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DETERMINANTS OF ADOPTION AND INTENSITY OF USE OF CLIMATE-SMART AGRICULTURE (CSA) PRACTICES AMONG SMALLHOLDER LEAFY VEGETABLE AGRIPRENEURS IN SEMI-ARID CENTRAL TANZANIA

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Abstract

The adoption of Climate-Smart Agriculture (CSA) practices is essential for enhancing agricultural resilience and productivity in semi-arid regions. This study examines the determinants of CSA adoption and intensity of use among smallholder leafy vegetable agripreneurs in semi-arid central Tanzania. Using a cross-sectional research design, data were collected from 385 farmers in Dodoma City and Singida Municipality through structured interviews. The study employs a double hurdle model to separately analyze adoption decisions and intensity of use. Findings indicate that CSA adoption is influenced by land tenure security, market access, and extension services, with farmers who rent or own land more likely to adopt CSA than those relying on family-owned land. Gender disparities were observed, with male farmers showing higher adoption intensity, particularly for capital-intensive practices such as agroforestry and drip irrigation. Additionally, smaller landholders exhibited greater CSA uptake, driven by the need to maximize productivity. However, high costs and technical complexity limit the adoption of certain CSA practices. The study highlights the necessity of targeted policy interventions, including enhanced financial accessibility, land tenure reforms, and improved extension services, to promote CSA adoption. These findings contribute to the growing body of knowledge on CSA adoption in climate-vulnerable regions and inform policy strategies for sustainable agricultural transformation.

Keywords: Climate-Smart Agriculture, Leafy vegetable, adoption intensity, double hurdle model, Tanzania

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Introduction

The semi-arid regions of Central Tanzania, particularly Dodoma City and Singida Municipal Districts, represent areas of acute vulnerability to climate change (Ekka & Mjawa, 2020; Swamila, Philip, Akyoo, Sieber, Bekunda, & Kimaro, 2020). These regions experience significant variability in precipitation, which disrupts agricultural systems that serve as the primary economic activities (Lente et al., 2023; Muralikrishnan et al., 2022). The increasing frequency and intensity of climate disturbances, manifested through rising temperatures and erratic precipitation patterns, have amplified threats to agricultural productivity, livelihood sustainability, and food security (Begizew, 2021; Swamila et al., 2020).

Smallholder leafy vegetable agripreneurs, who constitute the majority of the agricultural workforce in these regions, are particularly vulnerable due to their dependence on rainfed agriculture. This reliance exposes them to climate-induced risks such as crop failures and reduced yields (Egeru, Bbosa, Siya, Asiimwe, & Mugume, 2022; Ngetich, Mairura, Musafiri, Kiboi, & Shisanya, 2022). Addressing these challenges requires targeted interventions, with Climate-Smart Agriculture (CSA) practices emerging as a promising solution for adapting to climate variability and mitigating its adverse effects. CSA encompasses agricultural strategies that enhance resilience to climate change while simultaneously improving productivity (Jones et al., 2023; Mbwambo, 2022). By improving soil health, optimizing water use, and increasing crop productivity, CSA offers a practical framework for sustainable agriculture, particularly in vulnerable regions like Central Tanzania.

The selection of appropriate crops plays a crucial role in the effectiveness of CSA practices. Leafy vegetables are particularly well suited for semi-arid environments due to their adaptability, high market demand, multiple harvest cycles, and shorter production periods compared to staple crops (Imathiu, 2021; Xiao et al., 2021). Their resilience to harsh climatic conditions positions them as an important option for enhancing food security and farmer incomes (Habiyaremye, Ochieng, & Heckelei, 2021). However, despite their potential, research on CSA adoption has predominantly focused on staple crops such as cereals, legumes, roots, and tubers (Casali, Herrera, & Rubio, 2022; Mugari & Masundire, 2022). This emphasis has left critical knowledge gaps regarding the adoption levels, influencing factors, and intensity of CSA practice use specifically for leafy vegetable production in semi-arid regions. Without addressing these gaps, the scalability and effectiveness of CSA interventions tailored to leafy vegetables remain limited.

This study seeks to bridge this gap by investigating three key questions: (1) What are the current adoption levels of various CSA practices among smallholder leafy vegetable agripreneurs in semi-arid Central Tanzania? (2) Which factors influence agripreneurs' decisions to adopt CSA practices? (3) What factors determine the intensity of use among those who have adopted these practices?

The remainder of this paper is structured as follows. The next section presents the theoretical and conceptual frameworks that guide the study. The methodology section outlines the study design, data collection methods, and analytical techniques. The results and discussion section provides findings on the adoption levels of CSA practices, factors influencing adoption, and the determinants of adoption intensity. The final section concludes the study by summarizing key findings, offering policy recommendations, and suggesting directions for future research.

Theoretical Framework

This study is guided by the Expected Utility Theory, a fundamental concept in decision-making under uncertainty (von Neumann & Morgenstern, 1944). The theory suggests that individuals make choices by evaluating potential outcomes and selecting the option that maximizes their expected utility, which is influenced by the probability of each outcome occurring (Tinh et al., 2021; João et al., 2020).

The adoption of Climate-Smart Agriculture (CSA) practices by smallholder leafy vegetable agripreneurs aligns with this theory, as their decision-making process involves weighing the potential benefits of CSA practices against the associated costs and risks. CSA practices offer advantages such as improved crop yields, enhanced resilience to climate variability, and reduced production risks (Ogunyiola et al., 2022; Ng'ang'a, S. K., Miller, V., & Girvetz, E. (2021). These benefits are particularly significant for smallholder leafy vegetable agripreneurs operating in semi-arid regions, where climatic conditions are unpredictable and pose significant challenges to traditional farming methods.

However, the adoption of CSA practices also comes with costs, including the initial financial investment in new technologies and inputs, as well as the time and effort required to acquire technical knowledge. Additionally, uncertainties related to transitioning to CSA, such as inconsistent results or increased labor demands, may discourage agripreneurs from adopting these practices (Ogada et al., 2020). Furthermore, in the semi-arid context of Central Tanzania, the decision to adopt CSA practices is influenced by the unique characteristics of leafy vegetable production. These crops offer multiple harvest cycles, shorter production periods, and high economic returns, which increase the perceived utility of adopting CSA practices.

Expected Utility Theory provides a useful lens for understanding CSA adoption because it accounts for both the rational calculations that agripreneurs make and the external factors that shape their decisions. Agripreneurs are likely to adopt CSA practices if they perceive the expected benefits such as increased profitability and improved resilience to outweigh the risks and costs. On the other hand, if perceived barriers such as financial constraints, lack of technical support, or uncertain results outweigh the anticipated benefits, agripreneurs may be reluctant to adopt CSA practices. Through applying the Expected Utility Theory, this study examines how smallholder leafy vegetable agripreneurs evaluate CSA adoption in terms of expected returns, costs, and risks. Understanding this decision-making process is critical for designing interventions that address barriers to adoption and enhance the effectiveness of CSA promotion strategies in semi-arid regions.

Conceptual Framework

The conceptual framework for this study is based on the Expected Utility Theory (von Neumann & Morgenstern, 1944), which explains decision-making under uncertainty. The theory suggests that individuals assess potential choices by evaluating perceived benefits, costs, and risks to maximize their expected utility. In this study, the adoption and intensity of Climate-Smart Agriculture (CSA) practices among smallholder leafy vegetable agripreneurs are shaped by external factors and their perceptions of utility.

The framework consists of three main components: independent variables, a mediating variable, and dependent variables. The independent variables represent external influences and are categorized into demographic factors (age, gender, education, marital status, and household size), socioeconomic factors (land size, land ownership, and market access), and institutional and environmental factors (extension services, water access, and climate variability). These factors create the conditions under which smallholder leafy vegetable agripreneurs decide whether to adopt CSA practices. The mediating variable, perceived utility, reflects agripreneurs' evaluation of CSA practices in terms of costs, benefits, and risks. Costs include financial investments, labor requirements, and technical knowledge. Benefits involve increased yields, improved resilience to climate change, and enhanced profitability. Risks refer to uncertainties such as inconsistent yields or increased labor demands. Perceived utility acts as the link between external factors and the decision-making process.

The dependent variables are CSA adoption and adoption intensity. Adoption is treated as a binary outcome, while adoption intensity reflects the extent of CSA implementation. Independent factors influence perceived utility, which in turn determines both adoption and intensity. Additionally, perceived utility mediates the impact of external factors, meaning that external conditions affect adoption and intensity through their influence on agripreneurs' cost-benefit evaluations. This framework provides a structured approach to understanding how external factors and farmers' perceptions shape CSA adoption. By emphasizing perceived utility, it highlights the need for interventions that reduce financial and technical barriers to enhance adoption rates. Recognizing the role of institutional and environmental conditions can help policymakers design targeted strategies that support sustainable agriculture in semi-arid regions, as shown in **figure 1**

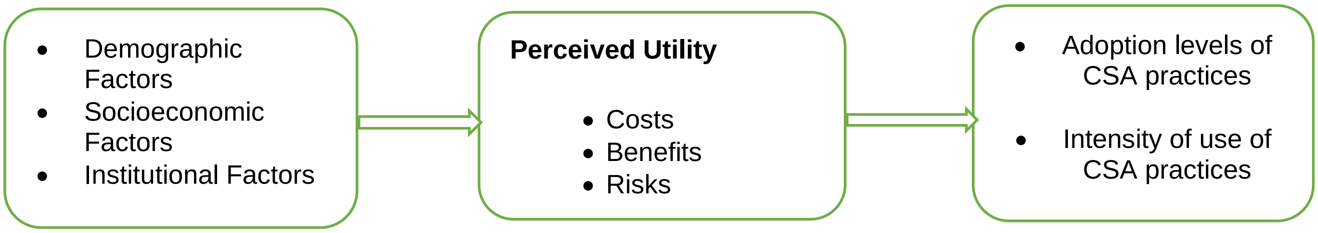
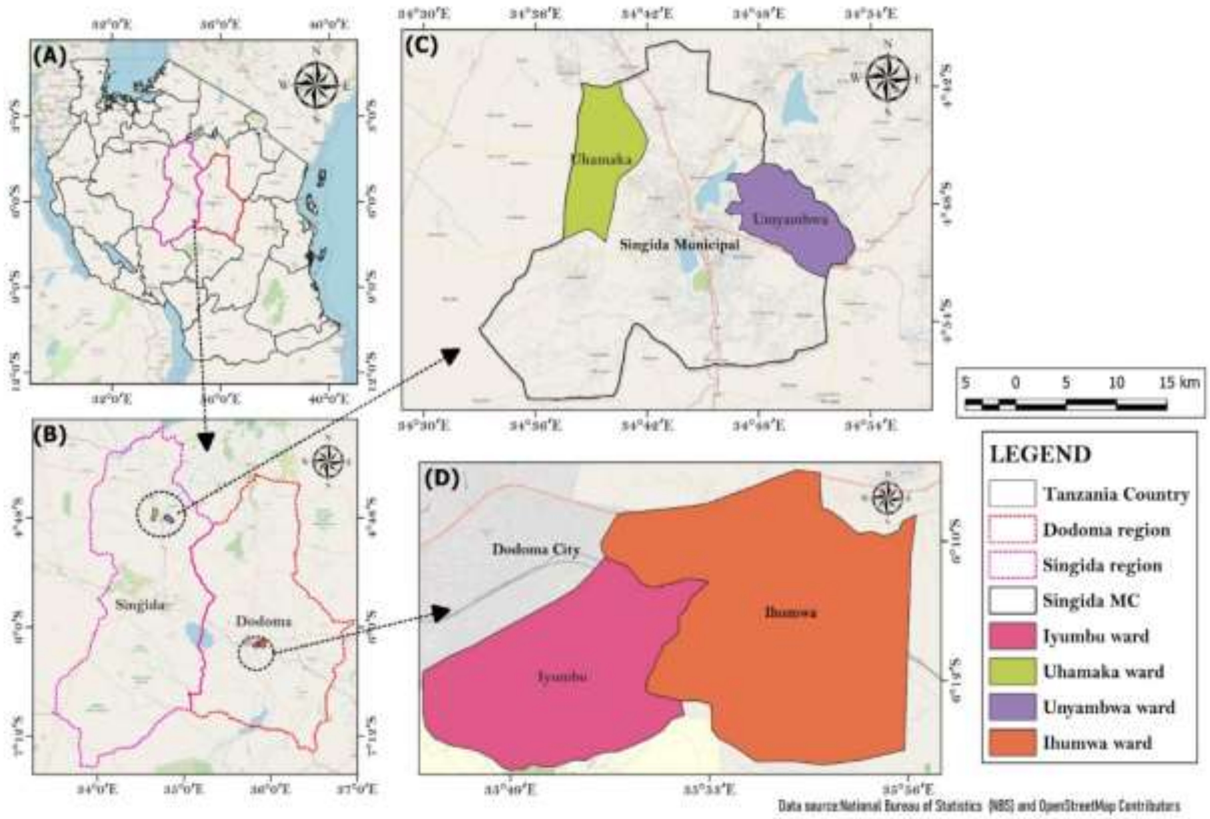


Figure 1: Conceptual framework

Materials and Methods

Study Area

The study was conducted in the Ihumwa and Iyumbu Wards of Dodoma City and the Uhamaka and Unyambwa Wards of Singida Municipality, located in the semi-arid regions of Central Tanzania. These areas experience high temperatures ranging from 15°C to 35°C and annual rainfall between 500 and 600 mm, primarily occurring between November and April (Ekka & Mjawa, 2020; Swamila et al., 2020). The wards were purposively selected due to their significance in leafy vegetable production within the region. The study population comprised smallholder leafy vegetable agripreneurs identified through ward extension officers, ward executive officers, leafy vegetable producer leaders, and the ward horticulture producers' register. To provide further context, **Figure** 2 presents maps depicting the administrative divisions of Dodoma and Singida regions, as well as the specific wards where data were collected. These maps were developed using data from the National Bureau of Statistics (NBS) and Open Street Map Contributors, highlighting the spatial distribution of the selected wards and their geographic significance within the semi-arid zone.



Data source:National Bureau of Statistics (NBS) and OpenStreetMap Contributors

Figure 2 presents maps depicting the administrative divisions of Dodoma and Singida regions, as well as the specific wards where data were collected.

Study Population and Sampling Procedure

The target population consisted of smallholder leafy vegetable agripreneurs actively involved in production and marketing of leafy vegetable crops. Leafy vegetable crops produced in the study area includes, Chinese cabbage, amaranth, spinach, kale, sweet potato leaves, pumpkin leaves, cowpea leaves, and other traditional vegetables.

A cross-sectional research design was employed to collect data at a single point in time. A multistage sampling approach was used to ensure representation across different agro-ecological and socioeconomic conditions. Dodoma City and Singida Municipality were purposively selected due to their prominence in leafy vegetable production in comparison with other districts of Dodoma and Singida regions. Four wards Ihumwa, Iyumbu, Uhamaka, and Unyambwa, were then chosen based on their high concentration of smallholder leafy vegetable agripreneurs. Within each ward, stratified random sampling ensured the inclusion of both experienced and less experienced agripreneurs.

The sample size was determined using Cochran's formula at a 95 percent confidence level and a 5 percent margin of error, resulting in a total of 385 respondents, with 193 selected from Dodoma and 192 from Singida. This sampling approach was consistent with previous CSA adoption studies in Tanzania, which emphasized the importance of accounting for land tenure variations, market accessibility, and institutional support in determining CSA adoption patterns (Kurgat et al., 2020; Tadesse & Ahmed, 2023).

Data Collection Methods

Primary data were collected between January and May 2024, covering both wet and dry seasons to capture seasonal variations in CSA adoption. Data collection was conducted through structured face-to-face interviews using a questionnaire that assessed CSA adoption levels, identified factors influencing adoption decisions, and determined the intensity of CSA adoption among smallholder leafy vegetable agripreneurs.

To ensure the reliability and validity of the data, the questionnaire was pre-tested with 30 agripreneurs in Ikungi District, a District with similar agro-ecological conditions. Adjustments were made based on feedback to improve clarity and cultural relevance. The final questionnaire exhibited strong internal consistency, with a Cronbach's alpha coefficient of 0.78. Content validity was further confirmed through expert reviews by agricultural extension officers and researchers. A similar pre-testing approach has been applied in other CSA adoption studies (Singh et al., 2021; Sewando, 2023).

Selection of Independent Variables

The selection of independent variables was based on empirical literature and contextual relevance to smallholder agripreneurs in semi-arid regions. Recent studies have emphasized that CSA adoption is influenced by demographic, socioeconomic, and institutional factors. Demographic variables included age, gender, education level, marital status, and household size. Socioeconomic variables encompassed land size, land ownership, market access, and income levels. Institutional and environmental factors considered included access to extension services, proximity to water sources, climate variability, and access to credit (Tadesse & Ahmed, 2023).

The inclusion of these factors aligns with previous research in Tanzania and other parts of Sub-Saharan Africa, which found that land tenure security, market participation, and institutional support play a significant role in CSA adoption (Kurgat et al., 2020; Thinda et al., 2020). These variables were hypothesized to influence CSA adoption and intensity by shaping agripreneurs' perceptions of costs, benefits, and risks associated with CSA practices.

Data Analysis

Data analysis involved both descriptive and inferential statistical techniques. Descriptive analysis was conducted using frequencies, percentages, and means to classify CSA adoption levels into high, moderate, and low categories. Chi-square tests were employed to assess associations between independent variables and CSA adoption. The chi-square statistic was calculated as follows: $\chi^2 = \Sigma [(O - E)^2 / E]$
where O represents the observed frequencies and E represents the expected frequencies. Statistical significance was established at a p-value of less than 0.05.

Double Hurdle Model

The double hurdle model was applied to analyze both the adoption decision and the intensity of CSA adoption among agripreneurs who had adopted these practices. This model was chosen because CSA adoption and its intensity are separate but interrelated decisions influenced by different factors. Recent studies in Tanzania and Ethiopia have confirmed the validity of this model in CSA research, as it effectively captures the distinct nature of adoption and implementation choices (Kurgat et al., 2020; Tadesse & Ahmed, 2023).

First Hurdle – Probit Model:
The decision to adopt CSA practices was modeled using a probit regression. The latent variable representing the difference in expected utility between adoption and non-adoption was expressed as: $Y^* = E(U_{i1}) - E(U_{i0})$ …………………………………………………………… (1)
Where : $E(U_{i1})$ is the expected utility of adopting CSA practices for the ith agripreneur, $E(U_{i0})$ is the expected utility of not adopting CSA practices for the ith agripreneur. The individual agripreneur will decide to adopt CSA practices if $Y^* > 0$, i.e., if the expected utility of adoption exceeds the expected utility of non-adoption.
The Probability of adoption: $P(Y_i = 1 \mid X) = F(\beta X) = \int (-\infty \text{ to } \beta X)\, (1/\sqrt{(2\pi)}) \exp(-z^2/2)\, dz$……... (2)
where: $P(Y_i = 1 \mid X)$ is the probability that the agripreneur adopts CSA practices, given the independent variables X. Additionally $F(\cdot)$ is the cumulative distribution function of the standard normal distribution, and β are the coefficients to be estimated.

Second Hurdle – Truncated Regression Model:
The expected utility theory also informs the second hurdle, where the intensity of adoption is examined using a truncated regression model. The intensity of adoption reflects the extent to which an agripreneur anticipates deriving utility from adopting CSA practices.
The truncated regression model, grounded in the expected utility framework, can be formulated as: $E(I_i \mid I_i > 0, Z) = E[U(I_i) \mid I_i > 0, Z] = \gamma Z + \nu_i,\ \nu_i \sim N(0, \sigma^2)$ …………………………. (3)
where:

- It is the intensity of adoption of CSA practices for the agripreneur.
- $U(I_i)$ is the utility derived from the intensity of adoption I_i.
- Z is a vector of independent variables influencing the intensity of adoption.
- γ are the coefficients to be estimated.
- ν_i is the error term, assumed to be normally distributed with mean 0 and variance σ^2.

The statistical analyses were performed using Stata 17.0. Results from the descriptive and inferential analyses were interpreted in relation to the conceptual framework, focusing on the role of perceived utility in CSA adoption and intensity.

Model Assumptions

The double hurdle model relies on several key assumptions. The independence of adoption and intensity decisions assumes that the factors influencing the initial decision to adopt CSA may differ from those determining the extent of adoption. The normality of error terms in both the probit and truncated regression models ensures valid coefficient estimates and hypothesis testing. The assumption of no perfect multicollinearity prevents model instability and ensures that each independent variable's impact is accurately measured. The assumption of exogeneity implies that independent variables are not influenced by unobserved factors related to CSA adoption, justifying their inclusion in the model.

These assumptions align with best practices in CSA adoption research, where multicollinearity is tested using the variance inflation factor (VIF), and normality is assessed through residual diagnostics (Kurgat et al., 2020; Thinda et al., 2020). Robustness checks were performed to validate the findings and ensure model reliability.

Statistical Software

All statistical analyses were performed using Stata 17.0. Findings were interpreted within the study's conceptual framework, emphasizing the role of perceived utility in shaping CSA adoption and intensity among smallholder leafy vegetable agripreneurs.

Results and discussion

Factors Associated with CSA Adoption

The chi-square test results presented in Table 1 provide valuable insights into the factors influencing the adoption of Climate-Smart Agriculture (CSA) practices among smallholder leafy vegetable agripreneurs in semi-arid central Tanzania. The study identified significant associations between CSA adoption and marital status ($\chi^2 = 0.019$, $p < 0.05$), land ownership ($\chi^2 = 0.033$, $p < 0.05$), and land size ($\chi^2 = 0.005$, $p < 0.01$). Divorced or separated individuals exhibited the highest adoption rates (78.3%), followed by married respondents (62.7%). Farmers renting land demonstrated significantly higher adoption rates (70.5%) compared to those who owned land (61.4%) or relied on family-owned land (48.2%). Furthermore, those with smaller land sizes (<5 acres) were more likely to adopt CSA practices than those with larger plots.

Descriptive results indicate that marital status plays a role in CSA adoption. Divorced or separated individuals exhibited the highest adoption rates (78.3%), followed by married respondents (62.7%), whereas single (36.8%) and widowed (48.3%) respondents adopted CSA practices at lower rates. These patterns suggest that marital status, often linked to household structure and economic stability, may influence CSA adoption decisions. Previous studies by Phiri et al. (2022) and Tadesse and Ahmed (2023) support this observation, suggesting that household composition and support systems influence agricultural decision-making. However, our findings diverge from those of Ghimire, R., Khatri-Chhetri, A., & Chhetri, N. (2022), and Msalilwa et al. (2020), who report mixed results regarding the relationship between marital status and CSA adoption. These discrepancies may be attributed to differences in socio-economic contexts, sample sizes, or regional variations in land tenure systems and household structures.

Land ownership also emerges as a crucial determinant. Farmers who rent land exhibit higher adoption rates (70.5%) than those who own land (61.4%) or depend on family-owned land (48.2%). This trend suggests that secure and independent land tenure may encourage investment in sustainable practices. Chavula et al. (2022) and Kehinde et al. (2022) emphasize a similar point, arguing that secure land tenure often incentivizes farmers to implement long-term improvements. Our findings contribute to this discussion by demonstrating that farmers with rental or personally owned land, rather than those reliant on family-dependent tenure, are more likely to feel empowered to adopt CSA innovations.

The findings also reveal a strong negative correlation between land size and CSA adoption. Smallholders with less than one acre exhibit a high adoption rate (69.6%), while farmers with larger plots (6–10 acres) adopt at a lower rate (52.4%). This pattern aligns with the findings of Kurgat et al. (2020) and Mugari (2022), who argue that smallholders are more likely to adopt CSA practices due to the necessity of maximizing productivity on limited land. In contrast, larger landholders may not experience the same urgency to adopt intensive land management practices, as they generally possess more resources to buffer against environmental risks.

	Non-adoption of CSA		**Adoption of CSA**		**Total**	**Chi-Square**
	N	Percent	N	Percent	N	
Ward						0.093
Ihumwa	48	31.2%	106	68.8%	154	
Iyumbu	22	40.7%	32	59.3%	54	
Uhamaka	33	44.0%	42	56.0%	75	
Unyambwa	36	45.1%	66	64.7%	102	
						0.194
Sex of respondent						
Female	79	35.9%	141	64.1%	220	
Male	70	42.4%	95	57.6%	165	
						0.618
Age Range of respondent						
18-28	42	37.5%	70	62.5%	112	
29-35	45	37.2%	76	62.8%	121	
36-45	51	40.8%	74	59.2%	125	
46-60	7	33.3%	14	66.7%	21	
Above 60+	4	66.7%	2	33.3%	6	
						0.936
Household size						
Less than 3 members	6	42.9%	8	57.1%	14	
3-5 members	64	38.1%	104	61.9%	168	
Above 5 members	79	38.9%	124	61.1%	203	
						0.375
Education level of respondent						
Certificate	6	40.0%	9	60.0%	15	
Diploma	0	0.0%	4	100.0%	4	
Informal education	29	39.2%	45	60.8%	74	
Primary	93	40.3%	138	59.7%	231	
Secondary	21	36.8%	36	63.2%	57	
University	0	0.0%	4	100.0%	4	
						0.019*
Marital status						
Divorce/Separated	5	21.7%	18	78.3%	23	
Married	117	37.3%	197	62.7%	314	
Single	12	63.2%	7	36.8%	19	
Widow/Widower	15	51.7%	14	48.3%	29	
						0.033*
Land Ownership						
Family owned	29	51.8%	27	48.2%	56	
Own	97	38.6%	154	61.4%	251	
Rented	23	29.5%	55	70.5%	78	
						0.005*

Land size (acres)						
< 1	63	30.4%	144	69.6%	207	
1-5	75	48.4%	80	51.6%	155	
6-10	10	47.6%	11	52.4%	21	
>10	1	50.0%	1	50.0%	2	
						0.228
Proximity to water sources						
<100	133	37.8%	219	62.2%	352	
100-200	16	48.5%	17	51.5%	33	
						0.201
Market access						
Average	2	100.0%	0	0.0%	2	
Good	37	37.8%	61	62.2%	98	
Very good	110	38.6%	175	61.4%	285	

Table1. Descriptive results

Adoption Levels of CSA Practices

The analysis in Table 1 shows that 61.3% of smallholder leafy vegetable agripreneurs in semi-arid central Tanzania have adopted Climate-Smart Agriculture (CSA) practices. Adoption rates vary significantly across wards ($\chi^2 = 0.093$), with Ihumwa (68.8%) having the highest and Uhamaka (56.0%) the lowest. Unyambwa (64.7%) and Iyumbu (59.3%) show intermediate adoption levels. These disparities likely stem from differences in agro-ecological conditions, resource access, and institutional support (**Figure** 3). Higher adoption in Ihumwa may be driven by better extension services, infrastructure, and environmental suitability, while Uhamaka's lower rate suggests limited institutional support, knowledge dissemination, or socio-economic barriers. In Unyambwa and Iyumbu, adoption is progressing but constrained by access to key resources like water, credit, and climate-resilient inputs (Phiri et al., 2022; Tadesse & Ahmed, 2023).

Spatial disparities may also reflect institutional support effectiveness, as governance structures, farmer cooperatives, and training programs significantly influence adoption (Chavula et al., 2022; Kehinde et al., 2022). Strengthening extension services and farmer-led knowledge-sharing could help close adoption gaps. Additionally, CSA adoption aligns with broader trends in smallholder systems, where climate variability drives higher uptake. Farmers in drought-prone areas are more likely to adopt CSA as a risk-mitigation strategy (Kurgat et al., 2020; Mugari, 2022).

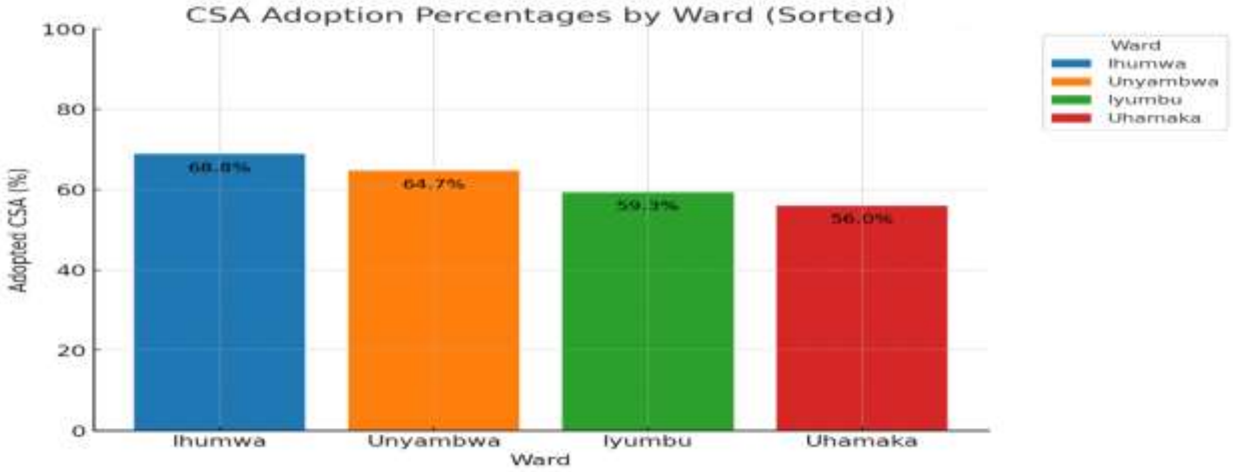


Figure 3: Adoption levels of CSA practices by Wards.

Based on a literature review regarding the adoption patterns of Climate-Smart Agriculture (CSA) (Grovermann *et al.,* 2023; Awiti *et al.,* 2022; Kananu *et al.,* 2023), the levels of CSA practice adoption are categorized into three distinct classifications: high adoption (greater than 65%), moderate adoption (between 35% and 65%), and low adoption (less than 35%), as illustrated in Table 2, and Figure 3.

The study identifies varying levels of adoption among different Climate-Smart Agriculture (CSA) practices, with crop diversification (94.3%), crop rotation (90.9%), and inorganic fertilizer application (88.3%) exhibiting the highest adoption rates. This widespread uptake is largely driven by government support, particularly fertilizer subsidies, which enhance accessibility and affordability (Faye et al., 2023; Swamila et al., 2020). Inorganic fertilizers, in particular, are highly adopted due to their targeted formulations for different crop growth stages, optimizing nutrient management and improving climate resilience (Musafiri et al., 2023; Chilagane et al., 2020). The popularity of these practices suggests that farmers prioritize CSA techniques that provide immediate productivity benefits while requiring moderate technical expertise and manageable initial investments.

Moderate adoption levels are observed for organic fertilizers (59.5%), improved seeds (65.2%), and mulching (60.8%). Despite their proven benefits for productivity and soil health, these practices face adoption barriers such as high implementation costs, inconsistent input availability, and limited access in remote areas (Adebiyi et al., 2020; Musara et al., 2022). The relatively lower adoption of organic fertilizers compared to inorganic alternatives highlights the challenges of transitioning to more sustainable soil fertility management. Overcoming these barriers requires targeted interventions to improve input accessibility and affordability, alongside awareness campaigns to demonstrate long-term benefits (Musara et al., 2022).

Low adoption rates are recorded for agroforestry (22.3%), greenhouse farming (3%), and drip irrigation (9%), indicating substantial implementation challenges. The primary obstacles include high initial investment costs, technical complexity, and the need for specialized infrastructure, which pose significant constraints for resource-limited smallholder farmers (Ntanasi et al., 2023; Singh et al., 2021). Additionally, the extended time required to see returns on investment discourages farmers from adopting these practices, as they often prioritize techniques that yield quicker benefits. Increasing the uptake of these practices necessitates comprehensive support mechanisms, including targeted subsidies, accessible credit facilities, and technical training programs. As illustrated in **Figure** 4, the adoption patterns clearly highlight the influence of implementation costs, technical requirements, and expected returns on farmers' decision-making. This contrast between widely adopted and less adopted practices underscores the need for policy interventions that promote a more inclusive and comprehensive approach to CSA adoption among smallholder farmers.

Adoption Category	**CSA Practices**	**Adoption Rate (%)**
High Adoption (>65%)	Crop diversification	94.3
	Crop rotation	90.9
	Inorganic fertilizer	88.3
Moderate Adoption (35-65%)	Improved seed	64.2
	Mulching	60.8
	Organic Fertilizer	59.5
Low adoption (<35%)	Agroforestry	22.3
	Drip irrigation	9
	Greenhouse farming	3

Table 2: Adoption levels of CSA practices

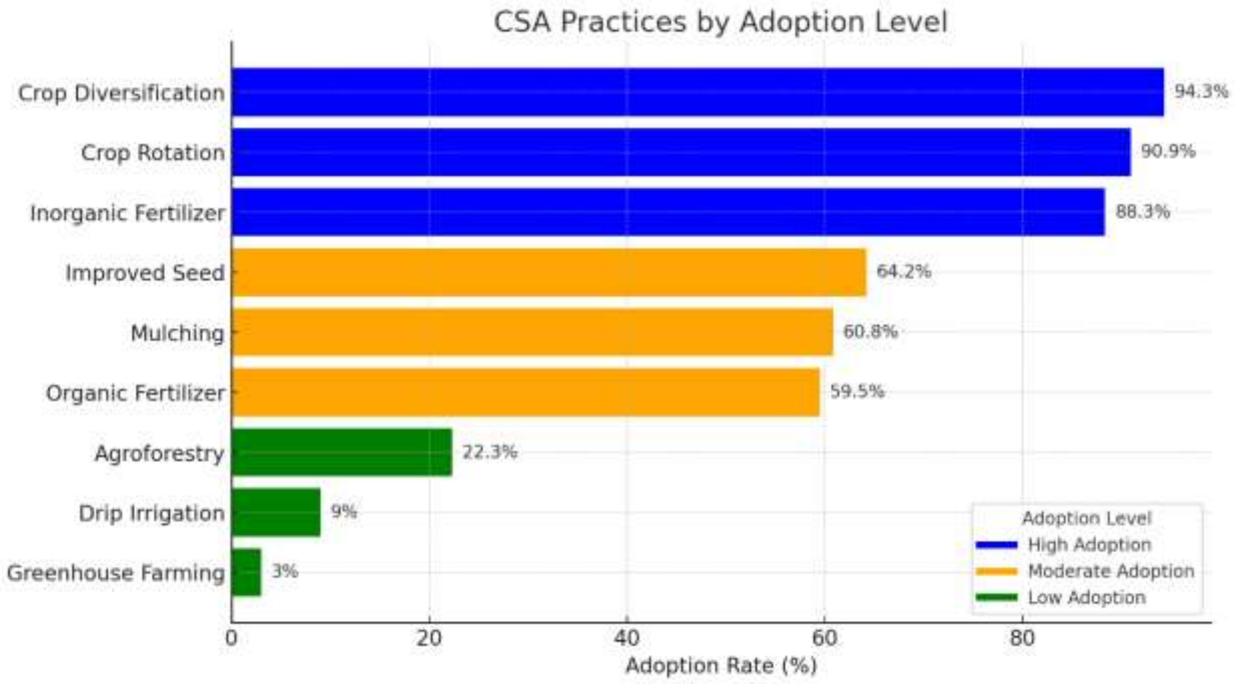


Figure 4: Adoption levels of Climate-Smart Agriculture (CSA) practices

Determinants of Adoption Decision of CSA Practices.

The probit regression analysis in **Table** 3 highlights key structural factors influencing Climate-Smart Agriculture (CSA) adoption among smallholder leafy vegetable farmers in semi-arid central Tanzania. Controlling for multiple variables, the findings confirm that marital status, land size, and land ownership significantly shape adoption decisions, while traditional demographic factors such as gender, age, education, household size, and market access show no significant effect. This suggests that CSA adoption is driven more by structural and economic constraints than by individual characteristics (Murage et al., 2021).

Being married negatively impacts CSA adoption ($\beta = -0.24$, $p < 0.05$), contradicting the descriptive findings that indicated higher adoption rates among married farmers. This discrepancy suggests that married farmers face hidden constraints such as financial burdens or risk aversion that limit implementation. These results align with Anum et al. (2022) and Murage et al. (2021), who emphasize that household structures introduce complexities in decision-making that may hinder adoption despite initial willingness. Similarly, land size significantly influences adoption, with smaller landholdings increasing the likelihood of CSA adoption ($\beta = -0.19$, $p < 0.01$). This supports arguments by Abdureman Omer and Hassen (2020) and Bongole (2023), who contend that smallholders, constrained by land scarcity, adopt CSA as a necessity-driven strategy, whereas larger landowners may not feel the same urgency to innovate.

Land ownership, though only marginally significant ($\beta = 0.23$, $p < 0.1$), also plays a role, with landowners and renters more likely to adopt CSA than those relying on family-owned land. This finding aligns with Chavula and Turyasingura (2022) and Kehinde et al. (2021), who highlight that secure land tenure fosters long-term investment in sustainable practices. Given the prevalence of family-owned land, policy interventions should focus on tenure security to enable independent decision-making.

The absence of significant effects for commonly assumed drivers of adoption, such as gender and education, challenges conventional perspectives. Instead, these results reinforce the argument that in semi-arid regions, adoption decisions are shaped more by access to resources and institutional support than by demographic traits. To enhance CSA adoption, policies should prioritize land tenure reforms, targeted financial support for smallholders, and initiatives addressing household-level adoption constraints**,** ensuring that interventions align with the economic realities of smallholder farmers (Antwi, K., & Antwi-Agyei, P. (2023).

Adoption	Coef.	St.Err.	Margin effect	p-value	[95% Conf	Interval]	Sig
Sex of respondent	-0.16	0.14	1.49	0.21	-0.43	0.13	
Age of the respondent	-0.03	0.08	2.19	0.63	-0.18	0.12	
Household size	0.04	0.05	5.36	0.44	-0.06	0.13	
Education level	0.00	0.08	3.84	0.10	-0.16	0.16	
Marital status	-0.24	0.11	2.14	0.03	-0.46	-0.03	**
Land Ownership	0.23	0.12	2.04	0.06	-0.01	0.47	*
Land size acres	-0.19	0.07	1.97	0.00	-0.33	-0.06	***
Proximity to water source	-0.04	0.25	1.09	0.87	-0.53	0.45	
Market access	-0.03	0.16	2.74	0.86	-0.34	0.28	
Constant	0.88	0.73	0.62	0.23	-0.54	2.32	***

Mean dependent var	0.613	SD dependent var	0.488
Pseudo r-squared	0.047	Number of Obs	385
Chi-square	24.369	Prob > chi2	0.007
Akaike crit. (AIC)	511.524	Bayesian crit. (BIC)	555.010

**** p<.01, ** p<.05, * p<.1*

Table 3. Probit regression: Determinants of adoption decisions CSA practices

Determinants of Adoption Intensity of CSA Practices

The truncated regression analysis in Table 4 highlights key factors influencing the intensity of Climate-Smart Agriculture (CSA) adoption among smallholder leafy vegetable farmers in semi-arid central Tanzania. Adoption intensity, measured as the proportion of land allocated to each CSA practice, varied across nine techniques, with gender, age, household size, land ownership, and land size showing significant effects. These findings emphasize that structural and socio-economic constraints play a larger role than individual farmer characteristics in shaping CSA adoption intensity.

Gender disparities were evident, with male farmers exhibiting higher adoption intensities for crop diversification ($\beta = 0.42$, $p < 0.05$), crop rotation ($\beta = 0.35$, $p < 0.05$), and mulching ($\beta = 0.29$, $p < 0.05$), reinforcing existing inequalities in resource access and decision-making power (Mensah et al., 2021; Ngigi & Muange, 2022). Without targeted gender-sensitive interventions, such as access to credit and training for female farmers, CSA adoption will likely remain uneven. Similarly, age influenced adoption intensity, with older farmers favoring traditional techniques like crop rotation ($\beta = 0.20$, $p < 0.05$) and drip irrigation ($\beta = 0.20$, $p < 0.05$), while younger farmers adopted modern methods, such as improved seeds ($\beta = -0.16$, $p < 0.05$) and mulching ($\beta = -0.19$, $p < 0.05$). These generational differences reflect long-standing challenges in technology transfer and adoption (Abegunde & Obi, 2022; Strauss et al., 2021).

Household size influenced labor-intensive practices, increasing the adoption of animal manure ($\beta = 0.18$, $p < 0.05$) and improved seeds ($\beta = 0.10$, $p < 0.05$), while larger households deprioritized capital-intensive methods like agroforestry ($\beta = -0.08$, $p < 0.05$) and greenhouse farming (β = −0.12, p < 0.05). These findings align with Timothy et al. (2022) and Zakaria et al. (2020), emphasizing the role of labor availability in shaping adoption choices. Secure land tenure encouraged greater investment in CSA, particularly inorganic fertilizer (β = 0.49, p < 0.05) and mulching (β = 0.47, p < 0.05), while tenure insecurity discouraged long-term investments like agroforestry (β = −0.39, p < 0.05) (Kehinde et al., 2021; Thinda et al., 2020). Additionally, land size constrained adoption intensity, with smaller farms more likely to implement CSA techniques to maximize productivity (Atuoye et al., 2021).

These findings challenge traditional narratives that emphasize demographic characteristics as key drivers of CSA adoption. Instead, they underscore the structural barriers that smallholders face, highlighting the urgent need for context-specific policies. Addressing gender inequities, ensuring land tenure security, and improving financial access for capital-intensive practices are crucial for enhancing CSA adoption. Without targeted interventions, smallholder farmers will continue to face systemic constraints that limit their capacity to implement climate-resilient practices effectively.

Practices	Diversification	Rotation	Inorganic fertlilizer	Animal manure	Improved seed	Mulching	Agroforest	Green house	Drip irrigation
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
Sex of respondent	-0.42*	-0.35*	0.16	0.04	-0.15	-0.29*	-0.23	-0.10	0.28
Age of the respondent	0.18	0.2*	0.02	-0.19*	-0.16*	-0.19*	0.02	0.02	0.20*
Household size	0.02	0.01	0.04	0.18*	0.10*	0.06	-0.08*	-0.12**	-0.16*
Education level	0.15	0.06	-0.25*	-0.08	-0.05	-0.11	-0.10	0.08	-0.04
Marital status	-0.06	0.04	-0.01	0.13	-0.20	-0.07	-0.45*	-0.33*	-0.24
Land Ownership	0.22	-0.18	0.49*	0.56*	0.32*	0.47*	-0.39*	-0.22	-0.38*
Land size acres	-0.02*	-0.24*	0.08	-0.16*	-0.08	-0.11	0.10	0.18*	0.20*
Proximity to water	0.42	0.34	-0.35	-0.23	-0.30	-0.52*	0.16	-0.25	-0.34
Market access	0.06	0.20	0.06	0.22	0.16	0.27*	-0.27*	-0.30	-0.23
Constant	0.57	1.01	0.02	-1.41*	0.45	0.45	2.32*	1.52	0.72
Margin effect	0.90*	0.88*	0.61*	0.58*	0.54*	0.60*	0.29*	0.29*	0.24*

** p<0.05*

Table 4: Determinants of Adoption Intensity of CSA practices

Theoretical Contribution

This study extends Expected Utility Theory (EUT) by applying it to the adoption and intensity of Climate-Smart Agriculture (CSA) practices among smallholder leafy vegetable agripreneurs.

While EUT explains decision-making under uncertainty by weighing perceived benefits, costs, and risks, this study refines its application by highlighting perceived utility as a mediating factor, where context-specific factors such as land tenure, institutional support, and climate variability shape adoption decisions.

The findings reveal that CSA adoption is often necessity-driven, influenced more by external constraints than purely rational optimization. Secure land tenure, particularly through rental or private ownership, enhances adoption, whereas reliance on family-owned land discourages long-term investment. Additionally, market access and extension services play a crucial role in shaping perceived utility, reinforcing that CSA uptake is not merely an economic choice but also a response to environmental and institutional conditions.

Through the integration of a Double Hurdle Model, this study differentiates between adoption decisions and adoption intensity, offering a nuanced perspective on technology uptake. Overall, it advances behavioral agricultural economics by refining EUT's relevance to smallholder farming in climate-vulnerable regions, providing valuable insights for policies that address both economic and behavioral barriers to CSA adoption.

Policy Implications of the Study

The findings of this study on Climate-Smart Agriculture (CSA) adoption among smallholder leafy vegetable agripreneurs in semi-arid central Tanzania provide key insights for policymakers, development practitioners, and agricultural stakeholders. Several policy implications emerge, emphasizing the need for targeted interventions to enhance CSA adoption and promote sustainable agricultural practices.

Land tenure security significantly influences CSA adoption, with farmers who rent or own land exhibiting higher adoption rates than those relying on family-owned land. Secure land tenure incentivizes investment in sustainable practices, while gender disparities in CSA adoption intensity suggest the need for inclusive policies. Amending the National Land Policy (1995) and the Village Land Act (1999) to enhance land tenure security for smallholder farmers can promote long-term investment in CSA. Legal frameworks that facilitate land ownership transitions and financial incentives for CSA adoption should be introduced. Additionally, strengthening women's participation in decision-making and ensuring equal access to land, credit, and training will enhance their engagement in CSA adoption.

Smallholder farmers with limited landholdings are more likely to adopt CSA, yet capital-intensive practices such as agroforestry, greenhouse farming, and drip irrigation remain underutilized due to high costs and technical challenges. The Tanzania Agriculture and Food Security Investment Plan (TAFSIP, 2011) and the Building a Better Tomorrow (BBT) Strategy (2021) should integrate targeted credit facilities, grants, and subsidies to improve access to CSA technologies. The BBT Strategy, which focuses on empowering youth and women in agribusiness, should be leveraged to enhance access to land, finance, technology, and markets. Expanding agricultural extension services through technical training, on-farm demonstrations, and digital advisory platforms can further improve CSA adoption rates.

Given the limitations of this cross-sectional study, future research should adopt a longitudinal approach to track CSA adoption trends over time. Comparative studies across different agroecological zones and farming systems would provide a broader understanding of adoption dynamics. The National Environmental Policy (2021) should prioritize funding for CSA research, particularly on evolving climate challenges and adoption barriers. Research should also consider gender-specific constraints to ensure inclusive policies that support women farmers. Strengthening collaborations between the government, research institutions, and development partners will facilitate evidence-based policymaking and sustainable agricultural development.

These policy measures align with key global commitments and international frameworks addressing climate change, food security, and sustainable development. The promotion of CSA adoption supports the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) by improving agricultural productivity, SDG 13 (Climate Action) by promoting climate-resilient farming, and SDG 5 (Gender Equality) by advocating for women's access to land, credit, and training. Furthermore, these policies reinforce Tanzania's commitments under the Paris Agreement (2015) and the United Nations Framework Convention on Climate Change (UNFCCC, 1992) by fostering climate adaptation strategies in agriculture. Aligning national policies with regional and global initiatives will enhance Tanzania's agricultural resilience, ensure sustainable livelihoods, and contribute to long-term food security in semi-arid regions.

Limitations of the Study

This study provides valuable insights into the adoption and intensity of Climate-Smart Agriculture (CSA) practices among smallholder leafy vegetable agripreneurs in semi-arid Central Tanzania. However, several limitations must be acknowledged. First, the study adopts a cross-sectional research design, capturing CSA adoption behavior at a single point in time. This limits the ability to establish causal relationships between determinants and adoption decisions, making it difficult to assess how adoption evolves over time. Additionally, the study relies on self-reported data, which may introduce social desirability bias or recall errors. Farmers might overstate or understate their CSA adoption levels due to personal beliefs, external pressures, or misunderstanding of certain practices, affecting the accuracy of findings.

Moreover, while the study focuses on smallholder leafy vegetable agripreneurs, its findings may not be fully generalizable to other agricultural sectors or geographical contexts in Tanzania. Adoption drivers may vary depending on the type of crop, farming system, or regional climate conditions. Finally, although the study accounts for economic and institutional factors, it does not deeply explore psychosocial and cognitive factors, such as risk perception, personal innovativeness, and learning behavior. These elements play a critical role in shaping farmers' decision-making processes, yet they remain underexplored within the study's scope.

Conclusion

This study provides critical insights into the adoption and intensity of Climate-Smart Agriculture (CSA) practices among smallholder leafy vegetable agripreneurs in semi-arid central Tanzania. By applying the Expected Utility Theory and a double hurdle model, the study highlights the structural and behavioral factors influencing farmers' decisions to adopt and implement CSA practices. Findings reveal that land tenure security, market access, and extension services are key determinants of CSA adoption, while financial constraints and technical complexity hinder widespread adoption.

One of the significant findings is that farmers who rent or own land are more likely to adopt CSA than those relying on family-owned land, suggesting that tenure security encourages long-term investments in sustainable practices. Additionally, gender disparities persist, with male farmers exhibiting higher adoption intensity, particularly for capital-intensive practices such as agroforestry and drip irrigation. Smaller landholders demonstrate greater CSA uptake due to the necessity of maximizing productivity, whereas larger landholders adopt at lower rates, possibly due to resource availability.

These findings underscore the need for targeted policy interventions. Enhancing land tenure security through reforms in the National Land Policy (1995) and the Village Land Act (1999) can encourage CSA investment. Financial support mechanisms, such as subsidies, low-interest loans, and credit facilities, should be expanded to mitigate adoption barriers. Strengthening agricultural extension services, particularly for women and youth, is also crucial for fostering inclusive adoption.

Aligning these policy measures with international commitments, such as the Sustainable Development Goals (SDGs) and the Paris Agreement (2015), will ensure that Tanzania enhances its agricultural resilience and contributes to global climate adaptation efforts. Future research should adopt a longitudinal approach to assess the long-term impacts of CSA adoption and explore additional socio-psychological factors influencing adoption decisions.

Recommendations for Future Research

To address these limitations, future research should consider adopting a longitudinal approach to track CSA adoption over time. This would provide a more comprehensive understanding of how adoption decisions evolve in response to changing environmental, economic, and institutional conditions. Additionally, incorporating direct farm-level observations, remote sensing technologies, or experimental studies would improve data accuracy and reduce the risk of bias associated with self-reported adoption claims.

Comparative studies across different agroecological zones and farming systems are also necessary to assess context-specific adoption drivers. Expanding research beyond leafy vegetable agripreneurs to include a broader range of crops and farming models would enhance the generalizability of findings. Lastly, integrating insights from behavioral economics and social psychology, with a focus on risk perception, decision-making heuristics, and farmer learning behavior, would provide a deeper understanding of the psychological and cognitive factors influencing CSA adoption. By addressing these areas, future studies can strengthen the evidence base for promoting CSA adoption and enhancing resilience among smallholder farmers in climate-vulnerable regions.

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