serves as a vital shield for food security, stabilizing crop yields against climate shocks and improving household nutrition through crop diversification. For these benefits to reach every farming family, policy must evolve from providing mere technical advice to making targeted investments in water infrastructure and market connectivity. Addressing these physical and capital bottlenecks is the only way to ensure a resilient and equitable future for Sri Lankan agriculture.

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