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Socio-Demographic Determinants of Climate-Smart Agriculture Adoption Among Smallholder Crop Producers in Bushbuckridge, Mpumalanga Province of South Africa

Variety Nkateko Thabane *, Isaac Azikiwe Agholor, Moses Zakhele Sithole, Mishal Trevor Morepje, Nomzamo Sharon Msweli and Lethu Inneth Mgwenya

School of Agriculture, University of Mpumalanga, Mbombela 1200, South Africa; isaac.agholor@ump.ac.za (I.A.A.); moses.sithole@ump.ac.za (M.Z.S.); 201503045@ump.ac.za (M.T.M.); 201836335@ump.ac.za (N.S.M.); 201971976@ump.ac.za (L.I.M.)

* Correspondence: 201988429@ump.ac.za

Abstract: Climate-smart agriculture (CSA) is a transformative approach to farming that aims to meet the demands of increasing food production under the growing pressures of climate change. CSA's goals are to boost agricultural productivity, enhance resilience to climate impacts, and reduce greenhouse gas emissions. Thus, the study explored farmers' socio-demographic factors influencing the adoption of CSA in sustainable crop production. The study was carried out in Bushbuckridge, Mpumalanga province of South Africa, with a focus on smallholder crop producers in the area. The study surveyed 300 smallholder farmers and employed simple random sampling, structured questionnaires, and a binary logistic regression model for data analysis. The significant and positive socio-demographic variables relevant to the adoption of climate-smart practices were level of education ($p < 0.014$), household size ($p < 0.007$), farm experience ($p < 0.053$), and farmland fertility ($p < 0.047$). Therefore, for CSA practices to be adopted by smallholder crop producers, a targeted approach is needed to address this issue. Therefore, support and training are needed to bridge the literacy gap among smallholder crop producers with the overall aim of improving their understanding of climate change and CSA practices that can mitigate the effects of climate change.

Keywords: climate change; climate-smart agriculture; smallholder farmers; crop production; adaptation strategies

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1. Introduction

Climate change significantly impacts agriculture and food security [1], particularly affecting smallholder farmers in developing countries like South Africa due to limited resources and rain-fed agriculture [2,3]. To address this, climate-smart agriculture (CSA) has emerged as a vital strategy to enhance productivity and resilience [4]. CSA aims to increase agricultural productivity, adaptive capacity, and reduce greenhouse gas emissions [5], mitigating climate-related risks [6]. Furthermore, CSA adoption is crucial for ensuring sustainable agricultural practices. Despite its benefits, CSA adoption remains low among smallholder farmers [5], hindered by limited access to information, financial constraints, cultural barriers, and inadequate institutional support [5,6]. Moreover, these constraints exacerbate vulnerabilities to climate-related stresses. CSA practices, including conservation agriculture, agroforestry, crop rotation, and integrated pest management enhance agricultural resilience by improving soil health, reducing emissions, and promoting water conservation [7]. Specifically, conservation agriculture enhances agricultural resilience by minimizing soil disturbance, retaining crop residues and promoting crop rotations [8].

CA further reduces soil erosion, improves soil organic matter, and enhances water infiltration, thereby reducing water loss. By minimizing tillage, CA decreases greenhouse gas emissions and promotes carbon sequestration. Additionally, CA improves soil biodiversity, reduces weed pressure and enhances nutrient cycling, leading to increased crop yields and reduced chemical fertilizer use [9]. Crop rotation involves alternating crops to break disease and pest cycles, improve soil fertility and structure, and promote ecological balance [10]. This practice enhances agricultural resilience by reducing soil-borne diseases and pests; improving soil organic matter and nutrient availability; increasing crop yields; and promoting water conservation.

Crop rotation also mitigates climate change by reducing synthetic fertilizer use, promoting carbon sequestration, and enhancing soil biodiversity [11]. Integrated Pest Management (IPM) combines physical, cultural, biological, and chemical controls to manage pests sustainably [12]. IPM enhances agricultural resilience by reducing chemical pesticide use; promoting ecological balance; conserving beneficial organisms; and improving crop yields. IPM also mitigates climate change by reducing greenhouse gas emissions from pesticide production and use and promoting soil health [13]. Additionally, agroforestry integrates trees into farming systems, promoting ecological interactions between trees, crops, and livestock [14].

This practice enhances agricultural resilience by improving soil health through shade, organic matter, and nutrient cycling; reducing soil erosion; increasing biodiversity; and providing additional income sources [15]. Agroforestry also mitigates climate change by sequestering carbon, reducing greenhouse gas emissions and moderating microclimates. This study is crucial because it highlights vulnerabilities of South African smallholder farmers to climate change. Understanding socio-demographic factors influencing CSA adoption informs tailored adaptation plans, improving food security and sustainable lifestyles [5].

Policymakers, agricultural extension agencies, and developmental organizations will benefit from these findings. Moreover, this research addresses knowledge gaps in CSA adoption dynamics. Additionally, this study investigates socio-demographic determinants influencing CSA adoption among smallholder crop producers in Bushbuckridge, Mpumalanga Province, South Africa. Given the region's reliance on subsistence farming and rain-fed agriculture practice, with dominant crops like maize, beans, and cowpeas, climate-related stresses frequently impact on yields. Uniquely, this study focuses on specific regional, cultural, and economic contexts, providing tailored insights for localized agricultural policies and programs [6].

2. Literature Review

2.1. Overview of Climate-Smart Agriculture

Smallholder farmers worldwide make climate-smart agriculture (CSA) adoption decisions based on socio-demographic factors influencing climate change [16]. Consequently, the relationship between socio-demographic characteristics and CSA adoption in South Africa's regional contexts remains poorly understood. Smallholder farmers should detect changes and implement adaptation strategies [6]. Climate change response strategies depend on access to CSA knowledge and mitigation techniques [7]. Adaptation strategies reduce household susceptibility to climate change. Understanding smallholder farmers' climate change perceptions is pivotal [17].

Previous research [18] has mostly concentrated on universal CSA adoption variables, ignoring the complex effects of regionally specific cultural, economic, and environmental factors, such as those seen in Bushbuckridge, Mpumalanga Province. Olabanji et al.'s [19] study in the Olifants catchment found 98% of smallholder farmers aware of climate change impacts. This awareness provides a solid basis for adaptation and mitigation measures.

Olabanji et al. [19] used the Mann–Kendall test to examine the impact of temperature and precipitation trends in the Olifants watershed of South Africa, and the result had significant implications for CSA adoption. The study conducted by Olabanji et al. [19] on the assessment of the smallholder farmers' perception and adaptation response to climate change in the Olifants catchment, South Africa, has significant implications for CSA adoption in South Africa. Increasing temperatures and decreasing precipitation necessitate adaptations like water harvesting, conservation agriculture, and drought-tolerant crops. Policymakers, researchers, and extension agencies must collaborate to enhance information access, farmer support services, and specialized training programs [20]. Sub-Saharan Africa's agriculture faces severe climate change threats, especially in Ghana and Kenya, with 1.5% to 10.2% precipitation. For instance, Ghana's sustainable agricultural development policy [nd National Climate-Smart Agriculture and Food Security Action Plan encourage CSA adoption [21,22].

Despite efforts, CSA adoption rates among smallholder farmers in South Africa remain low [23]. Antwi et al. [24] found CSA adoption influenced by socio-demographic characteristics, climate change understanding, extension services, and financial incentives. The adoption rate of CSA among smallholder farmers in various regions of South Africa is still surprisingly low. Effective CSA practices are vital for sustainably growing agriculture, guaranteeing food security, and reducing the impact of climate change [25].

2.2. Socio-Demographic Determinants of Climate-Smart Agriculture Adoption

Research indicates that socio-demographic factors, including age, gender, education, household size, and farming experience, significantly influence CSA adoption [24]. For instance, older farmers may be less likely to adopt CSA practices due to traditional methods, while female farmers face unique challenges, including limited access to resources and training. Higher education levels enhance CSA adoption, whereas larger households may face adoption challenges due to resource constraints. Understanding these socio-demographic determinants is crucial for developing targeted interventions and policies that are promoting CSA adoption.

CSA entails agricultural practices that sustainably enhance agricultural productivity, improve resilience to climate change, and decrease greenhouse gas emissions. CSA encapsulates three notable objectives: (i) yield, through improved crop and animal production, conservation of agriculture, and good water management; (ii) adaptation, by improving farmers' ability to cope with climate-related events; and (iii) extenuation, by reducing agricultural greenhouse gas [3,26–29]. Regional variations and local specificities play a crucial role in CSA adoption. Drought-tolerant crops and rainwater harvesting are essential in the Western Cape, while flooding resilience measures are crucial in the Eastern Cape.

Regional-specific adaptation strategies are vital [19]. The Olifants catchment's smallholder farmers have a solid basis for adaptation and mitigation measures since they are acutely aware of climate change impacts. Understanding regional variations and local specificities is critical for effective CSA adoption. Despite its importance, CSA adoption in South Africa faces multifaceted challenges. Land reform and tenure insecurity hinder the smallholder farmers' ability to invest in sustainable practices. The legacy of apartheid-era land distribution has resulted in fragmented and uneconomical farm sizes, reducing agricultural productivity and efficiency [30].

Inadequate knowledge transfer and extension services further impede CSA adoption. South African farmers require localized, climate-specific recommendations. Insufficient training and financial constraints exacerbate these issues [31]. Women and youth farmers face additional barriers, including limited access to resources, training, and markets [32]. Addressing existing research limitations, policymakers, researchers, and extension agencies must collaborate to enhance information access, farmer support services, and specialized training programs [20]. Sub-Saharan Africa needs a resilient agricultural sector; prioritizing CSA adoption and providing smallholder farmers necessary tools, resources, and assistance is imperative [33].

3. Theoretical Framework: The Innovation-Decision Process Theory

This study employs Everett M. Rogers' Innovation-Decision Process Theory of 1962, which examines how ideas and information disseminate among smallholder farmers [34]. The theory further provides an in-depth comprehension of the factors that lead to smallholder farmers adopting or rejecting innovations. Innovation, channels of communication, time, and social systems are the factors that determine the preservation of ideas [35]. The innovation-decision process theory consists of five stages, which are knowledge, persuasion, decision process, implementation, and confirmation [36]. The first step, knowledge, refers to smallholder farmers becoming alert about adaptation strategies and willing to learn more about these strategies and how they work [37].

Initially, smallholder farmers gain knowledge about adaptation strategies and express willingness to learn more. Persuasion depends on farmers' favorable perception of innovations [37]. The decision process comes into place when smallholder farmers employ activities that influence their choice to adopt or reject CSA practices [37]. Implementation is when the smallholder farmers make use of the CSA practices. Lastly, confirmation is undertaken when the smallholder farmers have made use of adaptation strategies and confirm that the strategies are useful or not [35]. This theory suggests CSA adoption depends on farmers' requirements, ease of use, affordability, education level, and access to funding [3]. Smallholder farmers may reject complex strategies due to limited education or perceive CSA practices as expensive [38].

Given its focus on adaptation strategy adoption, Rogers' theory guides this study. Frequent interactions among smallholder farmers within social systems necessitate consideration of regional, cultural, and economic variations [39]. This theory suits the study's objectives, providing recommendations for adaptation strategy adoption among farmers. The existing literature often generalizes findings without accounting for regional, cultural, and economic variations. This study addresses socio-demographic factors' independent and interactive effects on CSA adoption. By exploring sustained CSA adoption over time, this research fills knowledge gaps on long-term sustainability [39]. The study's findings contribute to designing effective, sustainable CSA initiatives promoting resilience among smallholder farmers. Understanding socio-demographic factors' impact on continued CSA practice adoption informs localized agricultural policies and programs. This research enhances Rogers' Innovation-Decision Process Theory by emphasizing regional specificity and socio-demographic nuances in CSA adoption [40].

4. Materials and Methods

4.1. Study Area

The study was conducted in the Bushbuckridge Local Municipality (Figure 1), Ehlanzeni District Municipality of the Mpumalanga province of South Africa. The main economic activities of the municipality are mainly tourism and agriculture [41]. The municipality covers an estimated area of 1,000,000 ha as some portion of the Kruger National Park forms part of the municipal land [42]. The population of the Bushbuckridge municipality was 750,821 people in 2022 according to a community survey [42].

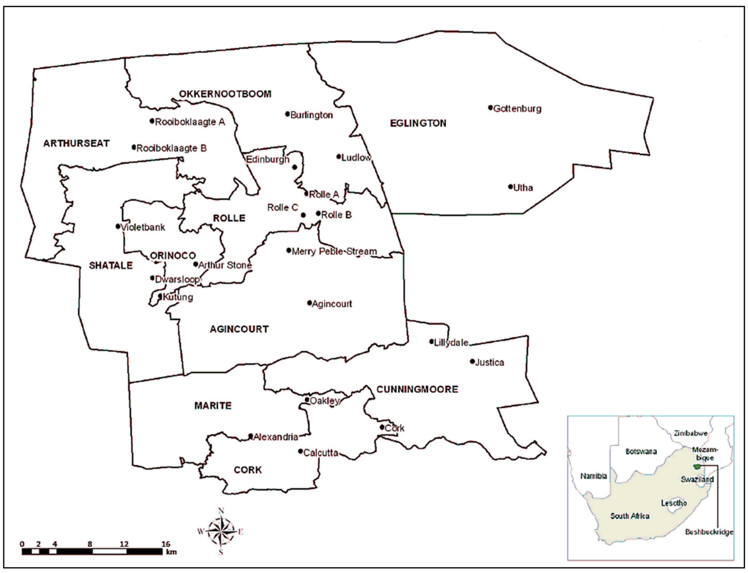

Figure 1. Map of Bushbuckridge local municipality [41].

4.2. Research Design

This study employed a descriptive research design and a quantitative approach, also known as survey research design. This design enabled the collection of quantitative data, providing valuable insights into smallholder farmers' climate-smart adaptation strategies in the study area.

4.3. Sampling Method

This study employed simple random sampling (SRS) to select participants from Bushbuckridge's registered (6000) smallholder farmers, ensuring fairness and unbiased representation. Simple random sampling method was chosen for its straightforward and equitable nature, alleviating selection bias concerns and facilitating generalizability [43]. The sampling frame comprised the local agricultural extension department's comprehensive farmer registry.

4.4. Sample Size

The units of analysis were smallholder farmers in the study area. Slovin's formula was used to determine the sample size, with a 5% margin of error and a 95% confidence interval. The sample was calculated as follows:

$$n \quad \frac{N}{1+N^2}$$

$$n \quad \frac{6000}{1+6000\left(0.05\right)^2}$$

$$n = 375 \text{ respondents}$$

The intended sample size of 375 smallholder farmers was not accomplished due to time constraints, and reluctance of extension officers to provide farmer information. Data were collected from 300 smallholder farmers in the study area. The questionnaire items were used to collect data from respondents.

4.5. Data Collection

Data were collected using a structured questionnaire, in which the participants were provided with questionnaires and were expected to select answers from the pre-formulated answers on the questionnaires [44]. Prior to data collection, enumerators were appointed to help with data collection. The pilot data collection survey and testing of the data collection instruments was performed. All ethical concerns were vigorously attended, and the privacy of all respondents in the survey was assured, and their rights and privileges were considered. The freedom to withdraw from the survey at any time was also clarified for all participants. Finally, ethical clearance certificate with Protocol Reference Number: UMP/Thabane/201988429/MAGR/2023) date 11 August2023. was issued by the University of Mpumalanga, South Africa.

4.6. Data Analysis

The socio-demographic factors of smallholder crop producers were analyzed by calculating the percentage of the relevant socio-demographic variables hypothesized to influence the adoption of CSA practices. The binary logistic regression model was used to analyze the relationship between the socio-demographic variables of smallholder crop producers and their hypothesized influence on smallholder crop producer's desire to adopt CSA practices. The regression model is the most suitable statistical method for analyzing the influence of socio-demographic factors on adopting CSA practices. This approach effectively models binary outcomes, such as adopt or not adopt, based on multiple predictor variables. Its key benefits include handling binary outcomes, accommodating multiple predictors, and providing probability estimations. Binary logistic regression has been successfully applied in various climate change-related studies [21].

The model categorizes individuals into groups and identifies qualities that predict decision-making. For instance, Waaswa et al. [45] carried out a study on the understanding of the socioeconomic determinants of adoption of climate-smart agricultural practices among smallholder potato farmers in Gilgil Sub-County, Kenya. Msweli et al. [26] analyzed socio-demographic factors affecting the acceptance of CSA adoption in South Africa. These studies demonstrate the effectiveness of binary logistic regression in understanding the complex relationships between socio-demographic factors and CSA adoption. The study used a dichotomous variable, Ri, to represent smallholder crop producer's desire to adopt CSA resulting from the hypothesized influence socio-demographic factors have on the adoption of CSA practices. The probability of adopting CSA practices as influenced by socio-demographic factors was calculated as Pr (Ri = 1):

$$Y = \beta o + \beta 1\ X1 + \beta 2\ X2 + \ldots + \beta 11\ X11 + \mu \ldots$$

where

Y = desire to adopt CSA practices (Desire to adopt = 1, No desire to adopt = 0).

X_1–X_{11} = Independent variables demarcated as: (socio)

X_1 = Gender = (Female = 1, Male = 2)

X_2 = Age (years) = (<36) = 1, (36–40) = 2, (41–45) = 3, (46–50) = 4, (51–55) = 5, (56–60) = 6, (>60) = 7

X_3 = Level of education = (Not educated = 1, Primary School Level = 2, High School Level = 3, Tertiary = 4)

X_4 = Household size (numerical) = ($\leq$3 members) = 1, (4–6 members) = 2, (7–9 members) = 3, ($\geq$10 members) = 4

X_5 = Source of income = (Remittance) = 1, (Sassa Grant) = 2, (Pension) = 3, (Farming) = 4, (Part-time Job) = 5, (Other) = 6

X_6 = Land ownership = (Own) = 1, (Renting) = 2, (Communal) = 3, (Inheritance) = 4, (Other) = 5

X_7 = Farming experience (years) = (<5 years) = 1, (5–10 years) = 2, (10–15 years) = 3, (15–20 years) = 4, (>20 years) = 5

X_8 = Farm size (numerical) = (<5 acres) = 1, (5–10 acres) = 2, (10–15 acres) = 3, (15–20 acres) = 4, (>20 acres) = 5

X_9 = Crop type = (Cabbage) = 1, (Spinach) = 2, (Tomatoes) = 3, (Lettuce) = 4, (Peppers) = 5, (Chilies) = 6, (Other) = 7

X_{10} = Land's fertility = (Very Infertile) = 1, (Infertile) = 2, (Neither fertile nor infertile) = 3, (Very Fertile) = 4, (Fertile) = 5

X_{11} = Source of water = (Rainwater) = 1, (Tap Water) = 2, (Borehole) = 3, (Wells) = 4, (Reservoirs) = 5, (Other) = 6

$\beta 0$ = constant

B_1-β_{11} = Regression coefficients

μ = error term

5. Results

5.1. Socio-Demographic Factors of Smallholder Crop Production Farmers

The study's sample of 300 smallholder farmers revealed intriguing socio-demographic trends and are presented in Table 1. Age distribution (Table 1) showed 9.5% of respondents were less than 36 years, 10.8% between 36 and 45 years, 17.6% between 46 and 55 years, 20.6% between 56 and 60 years, and 40.7% over 60 years, indicating potential succession challenges. By citing Table 1, female farmers (59.0%) outnumbered male farmers (41.0%), highlighting gender-based opportunities for CSA adoption [20].

Table 1. Socio-demographic characteristics of smallholder farmers in the study area.

Socio-Demographic Characteristics	Variables	Percentage (%)
Age	<36 years	9.5
	36–45 years	10.8
	46–55 years	17.6
	56–60 years	20.6
	>60 years	40.7
Gender	Male	41.0
	Female	59.0
Educational level	No school	6.7
	Adult school (ABET)	3.0
	Primary school	20.3
	Secondary school	61.7
	Tertiary education	8.3
Household Size	<3 members	17.0
	4–6 members	54.0
	7–9 members	20.0
	>10 members	9.0
Farm experience	<5 years	30.7
	6–10 years	20.7
	11–15 years	15.3
	16–20 years	10.3
	>20 years	23.0

Educational levels varied, with 6.7% having no formal education, 3.0% attending adult school (ABET), 20.3% completing primary school, 61.7% finishing secondary school, and 8.3% attaining tertiary education. Household size ranged from 17.0% with less than three members to 9.0% with over ten members, with 54.0% having four-six members. Farming experience varied significantly, with 30.7% having less than five years, 20.7% with six–ten years, 15.3% with eleven–fifteen years, 10.3% with sixteen–twenty years, and 23.0% with over twenty years [20,46].

5.2. The Relationship Between Socio-Demographic Variables and the Desire to Adopt CSA Practices

The relationship between the socio-demographic variables of smallholder crop producers and their desire to adopt CSA practices is displayed below. Moreover, the Nagelkerke R Square (0.228) indicated a moderate model fit (Table 2), and the Hosmer-Lemeshow goodness-of-fit test (Table 3) confirmed the logistic regression model's adequacy, lending credibility to the findings. Overall, the regression analysis (Table 4) highlighted statistically significant predictors, collectively explaining 17.1% of the variance in CSA adoption, with a log likelihood of −357.103 (Table 2), thereby providing valuable insights for policymakers and stakeholders seeking to promote climate-resilient agricultural practices. This study delved into the intricate relationship between socio-demographic variables and the inclination towards adopting climate-smart agriculture (CSA) practices among smallholder crop producers.

Table 2. Model summary.

Step	−2 Log Likelihood	Cox and Snell R Square	Nagelkerke R Square
1	357.103	0.171	0.228

Table 3. Hosmer and Lemeshow (HL) goodness-of-fit test.

Step	Chi-Square	Df	Sig.
1	5.937	8	0.654

Table 4. Regression results on CSA adoption and influential socio-demographic variables.

Predictor Variables	B	S.E.	Wald	Df	Sig.	Exp(B)	95% C.I. for EXP(B) Lower	Upper
Gender	−0.409	0.318	1.655	1	0.198	0.665	0.357	1.239
Age	0.204	0.623	0.107	1	0.743	1.227	0.361	4.163
Level of education	1.554	0.630	6.080	1	0.014 *	4.730	1.375	16.265
Household size	−1.307	0.481	7.373	1	0.007 *	0.271	0.105	0.695
Source of income	−1.326	1.070	1.538	1	0.215	0.265	0.033	2.160
Land ownership	−1.055	0.784	1.811	1	0.178	0.348	0.075	1.619
Farm experience	1.023	0.530	3.733	1	0.053 *	2.782	0.985	7.853
Farm size	−1.341	0.897	2.231	1	0.135	0.262	0.045	1.520
Crop type	−0.076	0.069	1.239	1	0.266	0.927	0.810	1.060
Land's fertility	0.262	0.132	3.936	1	0.047 *	1.300	1.003	1.684
Source of water	−1.110	0.906	1.500	1	0.221	0.330	0.056	1.947
Constant	21.473	40,193.085	0.000	1	1.000	2,115,488,200.163		
−2 Log likelihood					357.103			
Cox and Snell R Square					0.171			
Nagelkerke R Square					0.228			

The asterisk (*) represent statistical significance at 0.05.

The findings, as presented in Table 2, unequivocally indicate that the level of education (β = 1.554, p = 0.014) exerted a profound positive influence on CSA adoption, suggesting that educated farmers are more likely to embrace climate-resilient practices. Conversely, household size (β = −1.307, p = 0.007) emerged as a significant impediment to CSA adoption, implying that larger households may face greater challenges in implementing these practices. Moreover, farming experience (β = 1.023, p = 0.053) and farmland fertility (β = 0.262, p = 0.047) also positively impacted CSA adoption, underscoring the critical role of experiential knowledge and fertile land in facilitating the uptake of climate-smart practices [47]. Notably, the positive correlation between education, farming experience, and CSA adoption suggests that investing in human capital and agricultural productivity can enhance resilience to climate change [48].

6. Discussion

6.1. Socio-Demographic Factors of Smallholder Crop Production Farmers

The study examined the adoption of climate-smart agriculture (CSA) among smallholder farmers in Bushbuckridge, revealing significant implications that underscore the need for appropriate interventions. Notably, older female farmers showed great interest in CSA practices, but their limited education hindered their knowledge and ability to implement these practices effectively. This aligns with the study of Boudalia et al. [43] who observed the importance of addressing the educational needs of older female farmers. Moreover, this finding emphasizes the necessity of targeted support for older female farmers. The farming communities in rural areas are aging, according to Sanogo et al. [44], with women dominating the industry and playing a crucial role in agricultural operations and household food security.

Consequently, this demographic trend stresses the need for targeted support for older female farmers, ensuring they have the necessary skills and knowledge to adapt to climate change. Furthermore, Msweli et al. [26] emphasize that education emerges as a critical factor in CSA adoption, positively linked to informed decision-making and climate change adaptation. In line with established studies [47,49], educated farmers can access and process climate information more effectively, leading to improved decision-making. Additionally, education enhances farmers' ability to adapt to climate change by improving their analytical and problem-solving skills. On the contrary, farming experience also plays a vital role in CSA adoption. Ugwu et al. [46] support this notion, stating that experienced farmers possess valuable knowledge on climate variability and adaptation strategies, enabling them to make informed decisions.

As Fadina et al. [50] noted, this experience-based knowledge can be leveraged to promote CSA practices among newer farmers. Therefore, mentorship programs and knowledge-sharing initiatives can help bridge the gap between experienced and inexperienced farmers. However, household size presents an interesting complication. Contrary to expectations, larger households face difficulties in adopting CSA practices, potentially due to labor constraints and resource allocation [51]. This contrasts with established studies [47,49], highlighting the positive impact of household size on CSA adoption. The study further discovered that a sizeable portion of the household can also serve as a labor supply for labor-intensive agriculture operations. Therefore, it will be simple for CSA to accept more family members, particularly for labor-intensive practices [52].

6.2. The Relationship Between Socio-Demographic Variables and the Desire to Adopt CSA Practices

The implications of the level of education positively influencing the adoption of climate-smart agricultural practices are that education plays an important role in the adoption of CSA [53]. Higher education can help smallholder farmers, researchers, and professionals work together to promote the flow of knowledge about community-supported agriculture (CSA) [54]. This is consistent with a study by Ma et al. [48], that found the adoption of CSA is significantly influenced by educational attainment. The study also recommended that the government prioritize funding for the establishment of CSA training centers with ICT tools that target important demographics like women and the elderly to close the digital adoption gaps.

To guarantee farmers have access to meteorological and agro-advisory services, additional efforts should put a priority on awareness and training programs. Kassa et al. [55], contend that the suggestions would make it easier for smallholder farmers to implement the most modern CSA techniques. Additionally, Abid et al. [56] concur that this will enable the smallholder farmers to make informed decisions and spot possibilities for farm-related profit maximization when they arise. Consequently, this component is essential to the adoption of CSA methods and their dissemination among rural farmers. Moreover, educated farmers exhibit enhanced climate-risk comprehension, resource optimization and digital literacy [57–59]. Education fosters adaptability to climate change and enhances farmers' capacity to innovate and respond to climate-related risk [54]. Consequently, education is essential for CSA adoption, dissemination, and resilience among rural farmers.

Concerning household size, the empirical results depict that household size negatively influences the adoption of climate-smart agriculture (CSA). This is because households with more dependents may be less willing to take on risk, which lowers their likelihood of using novel, unproven farming techniques. Consequently, larger households exhibit reluctance in adopting innovative agricultural practices, hindering progress. This implies that to overcome labor, finance, and decision-making constraints, larger households could need specialized assistance and resources. Research argues that household members' active involvement in farming operations greatly improves the adoption of CSA, which in turn improves food security in rural areas [60,61]. The study notably discovers a favorable association between the level of CSA adoption and the involvement of household members.

The results are consistent with those of Mthethwa [62] who found that having a larger household size resulted in increased labor and exposure to information sources, which in turn generated more ideas for solutions for adapting to climate change. Conversely, Mthethwa [62] disproved the findings of Adeagbo, Mthwthwa. Refs. [60,62] study and emphasized that small family sizes were more likely to embrace labor-intensive CSA techniques and to hire workers to put them into practice. These contrasting perspectives underscore household size's complex role in CSA adoption, necessitating nuanced policy approaches. Farm experience is another factor that positively influences the adoption of CSA. Experienced farmers may enhance network and information access and make more accurate decisions about CSA adoption by learning from previous failures and breakthroughs.

This suggests that experienced farmers can use their knowledge to lessen the effects of climate change by advocating CSA practices in their communities and acting as role models. Researchers support this study by highlighting that the adoption of CSA is generally positively correlated with farming experience, meaning that the number of years of farming experience positively correlates with the level of CSA adoption [21,57]. Farmers who have previously used complementary or similar strategies may be more willing to adopt new ones because they may feel more capable of carrying them out successfully [21]. Fertile soil is more resilient to climate stress, encouraging farmers to adopt CSA practices that maintain or improve soil health. Therefore, farmers with fertile land are more likely to prioritize long-term sustainability over short-term gains, aligning with CSA's focus on climate resilience. Hence, land fertility has a positive influence on the adoption of CSA practice [58]. A related study by Dialo et al. [59] discovered that there is potential for higher production output concerning land fertility, thus supporting the findings of this study.

6.3. Study Limitations

In the context of climate-smart agriculture (CSA) research and practice, the study's scope and results were impacted by several restrictions. Due to transportation issues affecting the delivery of materials to smallholder farmers, data collection was delayed.

This made it difficult to reach the target group on time and underscored the need for CSA activities to address infrastructural and accessibility constraints. The fact that the extension officer could only supply a list of contacts rather than direct help meant that scheduling and data collection had to be performed on an individual basis, which further constrained the study's timeframe and sample size, which was just 300 respondents. This highlights the significance of efficient resource allocation and time management techniques in CSA research. To further validate and build upon these findings, more study is required as the small sample size may not be entirely representative of the larger population of smallholder farmers. Scaling CSA initiatives will be greatly impacted by these limitations, which call for creative solutions to address issues with accessibility, extension services, and resource management.

7. Study Summary and Its Applicability to Other Agricultural Contexts

Smallholder crop farmers' adoption of climate-smart agriculture (CSA) practices is highly influenced by socio-demographic factors according to the study findings. Adoption is positively influenced by education ($\beta = 1.554$, $p = 0.014$), suggesting that farmers with higher levels of education are more likely to use CSA techniques. On the other hand, adoption is negatively impacted by household size ($\beta = -1.307$, $p = 0.007$), indicating that adoption is hampered by resource limitations in bigger families. Also, adoption is positively influenced by farmland fertility ($\beta = 0.262$, $p = 0.047$) and farming experience ($\beta = 1.023$, $p = 0.053$), as farmers with fertile land and experience are more likely to embrace CSA techniques. To encourage CSA adoption, our findings emphasize the need of addressing household resource allocation, education, and utilizing agricultural expertise.

Moreover, the findings of this research offer significant perspectives that can guide the advancement of climate-smart agriculture (CSA) practices in other locations, nations, or locales, especially those with comparable agricultural and socioeconomic circumstances. The importance of these findings resides in their capacity to draw attention to important socio-demographic factors that affect the adoption of CSA, facilitating the development of focused and efficient interventions to improve sustainability in smallholder agricultural systems. The effectiveness of education in promoting the adoption of CSA highlights the necessity of knowledge-sharing and capacity-building initiatives in other areas affected by climate change. Farmer education may be given top priority by governments and development organizations through seminars, extension services, and the incorporation of

CSA concepts into agricultural curriculum. This approach is especially pertinent in areas where smallholder farmers have difficulty obtaining formal education since it may provide them with the information necessary to implement and reap the benefits of CSA practices.

The finding that adoption of CSA is adversely affected by family size raises the possibility that resource limitations may impede technological advances in agriculture. This knowledge may be used by policymakers in other fields to create support systems that lessen the resource demands of bigger farming households, such as targeted credit programs, labor-saving technology, or financial subsidies. Interventions can assist these households in making the shift to CSA practices by addressing these barriers. Furthermore, the beneficial impact of farming experience emphasizes the significance of having experienced farmers serve as CSA activists in their local farming communities. Governments and organizations can use experienced farmers to teach and train others in areas with a variety of farming specialties. Sustainable farming methods may be more widely adopted and made scalable through peer-to-peer learning models in which experienced farmers demonstrate the advantages of CSA techniques. The relationship between CSA adoption and agricultural fertility also raises the possibility that areas with different soil fertility levels may require different strategies.

For instance, agricultural extension agents and other stakeholders may concentrate on showing how CSA practices, such agroforestry or soil conservation techniques, may restore fertility in regions with less fertile land. On the other hand, initiatives may concentrate on maintaining production through CSA practices in areas with fertile land. These results on the socio-demographic factors that influence CSA adoption highlight how crucial it is to include socio-demographic factors when creating CSA initiatives. The study offers an overview for comprehending how education, household size, farming experience, and soil fertility influence the adoption of sustainable agriculture methods, even though the specific strategies may differ based on regional conditions. Regions and nations may strengthen their efforts to promote climate resilience and sustainable development in smallholder agricultural systems worldwide by putting these findings into practice.

8. Conclusions and Recommendations

The study conclusively demonstrates the pivotal role of socio-demographic characteristics in influencing smallholder farmers' adoption of climate-smart agriculture (CSA) approaches. Education level positively influences CSA adoption, while household size negatively impacts it. Farming experience and farmland fertility positively correlate with adoption. These findings align with the existing literature by emphasizing socio-demographic factors' importance in shaping agricultural practices. Moreover, female farmers' participation underscores the significance of gender-sensitive initiatives. The age distribution highlights the necessity of targeted training programs. Household size variations emphasize the importance of adaptable CSA strategies. Bushbuckridge farmers face intensified droughts, heat waves, and unpredictable rainfall patterns. To address these challenges, our study promotes CSA technologies like drought-tolerant crops, conservation tillage, and agroforestry.

Local NGOs and extension services play a crucial role in promoting these technologies. Specifically, drought-tolerant crops such as sorghum and cowpeas are being promoted, alongside conservation tillage techniques to reduce soil erosion. To address these complexities, policymakers should prioritize gender-sensitive CSA initiatives, addressing unique challenges faced by female farmers. Targeted education and training programs catering to diverse age groups and educational backgrounds are essential. Financial incentives and climate information services supporting smallholder farmers will enhance adoption rates. Soil conservation policies promoting sustainable land management and market access initiatives facilitating CSA product sales are equally crucial. Moreover, effective policy measures and stakeholder collaboration can empower farmers, enhance resilience, and promote sustainable agriculture. This synergy ensures a climate-resilient future for smallholder farmers.

Long-term sustainability necessitates ongoing monitoring, evaluation, and adaptation. Continuous capacity building, technology transfer, and extension services will foster innovative agricultural practices. Ultimately, adopting CSA approaches will improve agricultural productivity, enhance resilience to climate change, reduce greenhouse gas emissions, and ensure food security. Policymakers, researchers, extension agents, and civil society organizations must collaborate to address emerging challenges.

By prioritizing education, extension services, and financial support, policymakers can empower farmers to adopt CSA practices, mitigating climate change's impacts and ensuring sustainable livelihoods

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