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Influence of Communication Channels on Sustained Adoption of Climate-Smart Agricultural Technologies in The West Usambara Mountains, Tanzania

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Abstract: *Climate change has been reducing agricultural production, especially cereals, potatoes and vegetables in the West Usambara Mountains. One approach for farmers to increase crop productivity in the West Usambara Mountains is to adopt Climate-Smart Agricultural (CSA) technologies. From 2011 to 2019, the Climate Change Agriculture and Food Security (CCAFS) project employed different communication channels to promote CSA technologies such as terraces, tree planting, organic fertilizers, improved seeds and weather information services. Understanding the influence of communication channels on the sustained adoption of CSA technologies is essential to decision-makers and extension workers. This study assessed the influence of communication channels on the sustained adoption of CSA technologies. A cross-sectional research design was adopted whereby a sample of 124 households was chosen by using simple random sampling from 140 farming households which participated in the CCAFS project. Data were collected by using household surveys, key informant interviews and focus group discussions. Analysis of quantitative data was conducted by using the Multivariate Probit Model through STATA software version 17 while thematic analysis was done for qualitative data. Results show that mobile phone contacts had a positive significant influence on the sustained adoption of tree planting and terraces. Farmers' meetings had a positive significant influence on the sustained adoption of weather information services, tree planting and terraces. Farmer-extensionist contacts had a positive significant influence on the sustained adoption of weather information services, improved seeds, organic fertilizers and terraces. Farmer-researcher contacts had a positive significant influence on the sustained adoption of improved seeds. Demonstration farms had a positive significant influence on the sustained adoption of weather information services. This study concludes that communication channels are information pathways useful in promoting the sustainable adoption of CSA technologies in the study area. This study recommends that agricultural stakeholders including policymakers and extension workers should incorporate communication channels when promoting post-project adoption of CSA technologies and designing future sustainable CSA interventions since they are important information pathways to farmers.*

Keywords: *climate change, sustained adoption, climate-smart agricultural technologies, communication channels*

1. Background Information

Land degradation and climate change are major threats to sustainable agricultural production globally and in Sub-Saharan Africa (SSA) (Thompson *et al.*, 2010). These have contributed to low agricultural productivity, food insecurity and a rise in poverty levels especially for smallholder farmers who entirely depend on rain-fed agriculture (Yazar and Ali, 2016; Kanyenji *et al.*, 2020). The sector is already experiencing negative impacts from high temperatures, more unpredictable rainfall, more frequent extreme weather events and an increase in invasive pests and diseases, which will worsen as climate change accelerates (IPCC, 2021; World Bank, 2021). Frequent changes in weather and climatic conditions have highly reduced production of major cereals such as wheat, maize and beans (World Bank, 2021).

Like other Sub-Saharan African countries, smallholder farmers in Tanzania are facing challenges posed by climate change (URT, 2021; Mafie, 2022). In some areas, changes in climatic conditions have replaced perennial crops with annual crops due to shortened crop cycles (URT, 2016). Food and Agriculture Organization of the United Nations introduced Climate-Smart Agriculture (CSA) in 2010 as an approach to agricultural transformation under climate change (FAO, 2013). The CSA aims to achieve three main pillars; sustainably increasing agricultural productivity and incomes; adaptation and resilience building and reducing emissions of greenhouse gases (GHGs) from agricultural activities where possible (FAO, 2013; Bazzana *et al.*, 2021). These pillars can be achieved when farmers can adapt to a changing climate and reduce emissions of GHGs from farming activities (IPCC, 2021; Bazzana *et al.*, 2021).

The adoption process of innovation comprised of communication channels in the dissemination of information to ensure that farmers are aware of the importance of CSA technologies and able to apply technologies in adaptation to climate change (Kigatiira *et al.*, 2018; Lugamara *et al.*, 2019). Moreover, communication facilitates the transfer of technology from experts such as agriculture extension agents, researchers and community development workers to users such as farmers as well as facilitates the exchange of information (Idowu *et al.*, 2020; Muriithi *et al.*, 2021). A communication channel refers to a transmission medium or pathway used by participants to disseminate and share information (Rogers, 2003). Poor information communication about agricultural technologies contributes to low adoption of CSA technologies due to a lack of awareness and understanding about the use of technologies (Kigatiira *et al.*, 2018). In the promotion of agricultural technologies, mass media such as radio, television, magazines and newspapers, and interpersonal communication channels such as mobile phones, farmer meetings, farmer-extensionist contacts and demonstrations are used in the dissemination and sharing of information and knowledge between experts and farmers (Kigatiira *et al.*, 2018; Muriithi *et al.*, 2021). Farmers can adopt CSA technologies in combination to enable them to address a multitude of challenges such as moisture stress, low soil fertility, declining groundwater table, soil erosion and low crop productivity (Aryal *et al.*, 2018). A combination of communication channels has a more relative advantage in the adoption of agricultural technologies because different pathways can work together to enhance the effectiveness of information communication and rapid adoption and sustained use of CSA technologies (Lamptey *et al.*, 2024).

Empirical studies conducted in different geographical areas reported factors influencing adoption and continuous use of CSA technologies including socio-economic (Oleded and Wakatsuki, 2011; Okonji and Owolu, 2020; Nsele *et al.*, 2022), communication (Muriithi *et al.*, 2021; Idowu *et al.*, 2020; Kitagriira *et al.*, 2018) and farmers' perceptions (Pilarova *et al.*, 2018; Talanow *et al.*, 2021). Regarding the communication channels, the use of mobile phones had a positive influence on the sustained adoption of tree planting integrated into the cropping system in Machakos, Makueni and Kitui Counties in Kenya (Muriithi *et al.* (2021). Kitagriira *et al.* (2018) reported that the association of farmer meetings, farmer-researcher communication and demonstration had a positive significant influence on the sustainable adoption of improved potato variety in Kenya. The study conducted by Qin and Freeman (2020) found that mobile phone communication was a communication channel which had a positive significant relation to the continuous use of CSA technologies in Uganda. Another study conducted by Idowu *et al.* (2020) revealed that farmer-extension communication and farmer-to-farmer communication were communication factors with a positive significant influence on the long-term adoption of CSA technologies such as improved seeds in Nigeria. Aryal *et al.* (2017) also reported that farmer-to-farmer communication and farmer-extensionist communication were significant factors influencing the sustainable adoption of CSA technologies in the Indo-Gangetic Plains of India. Hence, determinants of sustained adoption of CSA technologies such as information communication channels are specific to a particular area.

In the West Usambara Mountains Tanzania, agricultural production is highly challenged by climate change (Lyamchai *et al.*, 2011; Rukanda, 2014; Ogada *et al.*, 2020). In response to climate change, the University of Leeds and the Consultative Group for International Agricultural Research (CGIAR) implemented a ten-year project known as the Climate Change Agriculture and Food Security (CCAFS) Project which was phased out in 2019. The project was implemented in collaboration with Lushoto District Council and Agricultural Research Institute based in Selian Arusha Tanzania. The main CSA technologies prioritized by the project include terraces, tree planting, organic fertilizers, improved seeds and weather information. Terraces are constructed across the slopes of mountains to control soil erosion by reducing water runoff and retaining soil moisture for plant growth (Debg *et al.*, 2021). Trees have several advantages including stabilizing agricultural land through their roots, adding organic fertilizers from decayed leaves, increasing carbon sink and a source of food and income generated from fruits and construction materials (FAO, 2013). Organic fertilizers enhance the resilience of to climate change by improving soil fertility and soil structure and maintaining soil moisture longer after the rainy season (Han *et al.*, 2015). Crop varieties developed from improved traits which are tolerant to drought and resistant to pests and diseases increase crop productivity under climate change (Acevedo *et al.*, 2020). Weather information generated from indigenous and scientific weather forecasting methods is essential to farmers since it provides predictions about weather conditions including the onset, termination and amount of rainfall (World Bank, 2016). Farmers' adoption and sustainable use of CSA technologies can increase crop productivity despite a change in weather and climatic conditions in the West Usambara Mountains.

Some previous studies reported substantial adoption of CSA technologies during the implementation of agricultural projects especially when execution was accompanied by some kind of support (Ogada *et al.*, 2020; Murwanashyaka *et al.*, 2021), but other studies reported a decline in the adoption of promoted CSA technologies after phasing out the projects (Odame *et al.*, 2011; McNiven *et al.*, 2016). Sustained adoption of CSA technologies refers to the continuous use of technologies after the end of the diffusion project which provides some kind of support to individuals such as farmers (Rogers, 2003; Oldenburg and Glanz, 2008). Effective communication through continuous awareness and information sharing is essential in promoting the adoption of CSA technologies during and after phasing out diffusion intervention (Rogers, 2003; Kigatiira *et al.*, 2018). The implementation of the CCAFS project employed different communication channels such as radios, mobile phones, farmers' meetings, farmer-extensionist communication, farmer-researcher communication and farm demonstrations to facilitate the transfer and sharing of information related to CSA technologies between farmers and agriculture experts including agriculture extension officers and researchers. Lack of effective communication may constrain adoption and long-term use of CSA technologies, and eventually reduce crop productivity in the West Usambara Mountains.

In the study area, previous research has already been conducted particularly the assessment of socio-economic factors influencing the adoption of CSA technologies and explanation of CSA information pathways in the early and mid-implementation of the CCAFS project (Nyasimi *et al.*, 2017; Ogada *et al.*, 2020). However, there is a lack of clear understanding about the influence of communication channels on the sustained adoption of CSA technologies in the West Usambara Mountains after the end of the CCAFS project. The scarcity of information regarding the influence of communication channels on sustained adoption may constrain a review of post-project interventions and designing future sustainable agricultural projects which are resilient to climate change. Hence, adequate information about communication channels can be useful to policymakers, extension workers and project managers in the dissemination of information that can foster post-project adoption of CSA technologies and crop productivity. Information may also assist in designing related future sustainable CSA projects. Therefore, this study assessed the influence of communication channels on the sustained adoption of CSA technologies in the West Usambara Mountains, particularly after phasing out the CCAFS project. Specifically, the study assessed farmers' access to information related to CSA technologies from communication channels; and examined the influence of communication channels on sustained adoption of CSA technologies.

Moreover, the study findings may assist implementation of Tanzania's National Agricultural Policy 2013, National Climate Change Response Strategy 2021-2026 and Tanzania's Climate-Smart Agriculture Guideline 2017. The study is also in line with Sustainable Development Goals (SDGs) especially SDG number 1 which aims at ending poverty in all forms, SDG number 2 aims at ending hunger, achieving food security and improving nutrition, and promoting sustainable agriculture, and SDG number 13 directs all countries to take action to combat climate change and its impacts.

2.0 Theoretical Framework

This study used the Diffusion of Innovation Theory to explain the influence of communication channels on farmers' sustained adoption of CSA technologies after phasing out of the CCAFS project. According to this theory, adoption refers to a decision to full use of an innovation (technology) as the best course of action available and rejection is a decision not to adopt an innovation (Rogers, 2003). Sustained adoption refers to the continuous use of innovation after the end of a diffusion project or program (Rogers, 2003; Oldenburg and Glanz, 2008). The Diffusion of Innovation Theory explains communication channels as one of the important components in the adoption and diffusion of technologies. According to Rogers (2003), the innovation-decision process comprises five stages including knowledge, persuasion, decision, implementation and confirmation. In the confirmation stage, individuals such as farmers decide either to continue adoption or discontinue after a period of repeated use of innovation.

Rogers (2003) and Onasanya *et al.* (2006) assert that communication is a process in which participants interact with one another through knowledge and information aiming at changing their attitudes towards the adoption of innovation. Information communication occurs through a pathway or channel whereby information originates from the source such as an agriculture extension officer and is transferred to the receiver (recipient) such as a farmer (Rogers, 2003). This theory explains two main categories of communication channels namely; 1) media of communication such as radio, television and newspapers, and 2) interpersonal communication which in the context of dissemination of agricultural innovation may comprise information communication channels such as mobile phones, farmer-extension interactions, farmer meetings and demonstrations (Rogers, 2003, Wafula, 2012; Kigatiira et al., 2018). Diffusion of Innovation Theory assumes that communication channels including mass media and interpersonal communication have a positive significant influence on the adoption and continuous use of innovation (Rogers, 2003).

Diffusion of Innovation Theory has a weakness of assuming that information flows in one direction from source (experts) to receiver (individuals such as farmers). However, the forward and backward flow of information is essential in the sharing of information between stakeholders such as extension officers, researchers and farmers for the promotion of adoption and continuous use of innovations. Regardless of some weaknesses, the Diffusion of Innovation Theory remains relevant in explaining the adoption of technologies. This study adapted the definition of sustained adoption and types of communication channels including mass media such as radio and interpersonal communication such as mobile phones, meetings, farmer-extensionist communication, farmer-researcher communication and demonstration. Moreover, theoretical assumptions regarding the influence of communication channels on the adoption and continuous use of innovation have been used to explain this study. Hence, this study assessed the influence of communication channels on the sustained adoption of CSA technologies in the West Usambara Mountains after phasing out of the CCAFS project.

3.0 Methodology

This study was conducted in Lushoto District in the West Usambara Mountains Tanga Region Tanzania. Lushoto District is located between latitudes $4^0$05' and $5^0$00', and between longitudes $38^0$05' and $38^0$40'. The study area comprises two agro-ecological zones including a humid warm zone (temperature is 22^0C and annual rainfall is 800-1700mm) and a humid cold zone (temperature is 18^0C and annual rainfall is 600-1200mm) (Minderhoud, 2011; Lyamchai *et al*., 2011). The study area comprised hills and v-shaped valleys with narrow flat bottoms. The main economic activity is agriculture whereby the major crops grown include maize, beans, Irish potatoes and different varieties of vegetables such as tomatoes and cabbages while few farmers engage in keeping livestock such as cattle, sheep, goats and chicken. The study area was selected because it is where the CCAFS project disseminated and promoted the use of CSA technologies for 10 years in seven villages to address challenges related to land degradation and climate change which were reducing crop productivity. The project was implemented in seven villages including Yamba, Gare, Masange, Boheloi, Mbuzii, Kwang'wenda and Milungui. During implementation, the CCAFS project used different communication channels to create awareness and disseminate information and knowledge that can enable farmers to adopt and continue using CSA technologies to improve crop productivity.

A cross-sectional research design was used since it allowed the collection of data at a single point in time. Estimation of sample size was done by using the hypergeometric formula shown below. This formula is very applicable to the determination of a study sample from a small population (Busbee, 2017).

$$n = \frac{Z^2Npq}{e^2(N-1)+Z^2pq}$$

$$\text{Thus, } n = \frac{1.96^2 \times 140 \times 0.5 \times 0.5}{0.03^2(140-1)+(1.96^2 \times 0.5 \times 0.5)} = 124$$

Whereby; n = sample size; N = survey population; p and q are population proportions (If they are not known, each set at 0.5); Z = is the value set at 1.96 that specifies the level of confidence at 95% and E sets the accuracy of the sample proportions of plus or minus 3% (or 0.03). Therefore, the sample size used in this study was 124 farming households. The study sample was equivalent to 88.6% of the survey population. The sample size was selected by using a simple random sampling method from 140 farming households which received CSA interventions during the CCAFS project.

Data collection was conducted between May to June 2022 by using mixed methods including household questionnaire survey, key informant interviews and Focus Group Discussions (FGDs). A structured questionnaire was used to collect quantitative data from heads of households. Qualitative data were collected through key informant interviews from the District Agriculture Irrigation and Cooperative Officer (DAICO) and two Agriculture Extension Officers from the Lushoto District Council who participated in the CCAFS project. There were seven (7) FGDs each one conducted in each village engaged in the CCAFS project. Each focus group discussion comprised seven smallholder farmers who participated in the CCAFS project including males and females.

This study analyzed both qualitative and quantitative data to generate results. Qualitative data collected from key informants and FGDs were analyzed by using thematic analysis to reveal in-depth information which complemented the quantitative results. The study employed STATA software version 17 to analyze quantitative data collected through household questionnaires. Specifically, the multivariate probit (MVP) model was used for the analysis of communication channels influencing sustained adoption of CSA technologies. The MVP model simultaneously explains the influence of predictors (communication channels) on the dependent variable (sustained adoption of CSA technologies) comprised of three or more categories while allowing unobserved factors (error terms) to be freely correlated (Belderbos *et al*., 2004; Lin *et al.*, 2005). The study used MVP since there were five CSA technologies which are mutually inclusive whereby an individual farming household can choose more than one technology (Rahut and Ali, 2018). Hence, the MVP model is applicable in examining factors influencing choices of CSA technologies when there are three or more categories of technologies each is measured at the nominal level (1, if farming household sustained adoption of a choice of CSA technology, 0 otherwise). Independent variables should be continuous and dummy in nature (Wuensch, 2014). The multivariate probit model is represented in equation 1:

$$Y^*_{mi} = \beta_{mi}X_{mi} + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

Whereby; *m* was categorized into *i* types of technologies (i_1=terraces, i_2=tree planting, i_2=organic fertilizers, i_4=improved seeds, i_5=weather information).

Y_i = 1 if Y_i*>0 and 0 otherwise

Where; Yi* is an unobservable latent variable which indicates the probability of sustained adoption of a choice of *m* (CSA technology), β_m = vector of unknown parameters (*m*=1, 2, 3, 4, 5), X_{mi} = vector of communication channels influencing sustained adoption of a choice of CSA technology and ε_i=error term (ε_1, ε_2, ε_3, ε_4, ε_5). Thus, statistically, the MVP model can be expanded into five equations which simultaneously explain the influence of communication channels on the sustained adoption of five categories of CSA technologies. Equations 1 to 5 below represent an extended multivariate probit model that explains the simultaneous influence of communication channels on sustained adoption of terraces, tree planting, organic fertilizers, improved seeds and weather information services respectively.

$$Y_{mi1} = \beta_1 X_{mi1} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$
$$Y_{mi2} = \beta_2 X_{mi2} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$
$$Y_{mi3} = \beta_3 X_{mi3} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$
$$Y_{mi4} = \beta_4 X_{mi4} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$
$$Y_{mi5} = \beta_5 X_{mi5} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Error terms are considered to be multivariate limited dependent variables in which the five error terms are normally distributed with zero conditional mean and variance normalized to unity where multivariate normal distribution MVN~(0, Ω) and symmetric covariance matrix Ω is given by;

$$\Omega = \begin{bmatrix} 1 & px1x2 & px1x3 & px1x4 & px1x5 \\ px2x1 & 1 & px2x3 & px2x4 & px2x5 \\ px3x1 & px3x2 & 1 & px3x4 & px3x5 \\ px4x1 & px4x2 & px4x3 & 1 & Px4x5 \\ px5x1 & px5x2 & px5x3 & px5x4 & 1 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots (7)$$

Equation seven (7) generates the MVP model that jointly represents farmers' decision to choose one or multiple CSA technologies. Explanations of dependent variables and measurements are shown in Table 1.

Table 1: Explanation of dependent variables and measurements used in multivariate probit model

Dependent variable	Measurement
Sustained adoption of CSA technologies (Y_m)	Y_{mi1} = 1 if sustained adoption of weather information services, 0 otherwise.
	Y_{mi2} = 1 if sustained adoption of improved seeds, 0 otherwise.
	Y_{mi3} = 1 if sustained adoption of organic fertilizers, 0 otherwise
	Y_{mi4} =1 if sustained adoption of tree planting, 0 otherwise.
	Y_{mi5} = 1 if sustained adoption of terraces, 0 otherwise

Independent variables are radio communication, mobile phones, farmers' meetings, farmer-to-farmer contacts, farmer-extensionist contacts, farmer-researcher contacts and demonstration farms. Explanations of independent variables and measurements are shown in Table 2.

Table 2: Explanation of independent variables and measurements used in the multivariate probit model

Independent variables	Measurement
Radio (X1)	1 if the farmer is well informed, 0 otherwise
Mobile phone (X2)	1 if the farmer had frequent contacts, 0 otherwise
Farmers' meetings (X3)	1 if the farmer is well informed, 0 otherwise
Farmer-extensionist contacts (X4)	1 if the farmer had frequent contacts, 0 otherwise
Farmer-researcher contacts (X5)	1 if the farmer had frequent contacts, 0 otherwise
Demonstrations farms (X6)	1 if the farmer visited farms or participated, 0 otherwise
Farmer-to-farmer contacts (X7)	1 if the farmer had frequent contacts, 0 otherwise

4.0 Results and Discussion

4.1 Famers' access to information related to CSA technologies from communication channels

Farmers' access to information disseminated through communication channels was assessed by understanding farmers' ability to receive and share information and knowledge using different sources of information including radio, mobile phone, farmers' meetings, farmer-extensionist contacts, farmer-researcher contacts, farmer-to-farmer contacts and demonstration farms. Access to information was measured by using dummies whereby the results are presented in Table 3.

Table 3: Access to information from communication channels (n=124)

Communication channels used by farmers	Number of respondents	Percent	Rank
Farmer-to-farmer contacts	98	79.0	1
Farmers' meetings	66	53.2	2
Demonstration farms	65	52.4	3
Mobile phones	59	47.6	4
Farmer-researcher contacts	47	37.9	5
Farmer-extensionist contacts	43	34.7	6
Radio	29	23.4	7

Based on access to information related to CSA technologies, the farmer-to-farmer contacts method was the most applied communication channel while radio was the least applied source of information in the study area (Table 3). The majority of farmers (79%) use farmer-to-farmer contacts for frequent communication and sharing information related to CSA technologies (Table 3). At different times, individual farmers can communicate with each other through the sharing of information and receiving knowledge related to CSA technologies such as improved seeds and weather information when they visit each other and communicate on mobile phones. This study also found that 53.2% of farmers utilize farmers' meetings to receive information and knowledge related to CSA technologies (Table 3). During the meetings, expert farmers can provide information to other farmers related to improved technologies adaptive to climate change that can improve crop productivity. Sometimes, the meetings invite agriculture extension agents and researchers to provide information and knowledge related to CSA technologies.

Furthermore, this study found that 52.4% of farmers had access to information and knowledge from demonstration farms (Table 3). When farmers visit or participate in demonstration farms, they get information and knowledge on how they can apply different CSA technologies and see evidence of the performance of CSA technologies in crop productivity. Hence, demonstration farms can motivate farmers to adopt CSA technologies on their farms. The findings from this study are related to Wafula (2013) who also reported that farmers engaged in a project known as the Dissemination of New Agricultural Technologies in Africa (DONATA) project in Karinyaga and Kathonzweni sub-counties in Kenya ever visited demonstration farms where they acquired technical skills related to CSA technologies. Similar findings were reported in the Savannas of West

Africa that demonstration farms gave access to smallholder farmers to learn the application of CSA technologies (Olarinde *et al.*, 2017). Further, FAO (2019) asserts that demonstrations enable farmers to see, hear, handle, discuss and practice CSA technologies before they decide on adoption.

The use of mobile phones was also among the sources of information related to CSA technologies which to some farmers (47.6%) in the study area (Table 3). Using mobile phones, farmers communicate with agriculture extension officers, expert farmers and agro-dealers to receive advice and knowledge related to CSA technologies. Through mobile phones, farmers can ask availability of technologies such as improved seeds and fertilizers and purchase inputs on time from agro-dealers. The study findings agree with Wafula (2012) who reported that some farmers use mobile phones to access information related to CSA technologies in Karinyaga and Kathonzweni Sub-counties in Kenya where the DONATA project promoted the adoption of improved maize varieties.

This study also revealed that there were 37.9% of farmers had frequent contact with researchers aiming at receiving information and knowledge related to CSA technologies (Table 3). Findings revealed by FGD confirmed that the majority of farmers rarely receive feedback information from researchers. Similarly, there was poor access to farmer-extensionist communication since only 34.7% of farmers had frequent contact with agriculture extension officers related to CSA technologies in the study area. FGDs also expressed that communication between farmers and extension officers is important but extension officers are not always available to visit farmers. During FGDs, one participant said that;

> *"Farmers highly demand information, advice and knowledge from agriculture extension officers, but we hardly get access to their services because they are not sufficient to attend every farmer regularly. There is only one extension officer for each ward compared to a large number of farmers"* (FGDs, Yamba Village, June 2022).

The interviews involved key informants revealed that agriculture extension officers are fewer in number to afford to visit many farmers at a time. Additionally, agriculture extension officers face several challenges such as difficulty walking in mountainous landscapes, scattered and fragmented farms and lack of means of transport which limit them from attending to farmers regularly. One of the extension officers said that;

> *"Despite the CCAFS project being phased out, we continue implementing our responsibilities by providing extension services to farmers through occasional visits to monitor progress, advising the use of CSA technologies and providing agricultural information. Although we are few, still most of us face some challenges including lack of access to motorcycles and high running cost for those possessing motorcycles."* (Key informant, Lushoto District Council, June 2022).

Aremu *et al.* (2015) noted that despite some limitations, extension agents are essential in providing advice, education and other agricultural information that enhance agricultural adaptation to climate change. The study findings concur with Muriithi *et al.* (2021) and Wafula (2013) who reported that there was poor access to communication between farmers and agricultural extension workers among farmers in Machakos, Makuneni and Kitui Counties and Katrinyaga and Kathonzwen Sub-Counties in Kenya.

Radio was the least-used communication channel in the study area whereby few farmers (23.4%) were listening to radio programs promoting the application of CSA technologies (Table 3). Findings revealed by FGD expressed that the use of radio is not a common source of agricultural information to farmers since some farmers do not own radio while in most villages the coverage of radio stations is still poor. One of the FGD participants said that;

> *"In our village, radio programs do not reach most farmers due to poor coverage of radio stations while others rarely conduct agricultural programs related to Climate-Smart Agriculture."* (FGDs, Yamba Village, June 2022).

The study findings correspond with Wafula (2012) who reported that there was poor access to information communication of CSA technologies through radio in Karinyaga and Kathonzweni Sub-counties in Kenya where the DONATA project promoted the adoption of improved maize varieties. Therefore, radio is only important if farmers have access to radio programs which are relevant and effective in promoting agricultural transformation to climate change which can increase crop productivity.

4.2 Influence of communication channels on sustained adoption of CSA technologies

After the end of the CCAFS project, sustained adoption of CSA technologies was 26% for terraces, 68% for tree planting, 82% for organic fertilizers, 85% for improved seeds and 75% for weather information services. Results revealed that five communication channels including mobile phones, farmer meetings, farmer-extensionist communication, farmer researcher communication and demonstration farms were among the CSA technologies which had a positive significant influence on the sustained adoption of CSA technologies after phasing out of the CCAFS project (Table 4). Hence, the likelihood to continue using CSA technologies increases when farmers have access to information through communication channels. In this study, the multivariate probit model examined the concurrent influence of explanatory variables (communication channels) on the adoption of CSA technologies where farmers had the decision to choose one or more technologies as the best option for climate change adaptation and combating land degradation. The log-likelihood is significant (Prob> Chi^2 = 0.0002) which justifies the probit model fitness.

Mobile phone communication had a positive significant influence on the sustained adoption of tree planting (β=0.685, p≤0.01) (Table 4). Information communication through mobile phones increases the likelihood of sustained adoption of tree planting among farmers. Mobile phone communication also had a positive significant influence on the sustained adoption of terraces (β=1.110, p≤0.01) (Table 4). The findings implied that most farmers who use mobile phones get information, knowledge and advice from agriculture extension officers and expert farmers. The information enabled them to continue the adoption of tree planting and terraces. Hence, farmers can use a mobile phone to get information regarding where they can buy tree seedlings or tree seeds. Farmers can also learn to prepare tree nurseries, plant trees and construct terraces across the slopes of mountains. The study findings agreed with Qin and Freeman (2020) who reported the positive influence of mobile phone communication on sustainable adoption of CSA technologies in Uganda.

Farmers' meetings which were also prioritized in the study area had a positive significant influence on sustained adoption of weather information services (β=0.173, p≤0.01), tree planting (β=0.639, p≤0.01) and terraces (β=0.852, p≤0.01) after phasing out of the CCAFS project (Table 4). Hence, farmers' participation in the meetings increases the likelihood of sustained adoption of CSA technologies particularly weather information, tree planting and terraces after the end of the CCAFS project. The findings can be justified that most farmers who attended farmers' meetings have sustained adoption of weather information disseminated by the Tanzania Meteorological Authority and later communicated by agriculture extension officers and expert farmers who attend meetings. Farmer meetings can also convey useful information about where farmers can get tree seedlings and how they can plant and manage trees together with crops especially when experts attend such meetings. Moreover, expert farmers, extension officers and researchers when attending farmers' meetings provide education on the usefulness and application of CSA technologies such as terraces. The study findings agree with Kigatiira *et al.* (2018) who reported the association between farmers' meetings and sustainable adoption of CSA technologies among farmers in Irish potato-producing areas in Kenya.

This study further revealed that farmer-extensionist communication had a positive significant influence on the sustained adoption of four CSA technologies including weather information (β=0.168, p≤0.1), improved seeds (β=0.501, p≤0.01), organic fertilizers (β=0.043, p≤0.1) and terraces (β=0.732, p≤0.01) as shown in Table 3. Farmer-extensionist communication increases the likelihood of sustained adoption of weather information, improved seeds, organic fertilizers and terraces in the absence of external support from diffusion projects such as the CCAFS project. Through farmer-extensionist interactions, agriculture extension officers were able to provide information and education to farmers that influenced the sustained adoption of CSA technologies to increase crop productivity irrespective of climate change. The study findings concur with Idowu *et al.* (2020) who reported that farmer-extension communication was positively associated with sustained adoption of improved seeds in selected areas of Nigeria. The study is in contrast with Nsele *et al.* (2022) who found that farmer-extensionist communication was not a significant predictor of sustained adoption of organic fertilizers because many farmers were not aware of the usefulness of organic fertilizers and there was poor access to manure and compost among the farmers.

Farmer-researcher communication significantly influenced the sustained adoption of improved seeds (β=0.173, p≤0.1) (Table 4). Effective communication about CSA technologies between farmers and researchers enhances the likelihood of continued use of improved seeds. Farmers who engaged in research on CSA technologies like improved maize, beans, and Irish potato seeds were more likely to sustain adoption. Dissemination of research findings on CSA technologies to farmers promotes long-term use beyond project periods. Kigatiira et al. (2018) also found that agricultural research information supports the sustainable use of CSA technologies in Kenya. Lamptey (2021) noted that research institutions are key sources of information for farmers and extension agents, influencing the adoption and long-term use of agricultural technologies under climate change.

Table 4: Multivariate probit analysis of communication channels influencing sustained adoption of CSA technologies in the West Usambara Mountains (n=124)

Variables	Weather information services		Improved seeds		Organic fertilizers		Tree planting		Terraces	
	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z
Radio	-0.055 (0.358)	0.878	-0.150 (0.323)	0.641	-0.023 (0.316)	0.941	0.164 (0.305)	0.590	0.432 (0.374)	0.248
Mobile phone	0.414 (0.287)	0.149	0.317 (0.278)	0.254	0.208 (0.259)	0.421	**0.685***** (0.268)	0.011	**1.110***** (0.305)	0.000
Farmers' meetings	**0.173***** (0.290)	0.001	-0.391 (0.288)	0.175	0.189 (0.272)	0.486	**0.639***** (0.279)	0.002	**0.852***** (0.314)	0.007
Farmer-extensionist contacts	**0.168*** (0.290)	0.061	**0.501***** (0.267)	0.001	**0.043*** (0.262)	0.069	0.102 (0.261)	0.697	**0.732***** (0.307)	0.017
Farmer-researcher contacts	0.210 (0.325)	0.519	**0.173*** (0.314)	0.080	-0.150 (0.307)	0.624	0.216 (0.302)	0.476	0.284 (0.327)	0.385
Farm demonstrations	**0.730**** (0.314)	0.020	0.275 (0.293)	0.349	-0.050 (0.286)	0.861	0.248 (0.289)	0.390	0.178 (0.326)	0.584
Farmer-to-farmer contacts	-0.098 (0.312)	0.755	0.258 (0.292)	0.378	0.216 (0.278)	0.437	0.195 (0.277)	0.482	-0.327 (0.347)	0.346
Constant	-1.732 (0.996)	0.071	0.229 (0.904)	0.903	-1.837 (0.885)	0.029	-0.436 (0.852)	0.678	-3.551 (1.018)	0.001

Log likelihood = -278.467

Wald Chi^2 = 129.07, Prob> Chi^2 = 0.0002

***, **, * Significant at 1%, 5% and 10% respectively

On-farm demonstration of CSA technologies had also a positive significant influence on the sustained adoption of weather information services (β=0.730, p≤0.05) (Table 4). Farm demonstration on the application of CSA technologies increases the likelihood of sustained adoption of weather information services. In the demonstration, weather information disseminated by the Tanzania Meteorological Agency and indigenous weather forecasting are applied to implement agricultural activities in demonstration farms. Additionally, agriculture extension officers use weather information together with other CSA technologies to demonstrate results related to farm preparation on time before the rainy season, selecting the type of seeds, planting seeds on time and harvesting yields on time. Hence, the application of weather information in demonstration farms motivated most farmers to adopt and continue using weather information in their farms after phasing out the CCAFS project. The study findings agree with FAO (2019) which revealed that result demonstrations can help farmers to compare obstinate innovations with modern ones and later adopt the best choice. The study findings are related to Kigatiira *et al.* (2018) who found that farm demonstration was associated with sustainable use of improved technologies among Irish potato farmers in Kenya.

Other communication channels including radio and farmer-to-farmer communication were not significant predictors of sustained adoption of CSA technologies in the study area (Table 4). Hence, statistically, there is a limited likelihood of sustained adoption of CSA technologies particularly terraces, tree planting, improved seeds, organic fertilizers and weather information due to farmer-to-farmer meetings. This can be justified because farmers had limited knowledge and information related to CSA technologies that usually can't help them share and decide on long-term adoption after the end of the CCAFS project. Some farmers also don't believe in each other if they can bring positive changes among themselves. Radio communication was also not a significant communication channel influencing the sustained adoption of CSA technologies in the study area (Table 4). This study corresponds with Idowu *et al.* (2020) who reported that there was no association between media including radio and sustained adoption of CSA technologies in Nigeria after the promotion of improved rice technology but contradicts Idowu *et al.* (2020) who reported a significant association between farmer-to-farmer communication and sustainable adoption of CSA technologies.

Apart from communication channels explained in this study, other empirical studies have explained factors influencing the adoption and continuous use of different types of CSA technologies from different study areas. For instance, it was found that socio-economic factors such as sex, age, education, household size, income, land size, credits and affiliation in social organizations had also a significant influence on the adoption of CSA technologies (Nyengere *et al.*, 2016; Oleded and Wakatsuki, 2011; Okonji and Owolu, 2020; Nsele *et al.*, 2022). Other empirical studies reported the influence of farmers' perceptions of climate-related factors such as increased temperature, unpredictable rainfall, droughts, floods and outbreaks of pests and diseases on adoption and continuous use of CSA technologies such as improved seeds, soil and water conservation practices and weather information services (Pilarova *et al.*, 2018; Talanow *et al.*, 2021).

4.0 Conclusions and Recommendations

The study concludes that communication channels including mobile phones, farmers' meetings, farmer-extensionist contacts, farmer-researcher contacts and demonstration farms are important predictors of farmers' sustained adoption of CSA technologies such as terraces, weather information services, improved seeds, organic fertilizers and tree planting. If effectively utilized, communication channels can influence farmers to adopt and continue using CSA technologies through appropriate information to combat land degradation and reduce the negative impact of climate change by increasing crop productivity after phasing out of the CCAFS project. This study recommends that policymakers, agricultural extension officers and project managers should integrate communication channels particularly the use of mobile phones, farmers' meetings, farmer-extensionist communication and farm demonstrations to enhance the dissemination of agricultural information and knowledge related to CSA technologies. it is also recommended that communication channels should be incorporated in designing future related projects to enhance sustainability and the positive impact of the adoption of CSA technologies. Information regarding the availability of CSA technologies and farmers' understanding of how they can use technologies and how technologies work can enhance sustainable adoption of CSA technologies and increase crop productivity regardless of further external support.

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