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Determinants of Climate-Smart Agriculture (CSA) Technologies Adoption by Smallholder Food Crop Farmers in Mangaung Metropolitan Municipality, Free State

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ABSTRACT

Climate change is already influencing agricultural production and distribution and heightening farming risks. Over the last decade, the sector has been subject to drastic economic and social evolutions contributing to the climate variability change in the agricultural sector. Smallholder farmers, especially from developing countries (South Africa), have been recognised as the most vulnerable to climate hazards due to the prevalence of low adaptive measures. Addressing climate change's effects on agriculture is an exceptional challenge. Policymakers have presented Climate-Smart Agriculture (CSA) as an alternative strategy to enhance agricultural productivity, which will help improve food security and reduce poverty, especially in developing countries. However, the adoption and diffusion of CSA have been slow. Therefore, this paper aims to assess the determinants of (CSA) technologies adoption by smallholder food crop farmers in the Mangaung Metropolitan Municipality, Free State.

The study used a cross-sectional research design to collect data using structured questionnaires. Stratified random sampling collected data from 120 smallholder food crop farmers. Descriptive statistics and multinomial logistic regression were employed for the analysis. The study findings show that using and adopting CSA by smallholder farmers

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enhanced agricultural productivity. The majority (66%) of the sampled food crop farmers fell in the category of users of CSA practices. The study found that farmers' knowledge influenced their use and adoption of CSA technologies and farmers' available financial support. Lack of financial support, knowledge and inadequate farm inputs and training were the challenges limiting smallholder farmers from using CSA. The paper recommends that to ensure a smooth transition to climate-sensitive agricultural practices, development actors must strongly support the inculcation of indigenous knowledge of modern agricultural technologies for easy use by farmers. It also recommends that policymakers develop and implement more elaborate capacity-building programs at the local level to influence farmers' attitudes towards pro-environmental behaviour.

Keywords: Adaptive Capacity, Climate-Smart Agricultural Practices, Food Security, Smallholder Farmers.

1. INTRODUCTION

Food and nutrition insecurity affects about 14% of the total population in developing countries and remains a huge concern (Wangu, 2020). The majority of the undernourished reside in Sub-Saharan Africa (SSA). Most of these people are found in rural areas and predominantly suffer from hunger and poverty. Almost 1.2 billion of the world's population is extremely poor, and about 78% of these live in rural areas of developing countries, where agriculture is their main livelihood (Muntambara, 2016). Agricultural productivity is, however, declining significantly in developing countries due to several challenges, such as climate change, high transaction costs, and lack of financial support (Giller *et al*., 2021). Climate change adds another layer of challenges to agricultural production and rural development, the most significant contributing factor affecting agricultural productivity.

Agricultural production remains the primary source of livelihood for most rural communities in developing countries (Serote *et al*., 2021). It is essential for ensuring food security and reducing poverty (Mutekwa, 2009). In SSA, agriculture provides a source of employment for more than 60% of the population and contributes about 30% of the Gross Domestic Product (GDP) (Nhemachena, 2008). Giller *et al*. (2021) and the Food and Agriculture Organisation (FAO) (2020) argued that farming activities of rural households provided the foundation of the food system in SSA, and are significant in achieving the Sustainable Development Goals: 1 – Zero Poverty and 2 – Zero Hunger.

Smallholder farmers have been at the forefront of stimulating rural economies in SSA, especially South Africa. It is estimated that there are 500 million smallholder farmers worldwide, upon which more than 2 billion people depend for their livelihoods, especially in developing countries (Serote *et al*., 2021; Kamara *et al*., 2019). Smallholder farmers grow and provide agricultural products for human consumption, and essential sources of human daily required nutrients and income generation to supplement government social grants and remittances (Abegunde *et al*., 2019).

In SSA, climate change results in low yield, total crop failure, reduced quality, and increased pest and disease occurrence, making vegetable production unprofitable (Abewoy, 2018). According to Wekesa *et al*. (2018), SSA faces deteriorating uncultivated periods, with inadequate investment in sustainable intensification and veering off from diversification in favour of mono-cropping in otherwise traditionally complex farming systems

Climate change is any change over time, whether due to natural variability or human activity (Kom *et al*., 2020; Ozor, 2009). Abegunde *et al*. (2019) define climate change to a great extent as resulting from green gas accumulation (GHG) caused by human activities. Climate change has influenced natural and social systems (IPCC, 2014). Evidence of climate change is seen in the continued rise in temperature (Komba & Muchapondwa, 2012), the increased incidence of heatwaves, a decrease in precipitation events, a decrease of rainfall in sub-tropical areas, rising sea levels, and the increased likelihood that these aspects will develop in a non-linear and non-predictable manner (IPCC, 2007). Because of changes in climatic conditions, farmers are seriously affected due to their reliance on rain-fed agricultural systems and low adaptive capacity, making them highly vulnerable to climate change (Mujeyi *et al.*, 2020). Additionally, smallholder farmers have low resilience to deal with the effects of extreme climatic events (drought and floods), high climate inconsistency, and change.

Scholars and previous studies, such as those by Mdoda (2020) and the Intergovernmental Panel on Climate Change (IPCC) (2007), argued that adaptation is the only way to be resilient to climate change. Many approaches have been recommended for mitigating the impacts of climate change on agricultural production, but CSA is the more sufficient and widely adopted approach (Mdoda, 2020). The need for involvement to combat climate change effects is crucial (Musafiri *et al*., 2022), and these interventions include adopting CSA practices by smallholder farmers. CSA is a sustainable approach developed by the FAO to climate change. It benefits farmers facing climate-induced agricultural impacts such as prolonged droughts, reduced rainfall amounts, and changing rainfall patterns, adversely affecting crop and animal productivity (Ouédraogo *et al*., 2019). CSA is an alternative form of agriculture for conserving the environment while addressing the food needs of the world's population (Musafiri *et al.*, 2022).

CSA has developed a significant adaptation and mitigation strategy for climate change (Partey *et al*., 2018) to provide food for the increasing population (Totin *et al*., 2018). CSA adopts sustainable land management techniques that involve farmers in sustainable strengthening measures such as agroforestry, conservation tillage, residue management, green manuring, and improved water management to improve agricultural performance (DeLonge *et al*., 2016). Abegunde *et al*. (2019) specified that CSA practices provide integrated benefits of a sustainable increase in agricultural productivity, adaptation, and the building of resilient agricultural and food security systems. This approach assists farmers in meeting the growing demand for food despite the changing climate and fewer opportunities for agricultural expansion onto additional land. It contributes to achieving food security, economic development, and poverty reduction.

The concept of CSA includes a set of agricultural techniques that smallholder farmers can adopt as single or multiple agricultural practices to cope with the impacts of climate change. However, there is little information concerning CSA adoption in South Africa, particularly regarding the smallholder farming system. Additionally, there is limited literature on adopting the combination of agricultural practices such as irrigation, soil water conservation, crop diversification, and crop-livestock integration in South Africa to lessen the impacts of climate change. It is argued that poor use and adoption of CSA technologies are due to limiting factors such as high initial cost and technical know-how, expensive and unaffordable, lack of insurance schemes and financing mechanisms, weak regulatory frameworks for most smallholder farmers (Ogunyiola *et al*., 2022). Therefore, looking at the determinants influencing the adoption of CSAs is significant in promoting policy design, technology transfer, and improving households' livelihoods.

2. METHODOLOGY

2.1. Study Area

The study was conducted in the Mangaung Metropolitan Municipality (Figure 2 below). The Mangaung Metropolitan Municipality is situated in the Free State Province in the central interior of South Africa. It is a Category A municipality, defined as a municipality with exclusive municipal executive and legislative authority (SAHO, 2019). The entire municipality covers an area of 9 886km² with 861 651 people. The climate in the metro is semi-arid, with the most precipitation occurring during the summer months, with snow in winter, sometimes in the mountains in the east (Mangaung Metropolitan Municipality, 2016). According to the Mangaung Rural Development Plan 2020, the area is relatively water-scarce, and the western area has a high drought risk.

The main economic activities in the municipality are community services, finance, and agriculture. The agricultural sector comprises large-scale and small-scale commercial and subsistence agriculture, contributing 1.7% to the metro's Gross Value Added (GVA) (DRDLR, 2020). Livestock production and poultry are the most prominent agricultural activities, with the largest concentration of dairy cattle in the metro contributing largely to the municipality. Livestock production and poultry are prominent in the metro, and the largest concentration of dairy cattle and poultry is apparent in the Botshabelo area (namely Supreme Chicken) (StatsSA, 2017).

2.2. Description of the Study and Research Design

The literature reviewed (Sikwela & Mshunje, 2013; StatsSA, 2017) and the authors' experience were fundamental in selecting the study area. The StatsSA (2017) survey established that Mangaung Metropolitan municipality houses numerous smallholder farmers practising crop farming in the Free State province.

This study employed a cross-sectional survey, where data collection was carried out simultaneously in Mangaung, Free State province. The study objective guided eligibility criteria, including inclusion and exclusion methods. Two methods were used to formulate a criterion that farmers had to meet to be part of the study. The criteria were as follows: farmers must/can/have:

a) Practise crop farming at the smallholder level.
b) Have access to climate-related information from varied sources of extension services.

c) Practice farming for either business purposes or household consumption.

d) Access to farming land, owning or leasing.

2.3. Research Design

This paper adopted a cross-sectional research design with a quantitative research methodology. A cross-sectional research design is adequate for analysing, and portrayal of implications from existing differences between people, subjects, or phenomena. A cross-sectional research design can employ data from diverse backgrounds of disciplines and contrasting observational studies (Creswell, 2017). It is comparatively less expensive to use and less time-consuming. This approach was used because it permits coherent and sound conclusions and time and cost-efficiency. Additionally, this research design is to thoroughly investigate the research problem to advance an improved insight into the determinants influencing the adoption of CSA practices by smallholder farmers.

2.4. Sampling Procedure, Frame and Sample Size

The target population was smallholder crop farmers in Mangaung Metropolitan Municipality. The Free State Department of Agriculture obtained a stratified list of smallholders practising livestock, crop, and mixed farming. The study used a systematic random sampling procedure to select farmers in six regions of Mangaung Metropolitan Municipality. This approach was preferred because it ensured an equal probability of inclusion of each unit in the population than simple random sampling (Nassiuma & Mwangi, 2004). The procedure comprised drawing a sample of size n from a population consisting of N units so that starting with a unit conforming to a number r chosen at random from the numbers 1,2…., k every k^{th} unit is selected.

A sampling of farmers was carried out considering two sampling frames of farmers: adopters of CSA technologies and non-adopters of CSA technologies. A farmer engaged in at least any CSA for two or more years was considered an adopter, and otherwise, if the farmer has not engaged. This is because of the intention not to consider opportunistic farmers who try for a year and abandon the following year. The study sample size of smallholder crop farmers who qualified was 120. This number is based on the list of farmers provided by the Department of Agriculture in the municipality.

2.5. Data Collection

Primary data was collected from smallholder crop farmers between January 2017 and August 2018 using structured questionnaires administered by trained enumerators. The questionnaire included open and closed-ended questions regarding production, climate change, and climate-smart agriculture usage. In addition, the questionnaire included information on demographic, institutional, physical, and socio-economic factors, climate change information, adopted climate-smart agriculture technologies, challenges farmers face in adopting CSA, and factors influencing their adoption of CSA to enhance agricultural productivity. In addition, face-to-face meetings with the respondents were held to attain in-depth information essential to the primary study objective. The secondary data was extracted from various sources for this study, including scientific publications, annual government reports, and other internet sources. This data was critical for comparison with survey data.

2.6. Data Analysis

The study used two data analysis tools: descriptive analysis and the Multinomial regression model. Descriptive statistics were used in the study to analyse demographic characteristics and production information of smallholder vegetable farmers. The study used frequencies, percentages, means, and graphs to explain farmers' characteristics and production information.

3. ANALYTICAL FRAMEWORK

The multinomial logistic regression model was used to explain and estimate the adoption of the CSA technology. Given various CSA practice combinations, the appropriate econometric model is a Multinomial Probit (MNP) or Multinomial Logit (MNL) regression model. The study selected a multinomial logit regression model to estimate the effect of explanatory variables on a dependent variable involving multiple combinations with unordered response categories. The advantage of the MNL is that it licenses the analysis of decisions across more than two categories (Wooldridge, 2002). According to Zizinga *et al.* (2017), different researchers widely use the model to analyse the determinant factors that affect the choice of household adaptation measures to climate variability, with more than two outcomes of the dependent variable. The theoretical substance of the MNL model is centred on the random utility theory, which highlights that consumer preference is modelled primarily using a discrete choice utility framework (Mujeyi *et al.*, 2020). Thus, farmer characteristics, access to information, markets, financial support, extension services availability, and other factors influenced farmer utility. With the theory of utility, what is deemed necessary concerning the choice/s being made is whether an option has a higher utility than another and not the measure of the difference between the available options. Abegunde *et al.* (2019) specified that the consideration of choices made on which agricultural practices to adopt by farmers depends on ordering available options based on the benefits they stand to receive from the practices.

The MNL computes a different continuous latent variable for each choice, and these variables are like the evaluation scores of each individual for each selection. Consider a rational farmer whose purpose is to smaximise the profits from production over a specific period and who has a set of CSA practice j options to choose from. The farmer i decides to adopt CSA practice j if the utility from j is perceived to be more than that from other alternatives (assume, K). This relationship is expressed as follows:

$$U_{ij} = \left(\beta' J X_i + \varepsilon_j\right) > U_{ik} \left(\beta' k X_i + \varepsilon_k\right),\ k \neq j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where

U_{ij} and U_{ik} denote the perceived utility by farmer i from CSA practice options j and k, respectively.

Xi is a vector of regressors that influence the CSA practice option the farmer chooses;

$\beta' J$ and $\beta' k$ are parameters of the independent variables, and

ε_j and ε_k are the error terms based on an econometric assumption that are independently and identically distributed.

Under the favourite assumption that the farmer decides to adopt a CSA practice option which is more beneficial and does not practice otherwise, the observable discrete choice of practice can be related to the latent continuous net benefit variable as:

$$Y_{ij} = 1 \; if \; U_{ij} > 0 \; and \; Y_{ij} = 0 \; if \; U_{ij} < 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

In the generated formula, Y is a binary dependent variable valued as 1 when the farmer selects for a CSA practice and 0 if otherwise. The probability that farmer i will choose CSA practice option j among the set of adaptation options could be expressed as:

$\left(X = \frac{1}{X}\right) = P\left(U_{ij} > {}^{U_{ik}}/_{X}\right) = P\big(\beta'\, J\, X_i + \varepsilon_j - \beta'\, k\, X_i - \varepsilon_k > {}^{0}/_{X}\big)$……………………………………………………………..3

$$P\big(\beta'\, J\, X_i + \varepsilon_j - \beta'\, k\, X_i - \varepsilon_k > {}^{0}/_{X}\big) = P\left(\beta^{*} X_i + \varepsilon^{*} > {}^{0}/_{X}\right) = F(\beta_{*} X_i)$$

Where

P is a probability function;

$\varepsilon^{*} = \varepsilon_j - \varepsilon_k$ is a random disturbance term;

$\beta^{*} = (\beta'\, J - \beta'\, k)$ is a vector of unknown parameters that can be explained as the net influence of the determinants of the choice of CSA practice and

F (β* Xi) is a cumulative distribution of ε^{*} estimated at $\beta^{*}\ X_i$

4. FINDINGS AND DISCUSSION

4.1. Socio-Economic Characteristics of Smallholder Farmers

The socio-economic characteristics of sampled farmers are presented in Table 2.

TABLE 2: Farmers' Socio-Economic Characteristics

Variable	Frequency (n)	Percentage (%)
Sex:		
Male	91	76
Female	29	24
Marital Status:		
Single	17	14
Married	76	63
Divorced	14	12
Windowed	13	11
Source of income:		
Fully employed	65	54
Farming	31	26
Pension and grants	24	20

Land ownership:		
Land rental	70	58
Inherited & Communal	38	32
Bought land	12	10
Extension officers:		
Yes	85	71
No	36	29
Member of farm organisations		
Yes	70	58
No	50	42
Variable	**Mean**	**SD**
Age	58.20	15.43
Family size	6.15	1.86
Years spent in school	9.23	2.78
Farm size	32.38	13.78
Distance to market	8.67	2.56
Years of farming	9.56	3.12
Farm income per season	32 860	9 065

The most frequently observed sex of farmers was males, with 76%. These results aligned with Mujuru and Obi (2020) and Mdoda and Obi (2019), that male farmers dominate smallholder farmers as females are responsible for household chores and home care. The mean average of farmers was 58 years, with an average family size of six persons. These results agree with Abegunde *et al*. (2019) findings that elderly people dominate smallholder farmers as young people migrate to cities to work for industries as they do not want to be involved in agriculture. Smallholder farmers usually spend nine years in school, equivalent to secondary school. This was crucial in allowing farmers to access and interpret agricultural information and innovative farming techniques to enhance farm returns. Farmers that were married comprised 63%, which assisted farmers in decision-making as it is easy to make decisions when married as you focus on improving agricultural productivity for the household compared to single or divorced farmers. Farmers, on average, have ten years of farming experience, which is beneficial as they know what is needed and essential to improving their agriculture and which climate-smart agriculture technology is suitable for their farming. The results are consistent with Kassa and Abdi (2022)

Most smallholder farmers had access to extension services (71%) and were members of farm organisations (58%). This membership and access to extension services played a crucial role in connecting farmers to markets to benefit from agribusiness, provided farmers with important training to raise their output, and provided the necessary climate change information.

4.2. Weather Changes and Effects Observed by Farmers as a Result of Climate Change

Smallholder farmers in the study area generated a living through practising farming to sustain their families. As a result, farmers generated profits that assisted household welfare and farm operations. However, climate change occurrence over 30 years has negatively affected smallholder farmers in the study area.

Farmers have experienced weather changes, which hampered their agricultural productivity and activities. Smallholder farmers have observed and experienced a prolonged drought (54%), which resulted in many farmers experiencing a decline in their agricultural productivity as they experience water shortages due to the drought and the decrease in rainfall patterns (20%) and hot seasons (18%). These changes resulted in farmers' many agricultural activities and declining agricultural output. Lastly, farmers experienced flooding (8%), although it was not as severe as the other three weather changes experienced by farmers.

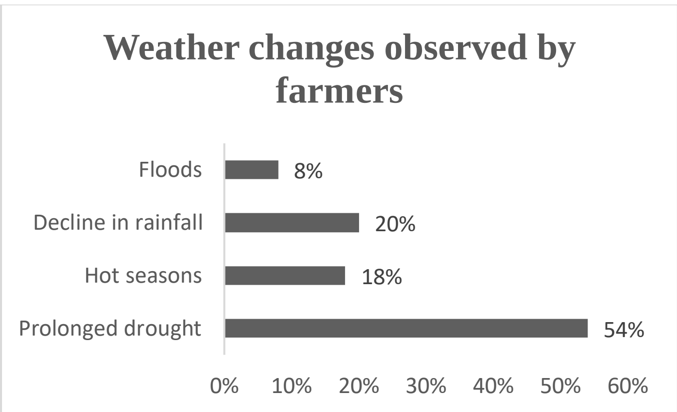

FIGURE 1: Weather Changes Experienced by Smallholder Farmers

Farmers have experienced severe effects due to climate change, adversely affecting their agricultural productivity and income. Figure 2 illustrates the significant impacts of climate change. Most of the smallholder farmers in the study area have experienced a decline in their agricultural output (58%), pests and disease outbreaks (22%), and lastly, crop failures and livestock death (20%). These effects have adversely affected farmers and the household welfare of farmers and households. The decline in agricultural output leads to an increase in food insecurity, a decrease in income generation from farms, an increase in food prices, and a reduction in employment, as farmers cannot keep up with the employed labour without generating income. Thus, it forced many farmers to rely on family labour for farm operations.

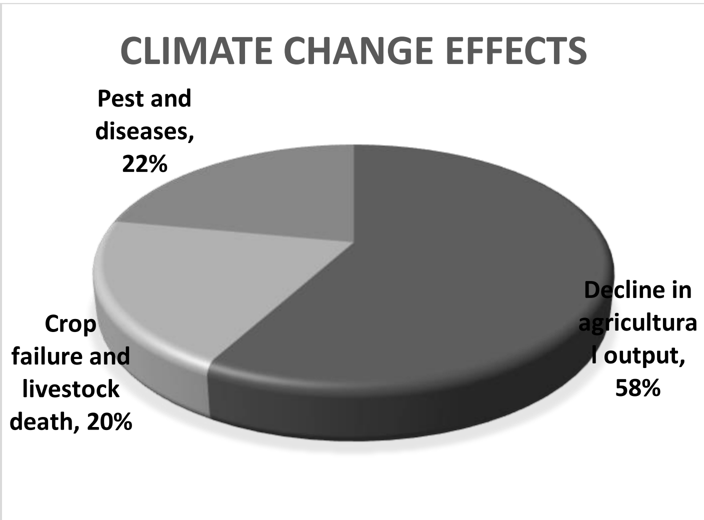

FIGURE 2: **Climate Change Effects Experienced by Mangaung Smallholder Farmers**

4.3. CSA Technologies Adopted by Farmers

Due to the climate change effects, the smallholder farmers decided to adopt CSA technologies on their farms as strategies to adapt to climate change and enhance their agricultural productivity.

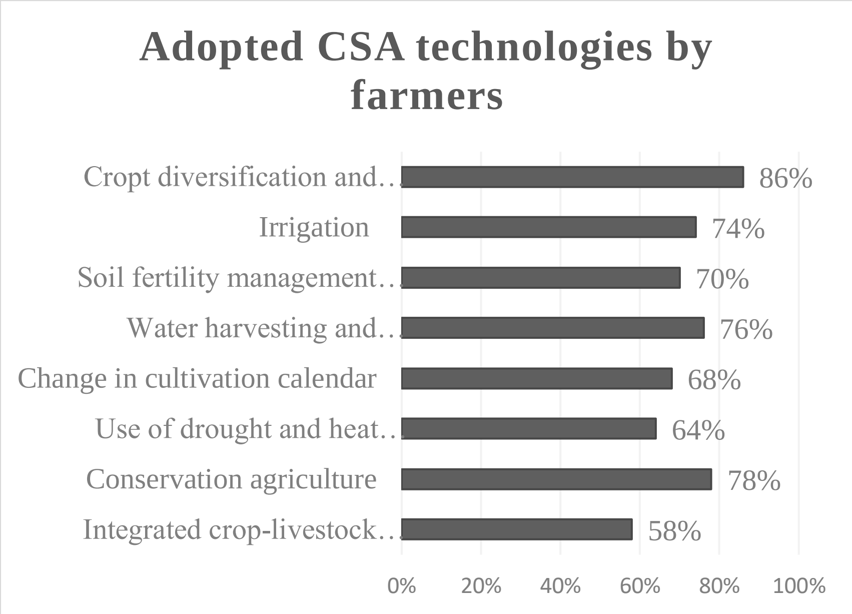

FIGURE 3: **Climate-Smart Agriculture (CSA) Technologies Adopted by Small Holder Farmers**

Results from Figure 3, which is the analysis of the frequency of use of the CSA practices among the sampled farmers, reveal that the use of crop diversification and rotation, irrigation, soil fertility and conservation management, water harvesting and management, change in ploughing calendar, conservation agriculture, use of drought & heat tolerant crops, and lastly integrated crop-livestock management were the most popular practices among the farmers in Mangaung Metropolitan Municipality. Farmers in the study indicated that they have decided to adopt CSA to improve their agricultural output, consequently enhancing farm returns, employment, and household food security status.

The adopted CSA technologies were grouped into three categories based on their adoption rate by farmers. These categories were grouped into one category based on their high adoption rate and yielded high returns to agricultural output. Category 1 (crop diversification and rotation, use of drought and heat resistant crops, irrigation and change the cultivation calendar), category 2 (conservation agriculture, soil fertility and conservation management, water harvesting and management), and category 3 (integration crop-livestock management). Category 1 is farmers' highest use of CSA technologies while category 2 is the second. The lowest use CSA practice was category 3. As a result, category 3 was used as a reference category for MNL regression analysis.

4.4. Challenges Faced by Smallholder Farmers in Adopting CSA

While adapting to CSA various barriers affect smallholder farmers to practice and implement adaptation programs in their major livelihood enterprises. Figure 4 below shows barriers faced by farmers in adopting CSA technologies.

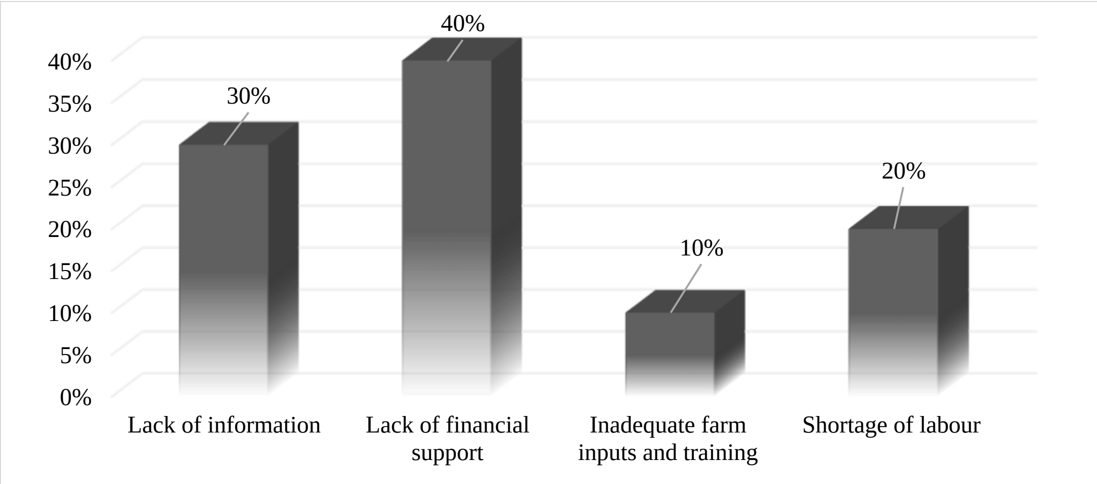

FIGURE 4: Challenges Faced by Mangaung Smallholder Crop Farmers in Adopting CSA

Figure 4 above shows the most common challenges that smallholder food crop farmers face in adopting CSA technologies. Farmers were constrained by their financial support (40%), as they relied on farm income and social security. The lack of financial support affected farmers' adoption of CSA technologies; they lacked the means to purchase or install the adopted CSA to improve their agricultural productivity. Lack of information or knowledge (30%) was found to be a challenge to farmers as they do not have adequate information on CSA or innovative techniques and do not have access to extension officers or members of farm organisations who can provide the necessary information.

Shortage of labour (20%) was found to challenge farmers as they lose farm labourers due to a decline in agricultural output, which assists farmers in paying farm labourers in return for selling their output. Lastly, inadequate farm inputs and training (10%) contributed to the low adoption of CSA by farmers. Most farmers lack farm inputs and training as they lack the financial backing to train their labourers on innovative practices and purchase updated farm inputs. These challenges contributed immensely to food crop farmers adoption of CSA technologies in the study area.

4.5. Determinants of Climate-Smart Agricultural Practices by Farmers

The model's dependent variable is the category of users of CSA practices, where the low user category is the reference category in the model. The study used multinomial logistic regression (MNL) to estimate smallholder food crop farmers' drivers of climate-smart agriculture (CSA) technologies. All the variables in the model fit for the regression analysis of the responses from smallholder food crop farmers in the Mangaung Metropolitan Municipality and the combined were constrained to have their effects satisfy the proportional odds or parallel lines assumptions. The log-likelihood of the MNL regression analysis was − 297.05. The chi-squared value of 104.21 at 60◦ of freedom is significant at the 1% level (p-value = 0.001). The Pseudo R^2 was 0.835 (84%), showing the model fit to analyse this data. Table 3 below indicates factors influencing the adoption of CSA by smallholder food crop farmers in the study area.

TABLE 3: Factors Influencing the Adoption of Climate Smart Agriculture Technologies

Variables	**Climate-Smart Agriculture Technologies grouped.**				**Marginal effect**	
	Category 1		**Category 2**			
	Coef.	**Std Er**	**Coef.**	**Std Er**	**Dy/dx**	**Std Er**
Sex	1.325 ***	0.600	0.765**	0.0254	0.655	0.03
Years spent in school	0. 0.24**	0.100	0.987**	0.588	0.515	0.032
Land ownership	0.012**	0.006	1.435***	0.312	0.053	0.056
Access to weather information	1.08***	0.320	1.621***	0.510	0.043	0.013
Access to credit	0.173	0.006	1.289***	0.122	0.631	0.879
Member of farm organisation	1.353***	0.125	0.337**	0.138	0.073	0.046
Knowledge about CSA	0.576** *	0.285	1.38***	0.644	0.326	0.044

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Distance to market place	0.342	0.764	-0.865**	0.231	-0.452	0.512
_con	-0.620	0.860	-3.18**	0.55		
likelihood − 297.05	Number of observations 120	LR chi-square (60) 104.21	Prob > chi-square 0.001	Pseudo R^2 0.835		

****Notes: *** p<0.01, ** p<0.05, *p<0.1, means significant at 1%, 5% and 10% significance levels, respectively***.

The sex of the farmer variable had a positive coefficient and was statistically significant at 1% for category 1 and 5% for category 2. This suggests a positive relationship between the sex of the farmer and the adoption of CSA. This implies that an increase in male farmers will induce an increase in the adoption of CSA for both categories by farmers. This means that the probability of males adopting CSI technologies increases by 66% compared to their female counterparts. This is because female farmers are risk-averse and think of their families before making farm decisions. These results were in line with Serote *et al.* (2021) that the sex of the farmer is essential in making farm decisions, and male farmers are the ones who adopt CSA technologies more as they want to enhance their farm output to improve household welfare.

Years spent in school had a positive coefficient for both categories and were significant at a 5% level. This suggests that an additional year spent in school by the farmer increases farmers' chances of adopting CSA to enhance their household welfare. This is because spending many years in school increases farmers' knowledge about farming and exposes farmers to innovative practices to improve agricultural productivity. This implies that the probability of educated farmers adopting CSA technologies increases by 52% compared to their uneducated counterparts. These results aligned with Issahaku and Abdulai's (2019) findings that spending years in school enhances farmers' knowledge and skills, improving farming operations and investing in new agricultural practices that enhance output farm returns.

Land ownership was positive and significant to farmers' adoption of CSA technologies. This implies that more farmer-owned land increases farmers' chances of adopting CSA to enhance household welfare. This means that the probability of land ownership adopting CSA

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technologies increases by 5.3% compared to their landless counterparts. Having land rights through land ownership is important in improving agricultural productivity as it motivates farmers to invest more in their land and use improved agricultural practices.

The variable's coefficient representing a member of a farm organisation was found to be positive and significant. This suggests that being a member of a farmer's organisation increases the propensity to adopt CSA technologies by farmers. Farm organisations provide farmers with new agricultural practices and information relevant to increasing agricultural output. This implies that the probability of being a member of a farm organisation increases the adoption of CSA technologies by 7.3% compared to their counterparts. These results are commensurate with Issahaku and Abdulai (2019), who found that organisation membership increased farmers' use and adoption of CSA technologies.

Knowledge about CSA was positive and statistically significant at 1% in both categories. This implies that the farmer is more knowledgeable about CSA technologies, increasing their chances of adopting them to improve their welfare status. This suggests that farmers' knowledge is essential for adopting innovative technology. The more knowledgeable farmers were about CSA, the more they adopted and used CSA practices to enhance their agricultural output. This implies that the probability of knowledge about CSA increases the adoption of CSA technologies by 33% compared to their counterparts. These results agree with Serote *et al*. (2021) that smallholder farmers with the necessary knowledge of CSA technologies tend to have higher chances of adopting and using CSA practices in their farms for better agricultural output.

Access to credit showed positive and significant correlations with category two and was statistically significant at 1%. This implies that a unit increase of 1% in access to credit by the farmer increases the chances of adopting CSA technologies to improve household welfare. Access to credit allows farmers to purchase inputs and invest heavily in the farm to enhance agricultural output. Farmers who have credit accessibility are more likely to adopt CSA technologies. This implies that the farmer's probability of access to credit increases the adoption of CSA technologies by 63% compared to their landless counterparts. These results aligned with Dung's (2020) conclusions that access to credit encourages farmers to invest in farming with innovative practices that enhance agricultural productivity and withstand climate change.

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Access to weather information had a positive coefficient and was statistically significant at 1% for both categories. This implies that farmers' access to weather information increases the chances of adopting CSA technologies that improve agricultural output. This is because weather information is crucial for farming, relying on the weather forecast. Access to weather information is imperative in increasing farmers' knowledge about climate change and what approaches are available to mitigate climate change. This implies that the farmer's probability of access to weather information increases the adoption of CSA technologies by 63% compared to their landless counterparts.

5. CONCLUSION

This study investigated the determinants of adoption of CSA technologies by smallholder food crop farmers in Mangaung Metropolitan Municipality, Free State, South Africa. The study found that males dominate smallholder crop farmers with an average of 58 years. Smallholder food crop farmers had access to extension services and were members of farm organisations, which played a crucial role in increasing farmers' knowledge about CSA practices and climate change. Climate change adversely affected food crop farmers as farmers have experienced a decline in agricultural output, the emergence of pests, and crop failure due to prolonged drought with high temperatures and a decrease in rainfall patterns.

As a result, climate change negatively affected farmers through agricultural output and household welfare, which was triggered by climate change. With the knowledge and impact they experienced due to climate change, farmers embarked on adapting to climate change by adopting CSA practices. CSA practices played a significant role in improving farmers' agricultural output. However, lack of information, lack of financial support, shortage of labour, and inadequate farm inputs and training were the challenges encountered by farmers in fully adopting CSA technologies in their farms. In conclusion, socio-economic determinants, farm characteristics, and institutional factors influence smallholder food crop farmers' adoption of CSA technologies. Therefore, the study recommends that government and policymakers invest in programs to improve farmers' education, ensure secure land rights, access to climate credit financing services, and empower them. There is a need for agricultural sector stakeholders to provide capacity building, technology transfer demonstrations, and strengthen knowledge dissemination as part of the science-policy interface.

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7. CONFLICT OF INTEREST

Authors have no conflict of interest of any kind.

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