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Factors Influencing the Adoption of Climate-Smart Irrigation Technologies for Sustainable Crop Productivity by Smallholder Farmers in Arid Areas of South Africa

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Abstract: The adoption of climate-smart irrigation technologies amongst smallholder farmers generally remains low beside their role in combating food and nutrition security in a society and in climate change adaptation strategies. This study identified the factors influencing smallholder farmers' decision to adopt Climate Smart Irrigation Technologies (CSIT) in the Limpopo Province of South Africa. Data were collected through the completion of a face-to-face structured questionnaire by 100 smallholder farmers selected through convenience and purposive sampling. A probit regression and OLS model were used to identify factors that influence the smallholder farmer's decision to adopt CSIT and the level of adoption. The results indicated that only 46% of the smallholder farmers adopted climate-smart irrigation technologies and suggested that adoption is influenced positively by factors such as gender, age, district, farm size, staple food production and knowledge on CSIT. There is an urgent need for related stakeholders to transform the smallholder farmer subsector through improved extension services, training, adopting resilient crop varieties, promoting underutilized and nutrient-dense crops adapted to harsh local conditions, and other interventions. This should be done by promoting awareness to smallholder farmers regarding these interventions and new technologies that have the potential to improve rural livelihoods and enhance resilience and adaptation.

Keywords: adaptation and resilience; traditional irrigation methods; climate change; Limpopo Province; probit model; OLS model

1. Introduction

In most developing countries, underprivileged people depend directly or indirectly on smallholder crop production to sustain their livelihoods [1]. These resource-poor people are often referred to as smallholder farmers (SHF). They are mainly found in rural areas where agriculture is the main activity to alleviate poverty [2]. Kamara et al. [3] indicated an estimation of about 500 million SHF worldwide, upon which more than 2 billion people depend for their livelihoods. Smallholder farmers have been at the forefront of stimulating rural economies in sub-Saharan Africa [3]. They support their households and local markets through products produced in less than three hectares of land [4–6]. However, despite their contribution to rural economic development, most SHF, particularly in Africa, have been experiencing poor yields, food insecurity and rural poverty due to extreme climatic events, climate variability and change [6,7]. Climate change refers to regional and global fluctuations in climatic patterns due to natural variability or human activity [8,9]. Cultivation practices are usually affected by climate change through the occurrence of extreme weather conditions such as heatwaves, droughts, flash floods, and changes in rainfall amounts and patterns, therefore causing shifts in the timing and length of growing seasons and differences in the prevalence and severity of pests, diseases and weeds [10]. Although all farming systems might experience the effects of climate change, SHF are usually the most vulnerable due to their high dependence on climate-sensitive rain-fed agriculture [11,12]. According to Maponya and Mpandeli [13], most SHF have a low adaptive capacity and low resilience to deal with the impacts of extreme climatic events, high climate variability, and change.

South Africa falls amongst the 30th driest countries in the world, and climate change has enhanced the situation further through changes in rainfall amounts and patterns [14,15]. The country receives a highly uneven annual rainfall distribution of approximately 500 mm, compared to the global average of 860 mm [15]. Although 70% of the grain crop production in the country occurs on dry land, only 35% receive enough rainfall required for successful dryland crop production. However, this is expected to vary across the different agro-ecological zones as areas represent unique combinations of homogenous agro-climate, ecology, soil units and agricultural activities, according to Fanadzo and Ncube [16] and Stevens and Van Koppen [17]. With climate being a prime factor that exerts major influence and control over vegetation, soil type, water resources and ultimately human activities, semi-arid regions in Limpopo Province, which produces only a small fraction of grain production in the country, have become particularly vulnerable to climate variability and change by raising temperatures and erratic inter-seasonal rainfall patterns [18]. Extreme weather conditions such as heatwaves and flash floods are estimated to become more frequent and intense in the Province [19,20]. Although Ubisi [11] and Ranakoana [20] indicated that all five districts in the Limpopo Province were affected by climate change, the Vhembe district in particular has been identified as the most drought-stricken. According to Maponya and Mpandeli [13], the majority of SHF farmers in the Vhembe district have developed several coping and adaptation strategies in order to deal with both climate variability and change, and some of these strategies include adopting crop diversification, using hybrid seeds, adjusting fertilizer inputs, using plant crops that require less water, using multi-cropping systems etc.

To address climate variability and change impacts, some SHF in the area modified their farming practices by using traditional irrigation methods based on their indigenous knowledge [11,12]. Traditional irrigation methods include surface methods such as flooding, furrows and basins [21]. In the past, using these methods were beneficial to farmers in reducing their vulnerability to drought spells, thus resulting in a more stable production and income generation [22]. Over the past years, existing literature has indicated that traditional methods have become ineffective for coping with the medium and long-term impacts of climate change [12]. Its use has been associated with the overexploitation of natural resources, increasing pressure on water reservoirs, creating pollution problems, consuming time and money, and low yields due to crop damage caused by over or under irrigation [22–24]. Therefore, this has triggered much discussion of converting to more improved agricultural technologies such as climate-smart irrigation technologies (CSIT) [21]. Climate-smart irrigation technologies are defined as a good irrigation practice for a given agro-climatic and societal context that takes explicit account of challenges and opportunities that may result directly or indirectly from different facets of climate change [25]. With proper planning and implementation, the use of CSIT such as rainwater harvesting, drip and sprinkler irrigation would assist in reducing the over-dependence on rainfall, usage of inefficient irrigation methods, and address the challenges of poverty and food insecurity [4,7,9,23,26]. However, despite the well-documented effectiveness and feasibility of CSIT to cope with climate change, particularly in resource-constrained rural communities, adoption remains low [4,24]. Masela et al. [27] agreed by indicating that in the Limpopo Province only 16.6% have adopted CSIT. This may be because the impacts of climate change and several adoption characteristics have not been fully understood by these farmers, resulting in low adoption rates [28]. Other factors for the low uptake of CSIT include the low levels of education and the age of the majority of the SHF. Factors influencing SHF from adopting CSIT have not been investigated in detail in this country. However, studies that were done in Zimbabwe, Mozambique, Zambia, and Malawi show that any technology that is not going to help SHF increase their yields and improve their income and livelihoods will not be adopted easily. South Africa is prone to climate change, drought, and uneven distribution of rainfall is affecting smallholder production, this is more prevalent in Limpopo. Against this background, the study was initiated to identify CSIT technologies and significantly assist SHF. This study aims to identify factors that influence adoption and the level of adopting CSIT.

2. Factors Influencing the Adoption of CSIT

A search of existing literature indicated that several factors are influencing the adoption of agricultural technologies. Mwangi and Kariuki [4] demonstrated that farmers' decisions about whether and how to adopt agricultural technologies are conditioned by the dynamic interaction between the characteristics of the technology itself and the arrangement of conditions and circumstances. Below (Figure 1) is a description of factors that play a role in influencing the adoption of CSIT by SHF. These factors have been categorized into demographic, farm characteristics, irrigation, and formal and informal training. This will enable an in-depth review of how each factor influences adoption.

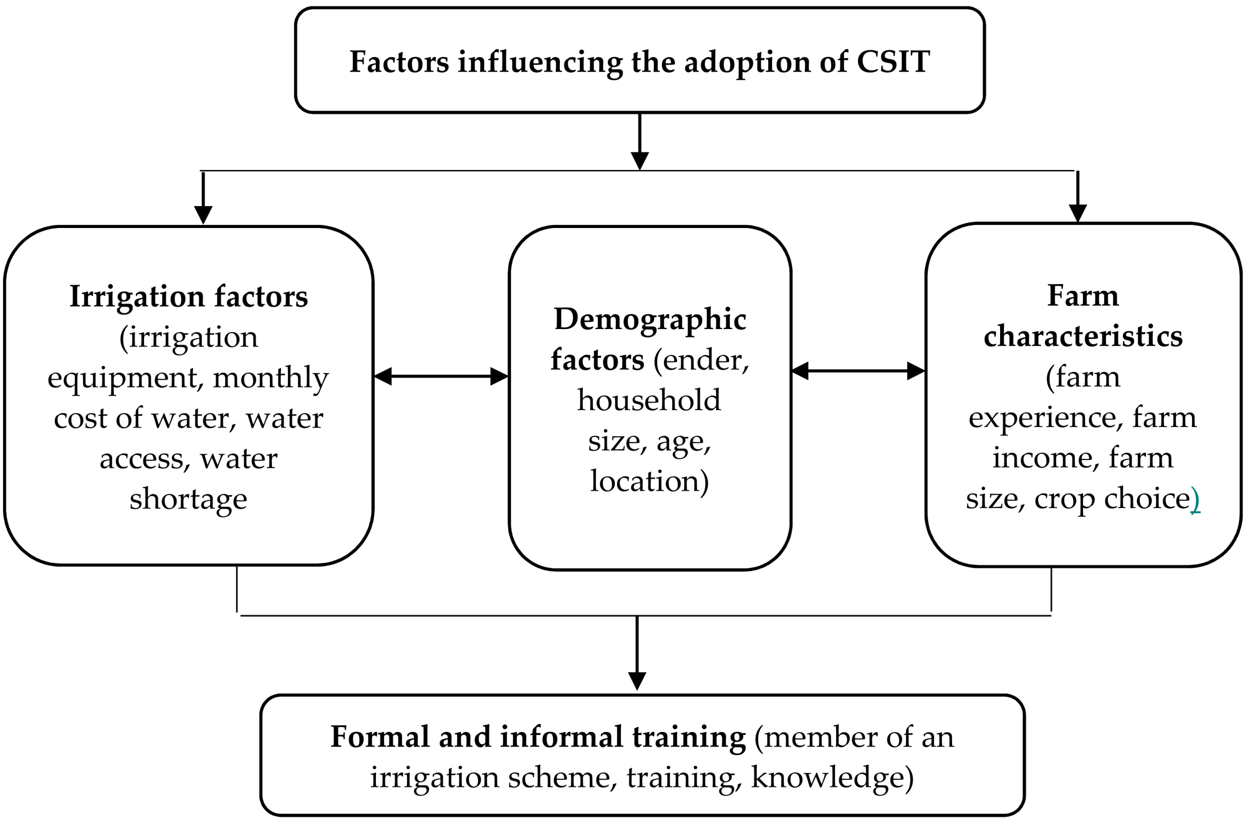

Figure 1. Conceptual framework for factors influencing the adoption of CSIT.

2.1. Demographic Factors

An understanding of gender composition in agriculture facilitates analyses of the roles, responsibilities, constraints, and opportunities for both males and females [29]. Studies investigating the role of gender in agricultural technology adoption reported mixed evidence on the different roles of men and technology adoption [4]. Shange [30] found that there is no significant association between gender and the adoption of technologies. As males and females are considered to play very different yet essential roles in agriculture, a clear distinction in labour divisions, roles, responsibilities, and access to productive resources is always present [14,31]. On the other hand, gender may significantly influence a farmer's decision to adopt technologies. The household heads are usually the primary decision-makers with more access and control over vital production resources [4]. This finding is consistent with Shange [30], who reported that male-headed households have a higher chance of adopting in-field rainwater harvesting technology than female-headed households.

The household size factor, which usually explains the number of people residing in one household, can be defined from two angles regarding technology adoption [27,32]. The first assumption is that households with large families are associated with cheap labour availability, enabling households to accomplish various agricultural tasks and remove labour constraints required to introduce new technologies [1,4,32]. Awinda [33] also found that family labour availability allows the household head to share responsibilities and save time for other development activities. The second assumption is that large family sizes may pressure household consumption and other expenses rather than the purported labour it provides to farming [32,34]. Therefore, other household expenses can limit irrigation technology adoption beyond the household budget [35].

Age is assumed to be amongst the many factors that play a role in influencing a farmers' decision to adopt agricultural technologies [4,29]. Wekesa [36] indicated that age could either positively or negatively affect technology adoption. A positive relationship can result from the fact that older farmers are usually considered to have more experience, have accrued more assets and developed wider social networks that enable them to have a higher likelihood of adopting technologies than younger farmers [5,36,37]. On the other hand, the negative relationship between age and adoption is explained by Van der Berg [38], Lebeta [39], Kurgat et al. [37] and Aryal et al. [40]:as farmers grow old, they become reluctant in adopting new technologies by being more risk-averse, and lack the physical ability for carrying out farm operations with short-planning horizons. By contrast, younger farmers are more adaptable and enthusiastic in adopting new technologies [26,38]. For example, Shange [30] findings on the adoption of rainwater-harvesting techniques indicated that young farmers are always ready to take risks and adopt expensive but effective agricultural technologies to enhance their food security status.

Despite the number of efforts made by different institutions and stakeholders to make farmers aware of improved agricultural technologies at a district level, some farmers are still unaware of these technologies [41]. The field survey results indicated that CSIT was already adopted by 73.91% SHF in the Capricorn district. While in the Vhembe district, the percentage of adoption was much lower at 26.09%. The main reason is that in the Vhembe district, there is a huge lack of knowledge regarding CSIT. Different climatic conditions in the Vhembe and Capricorn districts may influence the adoption of CSIT differently in each district. Nonvide [41] added that the difference in technology adoption between two regions is usually associated with the average profit gained from the adoption. Whereas, Kom et al. [9] indicated that the farmer's decision to adopt agricultural technologies is usually determined by the local agricultural cycle, including seasonal climatic variation and other socio-economic drivers. These findings are aligned with similar results highlighted by Maponya and Mpandeli [13].

2.2. Farm Characteristics

Experienced farmers generally have access to information due to efficient contact with extension services, providing relevant knowledge and skills [5,34]. Experience also impacts the farmer's managerial ability to make decisions, enabling them to set realistic goals and achieve these [29]. Therefore, the farming experience is expected to influence the farmers' decision to adopt CSIT positively. This suggests that the more farming experience one has, the more the likelihood of adopting CSIT.

A key factor in adopting a new technology is the farmer's income from adoption, including all the new technology costs [4]. Farm income can positively or negatively influence technology adoption depending on its relative contribution to household or farm profitability [30]. Abegunde et al. [5], Ndamani, and Watanade [42] indicated that farm income could drive the level of climate-smart agriculture adoption positively because increased income obtained from farming activities enables the farmer to acquire resources required for adoption. The majority of farmers in the Vhembe district indicated that any technologies that will assist them to increase their income and yields would be adopted without any delays [13]. On the other hand, some studies on technology adoption have indicated that the high cost of agricultural technologies can be a constraint to adoption [4]. Chuchird et al. [43] revealed that farmers were faced with expenses in terms of equipment, maintenance and fuel, which has led to a low farm income even after deducting expenses of using the water pump.

The farm size factor refers to the size of the cultivated land owned by the farmer in hectares. Farm size influences decision-making because it can limit farmers from adopting new technologies required for successful agricultural ventures [5,34]. Many studies have investigated the effect of farm size on the adoption decision, and the results indicated that the impact depended on factors such as fixed adoption costs, risk preferences, human capital, credit constraints, labour requirements, tenure agreements etc. [44]. Saha et al. [32] pointed out that farm size can positively or negatively affect adoption, suggesting that the influence of farm size on technology adoption is inconclusive. The positive relationship is based on the assumption that farmers who cultivate larger farm sizes generate more income, enabling them to have a better capital base and enhancing their risk-bearing ability to adopt new technologies than their counterparts [30,32]. On the other hand, the negative relationship can result from the fact that cultivation on larger land areas requires significant financial investments in labour and inputs, which can be too costly for resource-poor farmers [24].

The Limpopo Province is known for producing a wide variety of agricultural produce. Maponya and Mpandeli [13] indicated that the Province usually emphasizes growing maize and vegetables. Maponya and Mpandeli [13] further highlighted that crop diversification forms part of the risk aversion strategy in order to deal with extreme climatic events, high climate variability and change. However, most farmers in the Vhembe district practice mono-cropping, allowing them to have consistent crops throughout their entire farm. This will negatively impact the long run as the soil will become less productive over time because organic matter is reduced, and erosion will be enhanced.

Adoption enhances the production of crops, particularly those that cannot be cultivated under dryland. Higher yields mean that most households will be food secure as SHF usually produces for household consumption, and the surrounding communities can benefit from lower food prices [45]. Furthermore, farmers may be unenthusiastic about practicing supplemental irrigation on maize because they do not see the production value and would rather irrigate vegetables.

2.3. Formal and Informal Training

Being a member of an irrigation scheme has a positive and significant influence on technology adoption because it creates a convenient platform where farmers can learn about the benefits and usage of new technology [4,44]. This result concurs with the findings of Wekesa [36] and Anuga et al. [28], who indicated that group interactions whereby members can exchange ideas, handle farm demonstrations, and get connections for dissemination of significant research findings would create a strong bond between farmers thus enabling the easy transmission of information.

Training plays an essential role in technology adoption as it provides farmers with the required technical skills [46]. To adopt a particular technology, much time should be invested in farmer awareness, learning, and experimentation [41]. Key players such as the government, NGOs and private sectors provide training to farmers through various agricultural development programs [47]. SHF in rural areas usually rely on extension officers for skills training; therefore, those with regular contact have a higher chance of adopting agricultural technologies [18]. Jha et al. [48], who did a study on water productivity and economics of vegetable production under drip and furrow irrigation, reported that when farmers are part of the irrigation installation process, it will broaden their knowledge on the particular system, and they might learn to tackle minor repairs of the system. Whereas, Agholor [34] indicated that agricultural development initiatives such as CSIT should start with training the targeted farmers before any other support services are provided.

Knowledge is the main factor in determining SHF technologies [24], as it is the first step to adopting innovative technology, particularly one that is not yet widely known [44]. Farmers will only adopt the technology if they know its existence and effective use [4,36]. Awareness can be created through various sources of information such as extension officers, NGOs, farmers associations, radio and television etc. [18,44]. Musetha [18] and Wekesa [35] indicated that the availability of extension services plays an essential role in creating awareness on the adoption of new technologies as farmers are exposed to new information and equipped with technical skills through the field demonstrations. Therefore, the more farmers contact extension officers, the more knowledge is acquired, as technology adoption requires a whole set of new skills, including observation, monitoring, and risk assessment [36]. This is consistent with the findings of Adebayo et al. [35] that more educated farmers have better knowledge regarding the importance of adopting new technologies. Although most farmers may be aware of agricultural technologies, only a small number adopt the practices [49].

2.4. Irrigation Factors

The introduction of irrigation equipment such as pumps has resulted in a reliable water supply [1,41]. Farmers [49] use different energy sources such as diesel, petrol and electricity. Therefore, the level of technology adoption is usually determined by how water is channeled to the farmer's field [1]. On the other hand, the lack of affordability of this water access equipment can limit technology adoption, thus negatively affecting food security [50]. However, farmers have found an alternative by buying this equipment as a group and using them based on a set of ground rules [51].

The monthly cost of water negatively influences the adoption of CSIT, as the marginal costs of surface water are usually lower than the costs for groundwater [52]. Sinyolo [1] found that farmers who use gravity do not pay for water; therefore, they are often limited in demanding water when it does not reach their plots. However, the only cost of water would be bringing water to one's plot, depending on the distance [41]. These costs can discourage struggling farmers who usually generate a low farm income [53]. Therefore, this can have a negative influence on the adoption of CSIT.

On the other hand, Frisvold and Bai [53] indicated that monthly water costs positively and significantly affect CSIT technology, such as sprinkler adoption. Nonvide [54] agreed with this finding by demonstrating that farmers are usually sensitive to the increase in water prices therefore, it would encourage them to adopt the most efficient technology and discourage adoption of the least efficient options. According to Njoko and Mudhara [47], irrigation water fees should be set at a price level that most farmers could afford.

Water access, which has been captured as the number of days the farmers have access to water to their plots, may positively or negatively influence a farmers' decision to adopt CSIT. In most rural areas, the main water source includes rainfall, dams/rivers, communal taps, wells and boreholes however, because of the different rainfall amounts received, some water sources are seasonal, thus making it challenging for rural farmers to produce annually [8,31]. In the Tshiombo irrigation scheme in the Limpopo Province, SHF highlighted that water access is a serious challenge, especially for farmers that have plots far away from the canal system, and this group of farmers claim that due to limited amount of water available, they are getting low crop yields compared to SHF who have plots close to the canal system [13]. Limited water access has also created tension amongst SHF in the Tshiombo irrigation scheme.

Water shortage is still described as one of the many constraints to improving rural people's lives [30]. It is usually caused by irregular rainfall and high evaporative demand limiting rain-fed agriculture production in South Africa, making it almost impossible to perform agricultural activities as farmers' SHF are located in marginal and unsuitable crop production areas [30,46,55]. These marginal areas may range from semi-arid to arid and receive very low rainfall [30]. Therefore, the adoption of CSIT may positively affect production, as a change in the water management paradigm is required so that the demand can be met [56].

3. Materials and Methods

3.1. Study Area, Sampling and Data Collection

The Limpopo Province is located in the far Northern Province of South Africa, and it links the country with the rest of Southern Africa. This Province comprises five districts, namely: Sekhukhune, Mopani, Capricorn, Waterberg and Vhembe (Figure 2), which are made up of three distinct climatic regions: the lowveld (arid and semi-arid) regions, the middle veld, highveld, and semi-arid regions [11]. The experience of varied climates ranging from arid to semi-arid enables the Province to produce various agricultural produce, as it accounts for nearly 60% of fruit, vegetables, cereal crops (maize and wheat), and cotton [17,57] produced in South Africa. This is amongst the many reasons why the Province has been referred to as the breadbasket and agricultural engine of South Africa [57]. Despite the great agricultural potential, the Province is vulnerable to climate variability and change as decreasing rainfall amounts, altered rainfall distribution, and rising air temperatures, which are expected to advance, have already been witnessed. The study was carried out in the Capricorn and Vhembe districts since most farmers in these two districts still produce crops under traditional irrigation methods. In the Vhembe district, climate conditions are subtropical with mild, moist winters and wet, warm summers that frequently experience dry spells, often growing into severe drought [13]. The rainfall pattern ranges between 246 mm to 681 mm per annum, with over 80 percent of the rainfall occurring between October and December [18]. The district also experiences extremes in temperatures that can reach more than 35 °C during summer. In the Capricorn district, the annual rainfall varies from less than 400 mm in the north to 500 or more south of Polokwane. With summer temperatures ranging from mild to warm (Tmax in January 27–28 °C) on the Polokwane plateau and warm to hot (Tmax in January 29–32 °C) over the bulk of the area [58]. Therefore, the need for CSIT adoption is critical to build climate-resilient farming communities, improve crop yields, food security, and alleviate poverty as the potential effects of climate change continue to threaten agricultural production and sustainability.

Data were collected during September 2020 using a structured questionnaire. The questionnaire comprised open-ended questions that enabled individuals to express their opinion. However, the majority of the questions were closed-ended. This design simplified the process of capturing information by extracting as much information as possible from the respondent without taking too much time. The survey questionnaire covered a wide range of information, including demographics (gender, age, education level, household size, etc.), farm characteristics, irrigation sources, and institutional characteristics. Trained enumerators who knew the rural farming system well and spoke the local languages, i.e., Sepedi (Capricorn district) and TshiVenda (Vhembe district), administered the questionnaire to guard against the problem of misinterpretations or misunderstanding of words or questions. A convenience sampling technique was used to select 100 smallholder farmers from the purposely selected two districts within the Province. The main characteristics of the targeted SHF farmers were that they should use any irrigation system, be a vegetable grower, and be based in one of the two districts. The list of SHF was obtained from the respective local offices of the Limpopo Department of Agriculture and Rural Development (LDARD). A survey method was used for data collection through face-to-face interviews. The study was also conducted ethically, by firstly explaining the purpose of the survey to all participants, secondly by letting participants sign the consent form as an agreement to participate in the study, and thirdly by explaining how data would be collected, analyzed and interpreted in such a way that the procedure does not harm the participants, and that their privacy was protected. In relation to the COVID-19 pandemic, personal protective equipment (PPEs) were provided to all enumerators and farmers participating in the study. Social distancing at 1.5 m was observed at all times.

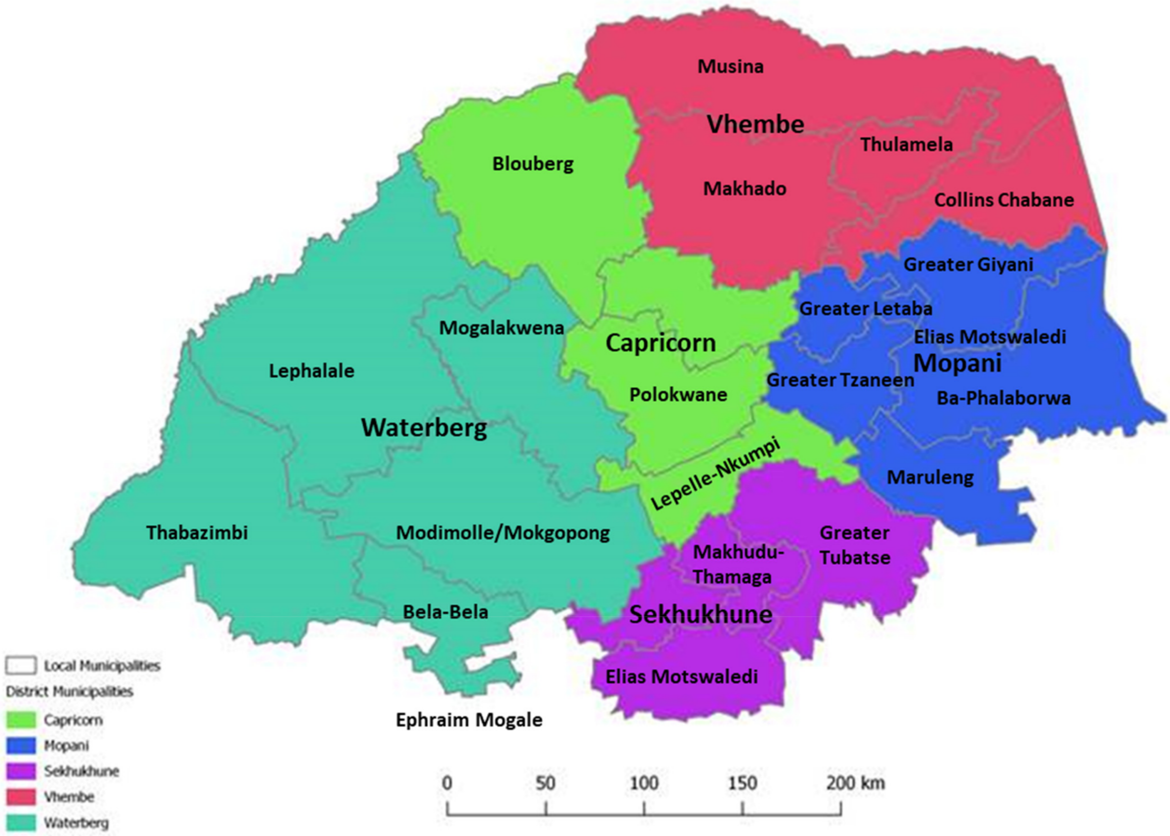

Figure 2. Map of the Limpopo Province showing the districts within the Province.

3.2. *Analytical Model Used in the Study*

Descriptive statistics summarize the data using Software for Statistics and Data Science (STATA 15). The probit regression model was used to determine factors influencing CSIT adoption by SHF. Whereas the OLS regression model was applied to evaluate the level of adopting CSIT. These different analytical techniques are explained in detail in the following subsections.

3.2.1. Probit Regression Model

The probit regression model was selected because the dependent variable is binary and takes a value of 0 or 1, meaning that it takes 1 if the SHF adopted CSIT and 0 if the SHF did not adopt CSIT. Limitations associated with a linear probability, such as non-normality of the error and the given probabilities that can exceed 1 or be lower than 0, can be solved by the probit model grounded in normal cumulative distribution functions (CDF) [58]. The model assumes that SHF will make adoption decisions based on the objective of maximizing utility [44]. The underlying utility function usually depends on various factors examined and an error term with a mean of zero [45]. The conceptual analysis of the model used in this paper is similar to the model adopted by Esabu and Ngwenya [59] and Shange [30] to estimate the adoption of improved agricultural technologies by farming households. This study refers to the following equations: [44,59].

$$U_{i1} = \beta_1 X_i + \varepsilon_{i1} \qquad \text{for adoption} \tag{1}$$

$$U_{i0} = \beta_0 X_i + \varepsilon_{i0} \qquad \text{for non-adoption} \tag{2}$$

Based on the fact that utility is random, the ith SHF will select the alternative "adoption" only if $U_{i1} > U_{i0}$. Therefore, for the smallholder farmer i, the probability of adoption is indicated by:

$$P(1) = P(U_{i1} > U_{i0}) \quad (3)$$

$$P(1) = P(\beta_1 X_i + \varepsilon_{i1} > \beta_0 X_i + \varepsilon_{i0}) \quad (4)$$

$$P(1) = P(\varepsilon_{i1} - \varepsilon_{i0} < \beta_1 X_i - \beta_0 X_i) \quad (5)$$

$$P(1) = P(\varepsilon_i < \beta X_i) \quad (6)$$

$$P(1) = \Phi(\beta X_i) \quad (7)$$

where, U_{i1} = The utility a farmer obtains from the technology; U_{i0} = No utility obtained by a farmer from the technology; P (1) = Probability of adopting CSIT technology; $\beta_0 \ldots \beta_1$ = Estimated parameters; X_i = Independent variables; Φ = is the cumulative distribution function of the standard normal distribution. εi = Disturbance term.

In the situations of a normal distribution function, the model used to estimate the probability of adopting CSIT among surveyed farmers can be presented as:

$$P(Yi = 1|\, x) = \Phi\,(x\beta) = \int \frac{x\beta}{-\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-z^2/2\right) dz \quad (8)$$

where P stands for the probability that the ith SHF adopted CSIT and 0 otherwise.

The simple latent form of the probit model is below where:

$$Y^* = \beta_0 + x\beta + \varepsilon \quad (9)$$

In the equation indicated above, $\varepsilon \mid x$ is an error term that is normally distributed. Y* is an underlying index that reflects the difference between the utility derived from technology adoption.

The equation for explaining the influence of factors regarding the SHF decision to adopt CSIT can be expressed as follows:

$$x\beta \text{ with } x\beta = \beta_1 X_1 + \ldots \beta_k X_k \quad (10)$$

3.2.2. Ols Regression Model

Ordinary Least Squares (OLS) has been identified as one of the most popular methods used for data analysis because it can be applied to single, multiple, or appropriately coded categorical explanatory variables however, it mainly assumes linearity, which was satisfied by the data used for this study [60,61]. However, the model would result in biased and inconsistent estimates [61]. Therefore, to ensure the best estimates from OLS, several assumptions must be satisfied, including the one of constant error variance (i.e., homoskedasticity) [61]. According to Njoko and Mudhara [47], the OLS regression model can be specified as:

$$Y_i = \beta_0 + \beta_i X_i + \beta_2 X_2 + \beta_i X_i + e_i \quad (11)$$

where Y_i is the dependent variable, which is the water access per week for the ith SHF; X_i is a vector of independent variables; β_0 and β_i are the vectors of parameters to be estimated, and e_i is the error term.

4. Results

4.1. Characteristics of Smallholder Farmers in the Vhembe and Capricorn District

The descriptive results from continuous variables used in the study indicated minor to almost no differences between adopters and non-adopters of CSIT for most parameters (Table 1). On average, an adopter farmer is 48 years old, while a non-adopter farmer is 49 years old. The average household size for both groups consists of five people. The results indicated that the average land size cultivated by adopters and non-adopters of CSIT in the study area is 3.7 ha and 3.3 ha, respectively. In addition to the total farm size used by both the adopters and non-adopters, there is still a large amount of land significantly utilized for dryland production. There is a significant difference in farming experience as adopters have an average experience of 9 years compared to the 11 years' experience of the non-adopters. The results also indicated that there is an insignificant difference regarding the farm income between adopters and non-adopters. As the average farm income of non-adopters was R30585.00 per season, the farm income of the non-adopters was slightly higher at an average amount of R31450.00 per season. The possible explanation for the low farm income of adopters is that SHF were not exposed to the full potential of CSIT, such as mulching which is meant to conserve moisture without any extra operational and maintenance costs. On average, four workers per season are employed to carry out activities by adopters. Adopting CSIT resulted in SHF having access to water at an average of 5 days per week while paying a reasonable amount of R2555.00 per month. As irrigation often takes place on a schedule, this results in low water costs. For comparisons to non-adopters who have access to water at an average of 4 days per week, the cost is R3658.00 per month. The high water costs amongst non-adopters are often a result of traditional irrigation methods such as flood irrigation, which uses a large amount of water.

Table 1. Continuous variable description of data collected from two districts (Vhembe and Capricorn).

Variable	Adopters (N = 46)		Non-Adopters (N = 54)		Total (N = 100)		T Tests (χ^2 Tests)
	Mean	Std.Err	Mean	Std.Err	Mean	Std.Err	
Household number (number)	5.34	0.37	5.33	0.25	5.34	0.25	ns
Age (years)	48.30	2.13	49.14	1.86	48.76	1.86	ns
Farming experience (years)	8.58	1.20	10.53	1.05	9.64	1.05	**
Number of labourers number (number)	4	0.59	2.97	0.30	3.40	0.30	ns
Farm income per season: winter/summer (Rand)	30,585	8952	31,450	7527	31,052	7527	ns
Farm size used (ha)	3.74	0.61	3.33	0.81	3.49	0.81	ns
Water cost (R/month)	2555	681	3658	870.63	2984	870	ns
Water access (per/week)	5.41	0.30	4.62	0.39	4.99	0.39	ns

Note: ***, **, and * mean significant at 1%, 5%, and 10% levels, and ns means not significant.

Table 2 presents the descriptive results of the categorical variables used in the study. The results show that males (50%) and females (50%) play an equal role in adopting CSIT, whereas the majority (59.26%) of non-adopters were females. The Capricorn district had the most adopters (73.91%), while most SHF (70.37%) in the Vhembe district decided not to adopt CSIT. Shange [30], who studied the adoption of rainwater-harvesting technology, pointed out that a farmers' decision to adopt agricultural technology in a particular area depends on how SHF perceives it. Most SHF producing staple food and tubers did not adopt CSIT. The possible reason for the low adoption of CSIT may be that most SHF still regard their staple food, such as maize, to be a dryland crop, or it may be that farmers lack awareness about how vegetables such as tubers thrive under irrigation, particularly CSIT [24]. Very few (6.52%) of the adopters were members of the irrigation scheme. This may result from the fact that group members are perceived differently amongst SHF; therefore, individual comparative advantage plays a vital role in deciding whether to join a group [62]. Farmers also cannot contribute the monthly fee required to maintain the irrigation scheme as most of them live below the poverty line. The majority of the SHF had access to training; however, CSIT adopters knew about CSIT, while the non-adopters had no knowledge (80.43%). Apart from the indigenous knowledge that farmers have had for many decades, frequent contact with extension officers and participation in training workshops has contributed to the high percentage of knowledge access among adopters [30]. The results also suggested that most adopters (86.96%) used an electric pump to access water from different sources, while non-adopters used both gravity (44.23%) and electric pumps (40.38%). Furthermore, (73.91%) of adopters experience water shortages, while (52.83%) of non-adopters use gravity and electric pumps. As a result, farmers may be discouraged from adopting CSIT due to a lack of relevant resources.

Table 2. Categorical variables description of data collected from two districts (Vhembe and Capricorn).

Variable	Category	Adopters (N = 46)	Non-Adopters (N = 54)	Total (N = 100)	T Tests (χ^2 Tests)
		(%)			
Gender	Male	50.00	40.74	45.00	ns
	Female	50.00	59.26	55.00	
District	Capricorn	73.91	29.63	50.00	***
	Vhembe	26.09	70.37	50.00	
Staple food production	Yes	13.04	55.56	36.00	***
	No	86.96	44.44	64.00	
Tuber production	Yes	4.35	9.26	7.00	**
	No	95.65	90.74	93.00	
Member of the irrigation scheme	Yes	6.52	37.04	23.00	**
	No	93.48	62.96	77.00	
Training on CSIT	Yes	80.43	70.37	75.00	ns
	No	19.57	29.63	25.00	
Knowledge of CSIT	Yes	97.83	16.67	54.00	*
	No	2.17	83.33	46.00	
Irrigation equipment	Diesel pump	8.70	11.54	10.20	**
	Electricity pump	86.96	40.38	62.24	
	Generator	0.00	1.94	1.02	
	Gravity	4.35	44.23	25.51	
	Solar	0.00	1.92	1.02	
Water shortage	Yes	73.91	47.17	60.61	**
	No	23.91	52.83	39.39	

Note: ***, **, and * mean significant at 1%, 5%, and 10% levels, and ns means not significant.

4.2. Relationship between Socio-Economic Factors and Adoption of CSIT

Table 3 presents the maximum likelihood estimates of the probit model in terms of adopting CSIT. The value of the Pseudo R2 (48%), the log-likelihood (−15.51), and the LR Chi2 (significant at the 5% level) indicate that the model's specifications provide a good fit to the data. The model had no multicollinearity problems, as it had a low average variance inflation factor (VIF) of 1.71.

The regression results revealed that gender was significant at the 1% and 10% levels and positively influenced both a farmer's decision to adopt CSIT and the level of CSIT adoption, respectively. This implies that the probability of males adopting CSIT increases by 68% compared to their female counterparts. In comparison, the level of adoption was more likely to increase by 2.35%. The household size was positive and significant at the 1% and 10% level in influencing both farmers' decision to adopt CSIT and the level of adopting CSIT, respectively. This implies that an increase in household size by one member increases the probability of SHF adopting CSIT by 21%. Therefore, larger households are more likely to increase the level of adoption by 39%. Age was significant at 10% and related positively to the level of CSIT adoption. This implies that a one-year increase in the farmer's age is more likely to increase the level of CSIT adoption by 6%. The estimated coefficient of the district was positive and significant at the 5% level in influencing a farmer's decision to adopt CSIT. This implies that farmers in the Capricorn district have a 52% likelihood of adopting CSIT than farmers in the Vhembe district. The farming experience variable was negative and significant at the 5% level in explaining the level of CSIT adoption. The negative effect implies that a decrease in farming experience is more likely to cause a decline in the level of CSIT adoption by 21%. The estimated coefficient of farm size was positive and significant at the 5% level in influencing farmers' decision to adopt CSIT. The estimated positive coefficient indicates that an increase in farm size by one hectare increases the probability of CSIT adoption by 4%. The production of staple food was observed to have a positive and significant influence on the farmers' decision to adopt CSIT at the 5%

level; however, this factor did not influence the level of adoption. This means that farmers who cultivate crops such as maize have a 28% probability of adopting CSIT. Whereas the production of tubers revealed a negative and significant influence on the SHF decision to adopt CSIT at the 1% level and no effect on the level of adoption. The negative coefficient suggests that the probability of adoption could decrease by 25% for SHF that produce tubers. It may be that SHF is shifting to crops with good market prices or that the type of production system used in the district is unsuitable for these particular crops. Knowledge of CSIT had a positive and significant effect on the adoption of CSIT at the 1% level. This suggests that SHF who have been equipped with the necessary knowledge regarding CSIT have a 31% higher chance of adopting CSIT.

Table 3. Factors influencing the adoption of CSIT: The probit model results (N = 100).

Variables		Adoption Coefficient	Std. Err	Level of Adoption Coefficient	Std. Err	Marginal Effects dy/dx	Std.Err
Gender	1 if male, 0 otherwise	3.073 ***	0.955	2.350 *	0.793	0.687 ***	0.143
Household size	Number	0.839 ***	0.252	0.390 **	0.169	0.217 ***	0.061
Age	Years	−0.024	0.040	0.064 *	0.035	−0.006	0.010
District	1 if Capricorn, 0 otherwise	1.829 **	0.937	-	-	0.529 **	0.260
Farming experience	Years	−0.126	0.080	−0.217 **	0.063	−0.032	0.021
Number of labourers	Number	−0.165	0.187	−0.152	0.152	−0.042	0.044
Farm income per season (summer and winter)	(Rand)	−6.240	4.206	−0.2040	4.680	−1.620	0.000
Farm size used	ha	0.190 **	0.081	0.008	0.075	0.049 **	0.022
Staple food production	1 if yes, 0 otherwise	1.102 **	0.553	0.365	0.414	0.285 **	0.137
Tuber production	1 if yes, 0 otherwise	−0.985 ***	0.380	−0.280	0.354	−0.255 **	0.097
Member of irrigation scheme	1 if yes, 0 otherwise	−0.710	1.320	−0.217	1.305	−0.226	0.471
Training on CSIT	1 if yes, 0 otherwise	0.333	0.628	0.810	0.755	0.092	0.185
Knowledge on CSIT	1 if yes, 0 otherwise	1.212 ***	0.496	−0.071	0.481	0.313 ***	0.111
Irrigation equipment	1 if electric pump, 0 otherwise	1.740 *	0.939	1.560 *	0.907	0.577 **	0.290
Monthly cost of water	Rand	−0.000 *	0.000	0.000 ***	0.000	−0.000 *	0.000
Water access per week	Number	−0.846 ***	0.213	-	-	-0.219 ***	0.066
Water shortage	1 if yes, 0 otherwise	−0.488	0.563	−1.659 **	0.684	−0.123	0.146
_cons		0.032	2.169	1.220	2.338		
	Number of obs	45					
	Wald chi2(17)	28.61					
	Llog likelihood	15.511971					
	Prob > chi2	0.0383					
	VIF	1.71					

Note: ***, **, and * mean significant at 1%, 5%, and 10% levels.

Empirical results indicated that farmers who have access to irrigation equipment such as pumps reflected a positive and significant relationship at the 10% level in influencing both farmers' decision to adopt and level of adopting CSIT, respectively. This means that SHF with access to irrigation equipment have a 57% probability of adopting CSIT, and the level of adoption is more likely to increase by 1.56%. Sinyolo [1] indicated that farmers with water access equipment such as pumps usually have a reliable water supply. The monthly cost of water showed a negative and significant influence on the adoption of CSIT at the 10% level. This implies that SHF who are unable to afford the required monthly cost of water are less likely to adopt CSIT.

In most cases, SHF in the rural areas are unemployed and depend on agriculture for income. Therefore, finance will always be a challenge when farmers only produce for household consumption and have limited market access. While the level of adoption was positive and significant at a strong 1% level, implying that if SHF were able to afford the water cost per month, it would have increased the level of CSIT adoption. The relationship between water access per week and the adoption of CSIT is negative and significant at the 1% level. The negative coefficient indicates that the probability of SHF adopting CSIT decreases by 21% when they continue to have less access to water. The ones that are often affected are those located at a distance from reliable water sources such as dams and rivers. Water shortage had a negative and significant influence on the level of CSIT adoption at 5%. An increase in water shortages could decrease the likelihood of increasing the level of CSIT adoption amongst SHF by 1.65%. This result is consistent with the findings of Zhou & Abdullah [55], who indicated that water shortages make it impossible to perform agricultural activities.

5. Discussion

This paper aims to assess the factors influencing the adoption of CSIT for sustainable crop productivity by smallholder farmers in the Limpopo Province from two selected local Districts, namely Capricorn and Vhembe district. Results on the category of the respondents based on their level of use of CSIT reveal a similar pattern in both districts. The majority of the respondents fell into the non-adopter category, while the least proportion fell into the adopter category. However, there is a higher proportion of respondents in the non-adopter category in the Vhembe district when compared to the Capricorn district. These findings suggest that the sampled smallholder farmers in the Vhembe district are better adopters of CSIT than those in the Capricorn district. While our results showed that 46% of the smallholder farmers adopted climate-smart irrigation technologies, Masela [27] reported only 16.6% for the adoption rate of CSIT. The limitation is that the study only relied on data collected from the SHF under the irrigation schemes, while the 46% reported included the adoption of CSIT for many characteristics for individual SHF and those under the irrigation schemes. The results indicated a similar pattern in age distribution in the sampled smallholder farmers, revealing that more aged people were involved in farming than youths in both districts. The low level of involvement of youths in agriculture could be because they find agriculture unattractive and prefer to search for jobs in other sectors. However, the dominance of older farmers in the farming system could be an advantage in terms of wealth experience and social capital. This result is consistent with the findings of Mokgwathi [14] and Abegunde et al. [5]. The expectation was that CSIT adoption would be higher amongst younger farmers because they are more innovative regarding adopting agricultural technology and not reluctant to take risks [14,39,40]. Results on the gender indicated that males and females were represented equally in the Capricorn district. While in the Vhembe district, a large proportion of the sampled farmers were males. However, it has been found that males have a higher likelihood of increasing the level of adoption. This is often a result of dominant cultural biases where males still have exclusive rights to make farm decisions regarding short-term and long-term adjustments [30,63]. In contrast, women are often faced with social, cultural and financial barriers that limit them from accessing the required resources for CSIT adoption [30,64]. This factor had a positive and significant influence on both the adoption and level of adopting CSIT. The average household size of the sampled smallholder farmers indicates that the activities required for CSIT adoption will be handled despite an external labour force. The possible explanation could be that an increase in household size is often associated with the availability of cheap labour that would enable a household to accomplish various agricultural tasks, particularly in labour-intensive technologies, thus reducing the labour constraints [5,30,32,36]. The result concurs with the findings of Marie et al. [65]. The particular district where the smallholder farmer is based also plays a role in the adoption of CSIT. For instance, the Capricorn district has a higher adoption rate than Vhembe. This may be because farmers in the Capricorn district have regular contact with extension officers who equip them with the appropriate skills and knowledge regarding CSIT. The results indicated a high farming experience for the sampled farmers in the two districts, which is in line with the descriptive evidence of the dominance of older farmers in the study areas. However, the non-adopters had more farming experience than the adopters, thus resulting in the farming experience having a negative and significant influence on the level of CSIT adoption. This result suggests that when SHF have less experience, it often restricts them from exploring the many benefits that come with the adoption of CSIT. This result also suggests that involving experienced farmers in promoting CSIT among smallholder farmers can have a substantial impact on the uptake of various CSIT practices and decrease the implementation of CSIT-related programs and projects among smallholder farmers. The size of the farmland had a positive and significant influence on the farmers' decision to adopt CSIT, thereby implying that that land fragmentation could be a constraint to CSIT adoption. Land is a crucial resource in agricultural production, and farmers will be able to accommodate innovations or practices necessary for a successful agricultural venture with access to land and other needed resources. This result concurs with the findings of [5,39,66,67]. Furthermore, cultivation on large farms would allow the SHF to experiment with the different CSIT technologies, thus enhancing their risk-bearing ability [29,31,35]. However, based on the results, there is a difference in the degree of the adoption practices. In the Vhembe district, adopters are less likely to adopt CSIT. The findings on knowledge revealed that it had a positive and significant impact on the level of CSIT adoption. However, it is most likely those equipped with the necessary skills and knowledge have a higher chance of adoption. In most cases, SHF obtains knowledge from reliable agricultural information sources such as extension officers, media, irrigation committee and fellow farmers [47]. The actionable guidelines for implementing climate-smart agriculture published by the Department of Environment, Forestry and Fisheries have paved the way for the rollout of CSA (climate-smart agriculture) in South Africa. Sani [28] indicated that education is an important factor determining SHF's ability to understand policies or programs affecting the adoption of CSIT. This is consistent with the findings of Adebayo et al. [35], who pointed out that in most cases, the expectation would be that farmers that are more educated have better knowledge of the importance of adopting new technologies.

6. Conclusions

This study used the probit and OLS models to determine the factors influencing the adoption and the level of adopting CSIT by SHF to improve sustainable productivity. Several factors, categorized as demographics, farm characteristics, economic factors, and formal and informational training, influence a farmer's decision to adopt CSIT. Based on the study's evidence, few SHF adopted CSIT, and males and females played an equal role in the adoption process, thus removing gender inequality issues. In addition, it was mostly older farmers with experience who adopted CSIT due to the indigenous knowledge obtained over the years and the exposure to secondary factors (such as funding and established enterprises).

The study would make the following contributions to the theoretical and empirical literature and understand the adoption of CSIT by SHF. This particular study focuses only on the Limpopo Province in South Africa, and it contains valuable information that SHF can use in other Provinces to adopt CSIT. Therefore, the factors that have been included in this study can be explored in terms of formulating strategies and implementing processes that would assist in developing programs aimed at improving the livelihood of smallholder farmers through the adoption of climate-smart irrigation. It has been found that literature on factors that influence the adoption of climate-smart irrigation in South Africa is limited. Therefore, the results of this study will provide an empirical contribution to the existing literature that identifies factors that play an essential role in the adoption of climate-smart technologies by smallholder farmers. The study recommends that stakeholders in the agricultural sector, such as extension officers, should continue educating smallholder farmers about CSIT, particularly because they are the ones who are usually affected negatively by climate change. This can be done by organizing workshops and farmers' days. In order to fast track the adoption of the CSIT amongst SHF, there is a need to provide capacity building, technology transfer demonstrations, and strengthen knowledge dissemination as part of the science-policy interface. The farmers will be able to interact with companies and see the different equipment required to adopt CSIT. This would enable the farmers to equip themselves with the necessary accurate information to adopt CSIT.

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