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ORIGINAL RESEARCH ARTICLE

Impact of Sustained Adoption of Climate-Smart Agriculture on Crop Productivity in The West Usambara Mountains, Tanzania

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ABSTRACT

Climate change in the West Usambara Mountains has added more challenges to smallholder farmers who are already negatively affected by land degradation. Sustained adoption of Climate-Smart Agriculture (CSA) can improve crop productivity by addressing challenges posed by both climate change and land degradation. From 2011 to 2019, the Climate Change Agriculture and Food Security (CCAFS) project disseminated and promoted the use of CSA technologies to improve crop productivity. Understanding the impact of CSA on crop productivity among farming households that received interventions is crucial for advising policy and improving extension services. This study assessed the impact of sustained adoption of CSA on crop productivity after phasing out the CCAFS project. Specifically, the study assessed sustained adoption of CSA technologies and evaluated the impact of CSA on crop productivity after the CCAFS project phased out. A sample of 124 households was selected by using simple random sampling from 140 farming households that received interventions. Methods of data collection were household questionnaire survey, key informant interviews and focus group discussions. Data analysis was conducted by using descriptive analysis, paired-samples t-tests and thematic analysis. Results showed that there was an improvement in sustained adoption of tree planting (from 45% to 68%), organic fertilizers (from 64% to 82%), improved seeds (42% to 85%) and weather information services (from 36% to 72%) compared to adoption at the beginning of the project while sustained adoption of terraces (26%), minimum tillage(21%) and contour ridges(19%) remained low. The t-test shows that sustained CSA had significant impact on crop productivity since it increased crop productivity for maize, Irish potatoes, beans and cabbages by 41.9%, 65.2%, 29.2% and 44.3%, respectively after implementation of the CCAFS project. The study concludes that sustained adoption of CSA increased crop productivity in the study area. This study recommends that policymakers, agricultural extension workers and researchers continue the dissemination and promotion of CSA technologies to improve crop productivity regardless of external assistance.

Keywords: sustained adoption, Climate-Smart Agriculture, technologies, climate change, crop productivity

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1.0 Introduction

Climate change is a worldwide challenge reducing agricultural productivity today, especially in developing countries dominated by smallholder farmers mostly relying on rainfall (Niang *et al.,* 2014). Recent modelling of climate change impacts on agricultural productivity revealed that Sub-Saharan Africa is highly vulnerable to the prevailing and incoming consequences of climate change (FAO *et al.*, 2020; Jägermeyr *et al*., 2021). Changes in climatic conditions such as heat and droughts, increased variability of precipitations and rising temperatures will increase the outbreaks of pests and diseases, strain water resources and reduce crop productivity in Africa, especially in dryland regions (IPCC, 2019; Bongole *et al*., 2020). It is expected that crop productivity could decrease by as much as 20% due to climate change-related challenges (Edame *et al*., 2011; Jägermeyr *et al*., 2021). Increasing climate variability exerts further pressure on the sustainability of the existing production system which has already been challenged by land degradation (Lyamchai *et al*., 2011; World Bank, 2021). Climate-Smart Agriculture (CSA) is a farming approach introduced by the United Nations Food and Agriculture Organization in 2010 (FAO, 2013). The CSA comprises three pillars; increasing agricultural productivity and income, adapting and building resilience to food systems, and reducing emissions of greenhouse gases where possible (FAO, 2013; World Bank, 2021). Technically, any agricultural practice can be considered CSA technology as long as it improves crop productivity or resource-use efficiency, reduces farmers' vulnerability to climate change, reduces emission of greenhouse gases and increases carbon sequestration (Neufeldt *et al*., 2013). Hence, CSA addresses three main components of sustainable development including economic development, social integration and environmental conservation. The use of CSA has already been acknowledged by the Government of Tanzania for addressing challenges posed by climate change and land degradation (URT, 2014; 2015).

The negative effects of climate change on agriculture in Tanzania have been documented by several empirical studies (Lyamchaiet *al*., 2011; Kaboteet *al*., 2017; Mafie, 2022) and government reports (URT, 2014; 2015). Challenges posed by climate change such as rising temperatures, unpredictable rainfalls, droughts, frequent floods and outbreaks of crop pests and diseases have also been reported to reduce crop yields in the West Usambara mountains, particularly to farms located on hills and in valley bottoms (Minderhoud, 2011; Lyamchaiet *al.,* 2011; Rukanda, 2014). In response to climate change challenges, the Climate Change Agriculture and Food Security (CCAFS) project was launched in the West Usambara Mountains in 2011 where from that time it disseminated and promoted the use of CSA technologies to smallholder farmers until it was phased out in 2019. During its period of implementation, different CSA technologies were advocated to foster adoption and continuous use among smallholder farmers. The main CSA technologies promoted include terraces, tree planting, organic fertilizers, improved seeds and weather information services. The use of CSA technologies has a multitude of advantages in addressing land degradation and climate change-related challenges. For instance, terraces and contour ridges are soil and water conservation technologies constructed across the mountain slopes to reduce soil erosion, improve soil fertility, retain soil moisture for a longer time after rain season and reduce floods (Muriuki and

Macharia, 2011; Kosmowski, 2015). Organic fertilizers including manure and compost provide important nutrients for crop production, retain soil moisture and maintain soil structure (Dhankher and Foyer, 2018). Minimum tillage and tree planting can reduce soil disturbances such as erosion, maintain soil structure and improve soil fertility (Lasco, 2011; Soka and Ritchie, 2016). Information from weather forecasting services provides predictions of weather conditions that enable farmers to become aware of the onset, termination and amount of rainfall. Additionally, understanding weather conditions can help farmers decide on the type of crops to grow, plan farm activities on time and harvest crops on time to minimize the risk of production (Muema, 2018; Elia, 2018). Sustained adoption of CSA technologies is relatively advantageous to farmers since it increases crop productivity over time.

Empirical studies conducted beyond the West Usambara Mountains have reported positive impact of sustained adoption of CSA technologies through increased crop productivity. In Punjab Province Pakistan, Sardar *et al.* (2021) reported an increase in yields by 32% to 44% for cotton, wheat and rice following the adoption of multiple CSA technologies compared to non-adopters. Sedebo *et al.* (2022) found better wheat yields due to sustained adoption of CSA technologies in Ethiopia. Another study conducted by Amadu *et al.* (2022) found an increase of 53% in maize yield after sustained adoption of CSA technologies despite having droughts in Southern Malawi in 2016. Asrat and Simane (2017) reported an increase in crop production after sustained adoption of CSA technologies in the Blue Nile Basin Ethiopia between 2015 and 2017 following the end of an agricultural project. In Uganda, Zizinga *et al*. (2022) reported that adoption of CSA technologies increased grain yield from 8% to 66%. Another study conducted in Kenya by Andati *et al.* (2023) found that sustainable adoption of multiple CSA technologies including organic manure, weather information services and soil water conservation practices such as terraces and minimum tillage increased productivity of Irish potatoes by 39% to 61% in Kenya. Hence, sustained adoption of CSA technologies especially the combination of different technologies can sustainably increase crop yields over time.

Other previous studies indicated a frequent occurrence of substantial adoption of agricultural innovations during the implementation of agricultural projects, particularly when projects are accompanied by various forms of support (Ogada *et al*., 2020; Murwanashyaka *et al*., 2021), but in some agricultural projects, adoption declines once projects have terminated implementation (Odame *et al*., 2013; McNiven *et al*., 2016). Thus, maintaining sustainable adoption of agricultural technologies remains a major challenge for improving agricultural productivity under adverse climatic conditions. Before the CCAFS project started implementation in the West Usambara Mountains, adoption of most CSA technologies was low by less than 50% and farmers were harvesting low yields especially for maize, beans, Irish potatoes and vegetables. In particular, it was reported that 22% of farmers were using terraces, 45% tree planting, 30% improved seeds and 28% weather information services before the CCAFS project (Lyamchai *et al.,* 2011). Understanding sustained adoption of CSA technologies and crop productivity after phasing out the CCAFS project is essential to decision-makers and agricultural extension workers in reviewing agricultural development plans and strategies that promote sustainable adoption (post-project adoption) of CSA technologies. Sustained adoption refers to the extent of continuous use of technology over time after the end of diffusion projects (Hulland *et al*., 2015; Wang *et al*., 2020; Oldenburg and Glanz, 2008).

Few empirical studies have already been conducted in the study area, in particular, the early and mid-project assessments of adoption of promoted CSA technologies (Nyasimi *et al*., 2017; Ogada *et al*., 2020). Although it was already known that adoption of most CSA technologies was low by less than 50% before the CCAFS project, information about sustained adoption of CSA technologies and crop productivity after phasing out the CCAFS project is scarce. Lack of such information can limit post-project evaluation of adoption and crop productivity that are essential in planning sustainable future CSA interventions. Therefore, this study assessed the impact of sustained adoption of CSA on crop productivity among farming households that received interventions during the CCAFS project. Specifically, the study determined sustained adoption of selected CSA technologies including tree planting, terraces, minimum tillage, contour ridges, improved seeds, organic fertilizers and weather information services, and evaluated the impact of sustained adoption of CSA on crop productivity especially for maize, beans, Irish potatoes and cabbages. The study findings contribute to the implementation of the Tanzania's National Agricultural Policy 2013, National Climate Change Response Strategy 2021-2026 and Tanzania's Climate-Smart Agriculture Guideline 2017. Moreover, the study is in line with Sustainable Development Goals (SDGs) especially SDG number 1 (end poverty in all forms), SDG number 2 (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture) and SDG number 13 (take action to combat climate change and its impacts).

2.0 Theoretical framework

2.1 The diffusion of innovation theory

This study adopted the Diffusion of Innovation Theory which was explained for the first time by Everett Rogers in 1962. According to this theory, the two terms; technology and innovation are synonymous (Rogers, 2003). Technology refers to a design for instrumental action that reduces the uncertainty of achieving a desired outcome (Rogers, 2003). In this study, technology refers to CSA technology promoted by the CCAFS project to farmers for addressing posed by climate change in agriculture. Rogers (2003) defined adoption as the full use of innovation as the best course of action available while rejection is defined by him as a decision not to adopt an innovation. The theory put forward five stages of innovation–decision process namely: knowledge, persuasion, decision, implementation and confirmation which follow each other over time. This theory assumes that at the confirmation stage, an individual decides to either continue or discontinue adoption after a repeated use of technology and evaluating advantages and disadvantages of using such technology. According to Rogers (2003) and Oldenburg and Glanz (2008), sustained adoption is a continuous use of innovation by an individual in a social system after phasing out of diffusion project. This theory has weaknesses since it assumes a one-way flow of information from a source (expert) to the receiver (individuals). It is also subject to pro-innovation bias by assuming that technology will be rapidly adopted by all members of a social system. Despite these weaknesses, the theory is still relevant because it assumes that for the adoption of technology to continue, there must be relative advantages to farmers. Among the relative advantage of CSA technologies include controlled soil erosion, improved soil fertility and sustainably increasing crop productivity over time. Additionally, from this theory, the study adopted definitions of terms such as adoption and sustained adoption of technology.

2.2 Utility maximization theory

The study also used the concepts and assumptions explained by the Utility Maximization Theory which was explained for the first time by utilitarian British philosophers called Jeremy Bentham and John Stuart Mill. The theory was employed to explain the rationale for farmers' adoption of a particular CSA technology. A farmer selects and adopts the CSA technologies specific to the area that maximizes profit (Terdoo and Adekola, 2014). Hence; farmers expect an increase in crop productivity from their actions of adopting CSA technologies. Usually, farmers adopt CSA technologies when there is an expectation of gaining higher utility or maximizing profit. The theory also assumes that farmers adopted one or a few CSA technologies for the first time and realize a higher pay-off would choose multiple technologies to maximize their utility (Kpadonou *et al*., 2017; Musafiri *et al*., 2022). For example, farmers will choose CSA technology A or a combination of A with other technologies provided that technology A or a combination maximizes profit. Hence, a combination of different CSA technologies on farms especially that located on mountain slopes has a multitude of advantages to farmers over time such as reducing soil erosion, increasing soil fertility, retaining soil moisture, reducing attacks of pests and diseases and increasing crop productivity under climate change. This theory assumes that individual farmers will select the more beneficial CSA technologies over others to enhance utility maximization. This study adapted the assumption of profit maximization put forward by this theory to assess the impact of sustained adoption of CSA technologies over time on crop productivity during and after phasing out the CCAFS project. The impact of sustained CSA on increasing crop productivity can motivate farmers to continue combining multiple CSA technologies for profit maximization as postulated by this theory. The strength of this theory is its ability to explain the impact of individual actions or efforts such as sustained adoption of CSA technologies on utility maximization over time. The weakness of this theory is that it assumes individuals have perfect information about their choices of actions that can enable them to maximize profit. However, in reality, individuals often operate with incomplete or imperfect information about the usefulness of technology. The Utility Maximization Theory is still relevant to this study since it provides explanations of utility maximization that enabled this study to assess crop productivity as profit gained over time from implementation of CSA technologies beyond the project period.

3.0 Research methodology

3.1 Description of the study area

The study was conducted in Lushoto District Tanga Region. The district is located in the West Usambara Mountains which form part of the Eastern Arc Mountain ranges. In the study area, the CCAFS project was implemented where the use of CSA technologies was advocated to farmers for ten years from 2011 to 2019. The district is located between latitudes $4^0$05’ and $5^0$00' and longitudes $38^0$05’ and $38^0$40’ with altitudes ranging from 600m to 2300m above mean sea level (Minderhoud, 2011). The study area comprises two agro-ecological zones including the humid warm zone characterized by an average temperature of 22^0C and the humid cold zone with an average temperature of 18^0C (Minderhoud, 2011; Lyamchai *et al*., 2011). The area was selected because farmers faced several agricultural challenges posed by land degradation and climate change before the project which reduced crop productivity. The implementation of the CCAFS project was the reason for this assessment of the impact of sustained adoption of CSA on crop productivity. The study informs farmers, policymakers, extension workers and other stakeholders. During implementation, the CCAFS project disseminated and promoted the use of CSA technologies in seven Climate-Smart Villages namely; Yamba, Gare, Milungui, Boheloi, Kwang'wenda, Mbuzii and Masange. The main crops grown in the study area include maize, beans, Irish potatoes, cabbages and other varieties of vegetables. Maize and beans are mostly used as food crops while Irish potatoes, cabbages and other varieties of vegetables are used as food and cash crops. These crops grow in lowlands, valley bottoms and on mountain slopes.

3.2 Study design and sample determination

The study adopted a cross-sectional research design which enabled the collection of data at a single point in time, whereby both qualitative and quantitative approaches employed. The sample size was determined by using a hypergeometric formula which provides a statistically realistic sample size from a small population (Busbee, 2017). The hypergeometric formula and calculations are shown below:

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

Where, n = a 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 that specifies the level of confidence at 95% which is set at 1.96, and e sets the accuracy of sample proportions of plus or minus 3% (or 0.03). Thus;

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

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Therefore, the sample size estimated was 124 farming households which is equivalent to 88.6% of the survey population. The study sample was selected from 140 farming households that received interventions from the CCAFS project. In this study, farming households were represented by heads of households.

3.3 Methods of data collection

The study used three methods of data collection including household questionnaire survey, focus group discussions (FGDs) and key informant interviews to collect primary data. During the household survey, a semi-structured questionnaire was used to collect quantitative data from the respondents. Qualitative data were gathered from key informant interviews which involved three participants including the District Agriculture, Irrigation and Cooperative Officer (DAICO) and two Agriculture Extension Officers. The key informants were chosen because they might have sufficient information because they participated in the CCAFS project. Seven FGDs comprised of seven farmers who participated in the project (one session of FGDs for each project village) were conducted to get in-depth information which complemented quantitative data. The FGDs involved farmers including males and females who participated in the CCAFS project. To make sure that males and females effectively participate in discussions, before starting discussions, the researcher clearly explained the aim of the study and asked for full participation during the discussions. Secondary data regarding the early adoption of CSA technologies, end-of-project adoption and crop productivity during the CCAFS project were collected from the CCAFS project records and progress reports. The use of mixed methods of data collection helps to overcome fundamental biases in social science research and simplifies the validation of data (Noble and Heale, 2019).

3.4 Data analysis

Qualitative data as well as quantitative data analysis was done to generate findings. Through STATA version 17, descriptive and inferential statistical analyses were conducted. Descriptive analysis generated descriptive statistics including frequencies and percentages. A paired-samples t-test used to examine differences in crop productivity during in-the-project adoption and post-project adoption (sustained adoption) periods whereby the Cohen value estimated the effect size of CSA intervention. For qualitative data, thematic analysis was used to obtain in-depth information which added more explanations to the quantitative results.

3.4.1 Paired-samples t-test

Paired-samples t-rest assumes that the distribution of the paired difference is approximately normal and the subsets are independent. Thus,

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_d^2}{N}}}$$

Where; t =t-statistic, $\bar{x}_1 - \bar{x}_2$ are difference in two means of crop productivity at different adoption periods, N is the number of items/cases and standard deviation squared(S_d^2). The t-statistic follows a t-distribution with N-1 degree of freedom. The null hypothesis of the t-test assumes that the means difference is equal to zero ($\mu_1 - \mu_2 = 0$) while the alternative hypothesis assumes the means difference is not equal to zero ($\mu_1 - \mu_2 \neq 0$). The alternative hypothesis of this study states that;

H1: Crop productivity is higher after phasing out the CCAFS project than at the beginning.

3.4.2The effect size

Suppose we assume that $\mu_1 - \mu_2$ represents the difference between paired means of crop productivity and σ represents the standard deviation of the paired differences, the effect size of due to implementation of CSA interventions is represented by *d,* where;

$$d = \frac{\mu_1 - \mu_2}{\sigma}$$

According to Cohen (**2002**), a *d* less or equal to 0.2 is a small effect, *d* near 0.5 is a medium effect and *d* greater or equal to 0.8 is a large effect whereby these values of the effect size of intervention are popular in social science research.

4.0 Results and discussion

4.1 Demographic characteristics of the respondents

Demographic characteristics of farmers who participated in household survey included sex, age, education, income and household size. Both males (64.5%) and females (35.5%) participated but there was no association between them on the level of sustained adoption of multiple CSA technologies on their farms (χ^2=1.666, p=0.435). Most farmers (78.3%) who participated in the study were adults above 40 years while a few comprised young people (21.7%). There was a significant association (χ^2=31.185, p=0.001) between the age of the household head and sustained adoption of CSA technologies since most farming households headed by older farmers sustained adoption of multiple CSA technologies compared to younger farmers. Among the respondents, the majority (86.2%) had formal education since they attended primary school education and few had secondary school education. Education of the household head had significant association with the level of adoption of multiple sustained CSA technologies (χ^2=6.229, p=0.044) which justified that most farmers who attended formal education continued adoption of multiple CSA technologies than illiterate farmers since they have more understanding regarding the usefulness of mixed CSA technologies. Moreover, household income (r=0.343, p=0.001) and household size(r=0.208, p=0.020) had a significant relationship with multiple sustained adoption of CSA technologies. Hence, income can be a source of capital for farm investment in CSA technologies. Large household size suffices labour especially when there are adequate members who can work on CSA technologies such as construction of terraces, contour ridges and tree planting.

4.2 Adoption of CSA technologies during and after phasing out the CCAFS project

4.2.1 Adoption of a choice of CSA technology

Farmers managed to choose the type of CSA technology which they preferred as being appropriate for climate change adaptation. This study found that adoption of organic fertilizers was 64% in the earlier implementation. Initially, adoption of other CSA technologies was low whereby less than 50%of farmers were using other technologies apart from organic fertilizers (Table 1). Key informant interviews revealed some reasons that contributed to the low adoption of terraces, minimum tillage, contour ridges, improved seeds and tree planting during the earlier period of the project. When the project started, most farmers had low awareness of CSA technologies, lack of access to agro-inputs such as improved seeds and tree seedlings, inadequate technical skills and insufficient labour. One of the key informants said that;

"When the CCAFS project started implementation in targeted villages, majority of farmers were not aware of CSA technologies and technology usefulness in addressing challenges posed by climate change. Some farming households had poor access to capital to buy improved seeds and a shortage of labour for construction of terraces and establishing tree nurseries. Others were reluctant to be the first to adopt promoted CSA technologies until they saw the outcomes of implementation from their fellows." (Key informant, Lushoto District, June 2022).

At the end of the project, the percentage of farmers who adopted tree planting, improved seeds, organic fertilizers and weather information services increased to above 50% except for terraces, minimum tillage and contour ridges (Table 1). The FGDs confirmed that adoption of CSA technologies increased over time during the CCAFS project due to improved extension services particularly the provision of technical skills and access to advice from agriculture extension officers. Agriculture extension officers also have been linking farmers with seed suppliers, markets and agricultural credit through Savings and Credit Cooperative Societies (SACCOS) which motivated continuous adoption. High adoption of CSA technologies at the end of the project was maintained even after phasing out of the project except for terraces, minimum tillage and contour ridges which remained with low adoption by far less than 50% (Table 1). Results revealed by key informant interviews identified some reasons which have contributed to the low adoption of terraces and contour ridges such as inadequate technical skills and lack of farm equipment such as shovels, picks, measuring tape, rods and poles that are used for construction and levelling across the gentle and steep slopes to control soil erosion, reduce water runoffs, improve water infiltration and maintain soil moisture. Additionally, for instance, one of the key informants expressed that;

“Inadequate labour, technical skills demanded and higher investment costs of construction were among the main reasons limiting adoption of terraces and contour ridges to most farmers.” (Key informant, Lushoto District, June 2022).

Table 1: Percentage of farming households that adopted different types of CSA technologies in different project periods (n=124)

Type of CSA technology	Percentage of adopters at the beginning of the project (2013)	Percentage of adopters at the end of the project (2019)	Percentage of adopters after phasing out the project (2022)
Terraces	23	24	26
Tree planting	45	65	68
Organic fertilizers	64	78	82
Improved seeds	42	86	85
Weather information	36	68	72
Minimum tillage	18	22	21
Contour ridges	20	23	19

Findings revealed by FGDs also confirmed that most farmers find it difficult to adopt terraces and contour ridges due to lack of technical skills, inadequate labour and lack of equipment such as shovels and picks. Most farmers also believed that minimum tillage does not provide crops with favourable conditions such as adequate soil water circulation and sufficient uptake of soil nutrients to crops. Most members of the FGDs expressed that minimum tillage by digging shallow seed holes contributes to poor rooting, poor seed germination and more weeds which eventually reduce crop productivity, especially on farms found in gentle and steep slopes. One member of the FGDs was quoted as;

"Most farmers do not afford the construction of terraces and contour ridges due to lack of technical skills, insufficient labour and poor access to capital for purchasing construction equipment." (FGDs, Yamba Village, June 2022).

Additionally, another farmer was also quoted during FGDs saying that;

“We are instructed by agricultural experts not to dig the soil deep when preparing our farms. But we don’t get enough yields from putting seeds in shallow holes and hard soil especially on sloping farms since it often results in poor seed germination and favours more weeds.”(FGDs, Milungui Village, June 2022).

Therefore, negative perceptions of minimum tillage make most farmers not adopt this practice. However, contrary to the findings regarding perceptions towards the use of minimum tillage revealed during FGDs in the study area, scientific studies reported that minimum tillage provides more relative advantages in crop production since it maintains soil structure, retains soil water and reduces the loss of soil fertility by controlling soil erosion compared to conventional tillage which accelerates soil degradation especially on steep slopes (Shukla *et al*., 2023; Bekele, 2020).

Based on the distribution of farmers based on adoption of CSA technologies across the CCAFS project villages, there was an overall high rate of sustained adoption of CSA technologies in each village except for soil management technologies such as terraces where sustained adoption was low. Only Gare village maintained a higher sustained adoption of terraces (64.7%) after phasing out of the CCAFS project (Table 2). For the adoption of tree planting, Yamba villages had the lowest rate of sustained adoption (47.1%) after phasing out of the project compared to other villages. The FGDs expressed the reasons for the low adoption of tree planting on cropping land that often there has been poor farmers' access to tree seedlings in Yamba village since they are not often available nearby farmers due to the absence of community or group-based tree nurseries within their villages. More results express that many farmers have sustained adoption of organic fertilizers, improved seeds and weather information services. The findings justified that most farmers have understood and appreciated the usefulness of these technologies in increasing crop productivity by combating land degradation and addressing adverse climatic conditions such as drought and unpredictable rainfall.

Sustained adoption of CSA technologies was compared with distribution of farmers based on their village location. Famers' responses were distributed according to their choices of CSA technologies across CCAFS project villages (Table 2).

Table 2: Distribution of farmers based on sustained adoption of choices of CSA technologies across the CCAFS project villages (n=124)

Village	Terraces (%)		Tree planting (%)		Organic fertilizers (%)		Improved seeds (%)		Weather services (%)	
	Continue adoption	Not adopt	Continue adoption	Not adopt	Continue adoption	Not adopt	Continue adoption	Not adopt	Continue adoption	Not adopt
Gare	64.7	35.3	70.6	29.4	70.6	29.4	76.5	23.5	76.6	23.5
Yamba	35.3	64.7	47.1	52.9	76.5	23.5	82.4	17.6	64.7	35.3
Bohelo	17.6	82.4	76.5	23.5	88.2	11.8	70.6	29.4	76.5	23.5
Masange	0	100	70.6	29.4	82.4	17.6	94.1	5.9	52.9	47.1
Milungui	35.3	64.7	58.8	41.2	88.2	11.8	100	0	88.2	11.8
Mbuzii	23.5	76.5	58.8	41.2	76.5	23.5	82.4	17.6	76.5	23.5
Kwang’wenda	13.6	86.4	86.4	13.6	81.8	18.2	81.8	18.2	68.2	31.8
Association	$\chi^2 = 22.787$*** p=0.001		$\chi^2 = 8.775$ p=0.187		$\chi^2 = 2.787$ p=0.835		$\chi^2 = 7.621$ p=0.267		$\chi^2 = 6.365$ p=0.384	

***Significant at $p \leq 0.001$

Based on the relationship between percentages of farmers who sustained adoption of CSA technologies across the CCAFS project villages after phasing out of the CCAFS project, the study revealed that there was no significant association between sustained adoption of four technologies including tree planting (χ^2= 8.775, p=0.187), organic fertilizers (χ^2= 2.787, p=0.835), improved seeds (χ^2= 7.621, p=0.267) and weather information (χ^2= 6.365, p=0.384) and project village where farming household practice agricultural activities. There was a strong association between sustained adoption of terraces and project villages where the farming household conducts farming activities (χ^2= 22.787, p=0.001) as shown in Table 2. Hence, throughout the villages, there was a higher rate of adoption of terraces than non-adoption.

4.2.2 Adoption of multiple CSA technologies

The study found that every farmer who participated as a respondent adopted at least one type of CSA technology in the study area. However, most farmers adopted more CSA technologies particularly at the end of the CCAFS project and after the project was phased out compared to the beginning of the project (Table 3).

Table 3: Multiple adoption of CSA technologies among farming households (n=124)

Number of adopted CSA technologies	At the beginning of the project (2013)	At the end of the project (2019)	After phasing out the project (2022)
1-3	81%	56.5%	39.7%
4-5	19%	31.1%	46.0%
6-7	0	12.4%	14.3%

The findings implied that most farmers understand the usefulness of CSA technologies and the relative advantage gained. Moreover, most farmers understand the relative advantage of combining different CSA technologies on their farms to reduce the risks posed by adverse climatic conditions and land degradation. Adoption of multiple CSA technologies such as terraces, minimum tillage, contour ridges, tree planting, organic fertilizers and improved seeds concurrently provides a multitude of advantages on farms such as improving soil fertility, reducing soil erosion, improving water infiltration, retaining soil moisture after the rainy season and increasing crop productivity despite the climate change.

Similar findings were revealed by key informant interviews who expressed that nowadays most farmers combine different CSA technologies because they better function complementary. Adoption of one type of CSA technology brings a need for adoption of another to enable farmers to address concurrently different agricultural challenges posed by climate change and land degradation. One of the key informants was specifically clarified that;

“These days, farmers are using a combination of CSA technologies such as integration of improved maize seeds, tree planting and application of organic fertilizers on a farm levelled by bench terraces helps to control soil erosion, maintain soil moisture and improve soil fertility. Thus, a combination of CSA technologies increases crop productivity for farmers.” (Key informant, Lushoto District Council, June 2022).

The FGDs confirmed that most farmers have realized the advantages of using multiple CSA technologies for increasing crop productivity under climate change. They invest in CSA to address adversities posed by climate change and land degradation. One of the participants who attended the FGDs expressed that;

"Farmers who adopted one or few CSA technologies harvest little maize yields. Crop productivity is higher among farmers who have invested in multiple CSA technologies since different technologies address different challenges posed by climate change and land degradation."(FGDs, Gare Village, June 2022).

The findings revealed by this study are contrary to Odame *et al.* (2013) who reported low adoption of most CSA technologies including improved varieties of beans, maize and cassava, and land management practices such as the use of terraces and tree planting by less than 50% after two years since the project supported by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) between 1997 and 2011 in the Democratic Republic of Congo, Ethiopia, Kenya, Sudan and Uganda was phased out. The reasons for the low adoption of CSA technologies after phasing out of the ASARECA project included high cost of technologies (high price of improved seeds, fertilizers and equipment); inadequate and untimely supply of technologies such as improved seeds, fertilizers and equipment; fake seeds supplied by some of the distributors; lack of information; poor access to credit and perceived poor food taste of some crop varieties disseminated. The study findings are also not corresponding with Sterve (2010) who reported low adoption of most CSA technologies including improved seeds, soil and water conservation practices and organic fertilizers after phasing out the agricultural project in the Potshin Community of South Africa due to poor participation of farmers in the project, low profit gain, high purchasing price for technologies (such as improved seeds, organic fertilizers and equipment), inadequate knowledge and high labour demand.

4.3 The impact of sustained adoption of CSA on crop productivity in the West Usambara Mountains

4.3.1 Comparison in crop productivity during implementation and after phasing out the CCAFS project

Table 4: Paired-samples t-test showing comparison in crop productivity during implementation and after phasing out the CCAFS project

Type of crops grown	Adoption phase of CSA technologies	Crop productivity in different project periods	Mean (kg/ha)	SD	% increase	t-value	Effect size (Cohen's *d*)
Maize (n=124)	Sustained adoption	Maize productivity (2022)	1,687.8	382.40	41.9	21.80***	1.46
	Early adoption	Maize productivity (2013)	1,189.4	24.87			
	Sustained phase	Maize productivity (2022)	1,687.8	382.40	0.2	0.860	0.01
	End-of-the project	Maize productivity (2019)	1,684.8	379.02			
Beans (n=124)	Sustained adoption	Beans productivity (2022)	394.3	95.81	29.2	8.007***	0.91
	Early adoption	Beans productivity (2013)	305.1	99.65			
	Sustained adoption	Beans productivity (2022)	394.3	95.81	5.5	8.190***	0.21
	End-of-the project	Beans productivity (2019)	373.5	100.84			
Irish potatoes (n=111)	Sustained adoption	Potato productivity (2022)	5,087.9	1.870.12	65.2	15.090***	1.33
	Early adoption	Potato productivity (2013)	3,080.6	996.63			
	Sustained adoption	Potato productivity (2022)	5,087.9	1,870.12	2.4	3.734***	0.06
	End-of-the project	Potato productivity (2019)	4,970.2	1,890.20			
Cabbage (n=91)	Sustained adoption	Cabbage productivity (2022)	5221	1,389.76	44.3	12.722***	1.4
	Early adoption	Cabbage productivity (2013)	3618	724.28			
	Sustained adoption	Cabbage productivity (2022)	5,221	1,389.77	-0.41	1.181	-0.02
	End-of-the project	Cabbage productivity (2019)	5,243	1,414.3			

***Significant at p≤0.001; *d*≤0.2=small effect, *d* near 0.5=medium effect, *d*≥0.8=large effect

The study compared the productivity of maize, beans, Irish potatoes and cabbages after phasing out the CCAFS project with productivity during implementation among the households that received CSA interventions. These are among the major crops grown by farmers in the study area and were promoted by the CCAFS project. The assessment of crop productivity was based on different phases of adoption particularly at early project adoption, end-of-the project adoption and post-project adoption (sustained adoption). The findings in Table 4 show an increase in crop productivity of maize, beans, Irish potatoes and cabbages at the end of the CCAFS project and after phasing out.

Maize crop productivity was significantly higher after phasing out the CCAFS project than at the beginning of the project (t=21.80, p=0.001) (Table 4). The productivity of maize crops increased by

41.9% from 1,189.4kg/ha at the beginning of the project to 1,687.8kg/ha after phasing out of the project. Cohen's test confirms a strong effect of sustained adoption of CSA on maize productivity from the beginning to the phasing out of the CCAFS project (*d*=1.50) (Table 4). Results revealed by FGDs confirmed that crop productivity continuously increased over time since most farmers' sustained adoption of CSA technologies in maize production during and after the project was phased out. One among the participants of the FGDs said that;

"In the beginning, I started using improved maize seeds that are tolerant to drought and early maturing but I ended harvesting little yields because I didn't combine with other CSA technologies. But when combined with other technologies such as manure, compost and constructing terraces, crop productivity has increased extensively." (FGDs, Kwang'wenda Village, June 2022).

Hence, the use of multiple technologies such as terraces, improved seeds, organic fertilizers and weather information in maize farming has an impact on increased crop productivity. The combination of different CSA technologies has a multitude of advantages including controlling soil erosion on hills, retaining soil moisture after the rainy season and reducing the risks of weather conditions. Related findings were reported by Amadu *et al.* (2022) that continuous adoption of CSA technologies had significant impact on increased maize productivity by 53% in Southern Malawi.

Other results show that there were no significant differences in maize crop productivity at the end of the CCAFS project and after the project was ended (t=0.864, p=0.389) (Table 4). Cohen's test revealed a small effect of sustained CSA on the increase in maize productivity from the end of the CCAFS project to the three years after phasing out (*d*=0.01) (Table 4). Thus, there was consistency in maize crop productivity from the end of the CCAFS project in 2019 to when this study was conducted in 2022. The findings justified that most farmers have maintained high maize crop productivity from the end of the project to 2022 when this study was conducted since they have sustained adoption of CSA technologies.

Based on bean crop productivity in the study area, results showed higher productivity after phasing out of the CCAFS project than in the beginning (t=8.007, p=0.001). Bean crop productivity increased by 29.2% from 305.1kg/ha at the beginning of the project in 2019 to 394.3kg/ha in 2022 three years since the CCAFS project was ended (Table 4). Sustained adoption of CSA had a strong effect on increasing crop productivity for beans from the early adoption phase to three years after the CCAFS project was ended (*d*=0.91) (Table 4). The productivity of beans also significantly increased by 5.5% from 373.5kg/ha in 2019 at the end of the CCAFS project to 394.3kg/ha in 2022 after three years since the project was phased out (t=8.190, p=0.001) (Table 4). Despite a significant increase in productivity from the end of the project to three years after phasing, Cohen's test (*d*=0.21) revealed a small effect size of CSA on farm productivity for beans. The findings demonstrate that continuous adoption of CSA technologies such as improved seeds, organic fertilizers, weather information, terraces and integration of trees with crops had an overall impact on the improvement of productivity of beans in the study area during implementation and maintained the same after phasing out the project. The findings revealed by FGDs confirmed that dissemination and promotion of improved varieties of beans such as Soya and Rose coco (*Lyamungo-90*) combined with other CSA technologies such as organic manure and compost have increased productivity in the study area than before the project since most farmers became motivated to use improved seeds after increasing access to information and the profit gained. One of the FGD participants appreciated the relative advantage of using multiple CSA technologies as he was quoted saying;

"Since we started using improved seeds of beans such as Soya and Lyamungo-90 together with other agricultural technologies such as weather information and soil and water conservation practices some years ago, yields per hectare have been highly increased." (FGDs, Mbuzii Village, June 2022).

Results revealed by this study agree with Zizinga *et al.* (2022) who found that continued adoption of CSA increased grain yield such as beans by 8% to 66% in Uganda.

For potato crop productivity, the study found that Irish potato productivity significantly increased by 62.5% after implementation of the CCAFS project from 3080.6kg/ha in 2013 during early implementation to 5087.9kg/ha in 2022 three years after phasing out of the CCAFS project (t=15.09, p=0.001) as shown in Table 6.4. Cohen's test confirmed a strong effect size of sustained adoption of CSA interventions on crop productivity after phasing out of the CCAFS project (*d*=1.33). Farm productivity for Irish potatoes also significantly increased by 2.4% from 4,970.2kg/ha to 5,087.9kg/ha after phasing out of the project in 2022 (t=3.734, p=0.001) although the effect size revealed by Cohen's test was small (*d*=0.06) (Table 4). The findings demonstrate that sustained adoption of CSA increased the productivity of Irish potatoes in the study area. The FGDs revealed that the advantages of adoption of CSA have increased farm productivity of Irish potatoes. Group members expressed that the use of technologies such as improved potato seeds combined with organic manure on conserved agricultural land reduces the negative effects posed by climate change and land degradation on crop productivity. During FGDs, one participant expressed said that;

"Before I decided to use improved varieties of Irish potatoes, I was harvesting little yields. However, since I started growing improved Irish potatoes and combining a crop with other CSA technologies such as organic manure on bench terraces, crop productivity increased." (FGDs, Yamba Village, June 2022).

The study findings concur with Andati *et al.* (2023) who reported that the adoption of CSA technologies in complementary such as organic manure, weather information and soil water conservation practices such as terraces and minimum tillage had an impact on Irish potato

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productivity in Kenya since it increased productivity by 39% to 61% after implementation of CSA interventions. Mireri *et al.* (2024) and Mensah *et al.* (2024) also agree with the study findings that adoption of improved seeds in Nakuru and organic fertilizer in Karinyaga and Kiambu Counties in Kenya increased yields. Furthermore, this study found that adoption of CSA technologies has significantly increased crop productivity of vegetables particularly cabbages in the study area. From 2013 when the CCAFS project was at the early implementation stage to 2022 which was three years since the project was phased out, productivity of cabbages significantly increased by 44.3% (Table 4). Farm productivity of cabbage crop significantly increased, from 3,618kg/ha in 2013 when promotion of adoption of CSA technologies was started to 5,221kg/ha after three years since the CCAFS project was phased out (t=12.722, p=0.001) (Table 4). Based on Cohen's test of effect size, there was a strong effect of CSA interventions from the early adoption phase in 2013 to three years after phasing out the CCAFS project in 2022 (d=1.4) as shown in Table 4. Hence, the findings demonstrated that sustainable adoption of CSA technologies significantly increased cabbage crop productivity in the study area. Results from FGDs confirmed that compared to the period before the CCAFS project, nowadays farmers have access to improved seeds of cabbage crop from nearby seed suppliers. Most farmers purchase seeds of improved varieties of cabbages from agro-dealers which produce more yields and are resistant to attacks from pests and diseases.

The findings revealed by the questionnaire survey also concur with key informant interviews which expressed that through training provided, access to improved seeds and evidence-based performance motivated many farmers to adopt and continue using CSA technologies to reduce climate risks posed by droughts, floods and unpredictable rainfall and reduce the rate of soil erosion. Other results didn't show significant difference in cabbage crop productivity from the end of the CCAFS project to the period after phasing out (t=1.181, p=0.241) (Table 4). Cohen's test approved a small effect of CSA on increasing Irish potato productivity from the end of the CCAFS project to three years after phasing out (d= -0.02) as shown in Table 4. Therefore, high crop productivity for cabbages remained consistent from the end of the project to three years after the project was phased out due to the continuous adoption of CSA technologies. Key informant interviews revealed that high productivity of cabbage crops beyond the project period was contributed by awareness created, regular training, and farm demonstrations that enabled farmers to continue using improved seeds on farms combined with different CSA technologies such as organic fertilizers, weather information services and terraces.

Moreover, this study failed to reject the alternative hypothesis which stated that crop productivity is higher after phasing out the CCAFS project than at the beginning. The hypothesis was rejected because crop productivity was higher after then CCAFS project was phased out than at the early implementation of CSA intervention. Hence, the study confirmed the impact of CSA on increased crop productivity due to ten years of implementation of the CCAFS project in the West Usambara Mountains.

5.0 Conclusions and recommendations

Sustained adoption of Climate-Smart Agricultural technologies particularly improved seeds, organic fertilizers, tree planting and weather information services disseminated and promoted by the CCAFS project in the West Usambara Mountains from 2011 to 2019 had an impact on increased crop productivity among the farming households that received CSA interventions. The use of CSA technologies has improved farm productivity, particularly for maize, beans, Irish potatoes and cabbage after at the end of the project and beyond the project period. A combination of CSA technologies helped farmers to address multiple climate change-related challenges including droughts, unpredictable rainfall, floods and outbreaks of pests and diseases. Additionally, sustained adoption of CSA reduced soil erosion and loss of soil fertility which ultimately increased crop productivity of beneficiaries. Both the Diffusion of Innovation Theory and the Utility Maximization Theory have adequately explained this study based on the use of concepts of relative advantage and utility maximization, respectively. Through these theories, the study confirmed the overall impact of sustained adoption of CSA technologies on increased crop productivity after implementing the CCAFS project. This study recommends to policymakers, researchers and agriculture extension officers that they should continue the dissemination and promotion of CSA technologies appropriate to the area to enhance sustainable adoption and improve crop productivity. Additionally, agricultural extension officers should continue providing agricultural education and conducting regular farm visits to enhance farmers' understanding of the application and advantages of sustained adoption of CSA technologies in increasing crop productivity. In particular, agricultural extension officers and researchers should apply an evidence-based performance approach to increase adoption of terraces, contour ridges and minimum tillage because these technologies are still used by few farmers in the West Usambara Mountains despite the promotion done by the CCAFS project.

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6.2 Conflict of interest

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7.0 References

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