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# Climate-smart agriculture adoption and technical efficiency of smallholder farms in Northern Togo

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## Abstract

Climate-smart agriculture is heralded for enhancing productivity and combating climate change. It has been purported that the adoption of climate-smart agricultural practices and technologies (CSAPT) remains limited, with various reasons. A key challenge in the existing literature is conflating traditional CSAPT, such as intercropping, with innovative CSAPT, like improved seeds, obscuring critical distinctions. Recognizing that CSAPT adoption is highly context-specific, especially in regions like Northern Togo with unique agro-ecological and socio-economic challenges, this study analyzed farm production efficiency under traditional and innovative CSAPT. Using data from over 500 households in Togo's Kozah prefecture, farmers were categorized into those who adopted only traditional CSAPT and those combining traditional and innovative CSAPT. A binary probit model identified adoption determinants, while stochastic frontier analysis evaluated farmers' technical efficiency. The findings indicate that most farmers continue to rely only on traditional CSAPT. Probit analysis indicates that factors like gender, land tenure, farm size, organization membership, and dry spell exposure influence the likelihood of adopting traditional and innovative CSAPT. Farmers combining traditional and innovative CSAPT had higher efficiency than those using only traditional methods. These findings have important policy implications. They emphasize the need for agricultural policies that reduce barriers to adopting innovative CSAPT. Policies should ensure land access for women, empower farmer organizations to spread technology, and develop localized climate-resilience strategies. These initiatives can increase the adoption of efficiency practices, boosting agricultural productivity and food security amid climate change.

**Keywords** Climate-smart agricultural practices and technologies (CSAPT) · Traditional CSAPT · Innovative CSAPT · Farm productivity · Adoption determinants · Northern togo

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Extended author information available on the last page of the article

## 1 Introduction

Agriculture is crucial for rural livelihoods in sub-Saharan Africa, as it ensures food security, promotes economic growth, and creates jobs (Modi 2019; Jayne et al. 2017). However, the region faces persistent low agricultural productivity (File and Nhamo 2023) and significant challenges from climate change, to which the sector contributes up to 14% of global greenhouse gas emissions (IPCC 2022). Addressing these issues through enhanced productivity is vital for poverty alleviation and fostering economic growth (Adom and Adam, 2020).

To this end, climate-smart agriculture (CSA) has emerged as an approach to enhancing farm systems' resilience to climate change's effects, defined by three principal objectives of sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions, where possible (FAO 2013). CSA integrates practices tailored to specific contexts and has been adopted in various African countries as a key approach for agricultural transformation and poverty reduction (Ali and Awume 2025; Ali 2021; Lipper and Zilberman 2018; Richards et al., 2016). Ali and Awume (2025) emphasize that credit rationing, an external constraint disproportionately affecting smallholder farmers, remains a significant barrier to CSAPT adoption, questioning the scalability of certain technologies beyond very small-scale operations (Asfaw and Lipper, 2016).

Although Ali and Awume (2025) provide valuable insights into the determinants of CSAPT adoption, their analysis overlooks an important distinction between traditional and innovative CSAPT. This differentiation is significant in the context of climate change adaptation, as the risk perception, costs, and technical demands of traditional practices such as mulching and composting often differ considerably from those of newer, more capital-intensive technologies like irrigation and weather-smart ICT tools. Previous research suggests that the adoption of innovative CSAPT tends to be lower due to greater financial, technical, and knowledge barriers (Ali and Awume 2025; Andersson and D'Souza 2014; Arslan et al. 2015). Consequently, developing effective policy interventions requires understanding not only credit constraints but also how adoption patterns differ between traditional and innovative CSAPT. Overlooking these differences could lead to misallocation of resources and undermine the effectiveness of climate resilience efforts in agriculture.

Farmers in sub-Saharan Africa have long-standing practices that stem from traditional knowledge, such as using animal dung as fertilizer, intercropping, employing neem for pest control, and creating stone bunds (effective for runoff control), Zai pits (crucial for moisture and nutrient concentration), and crop diversification during droughts, as well as pits for soil and water conservation (Bekuma et al. 2023; Zougmore et al. 2014). This traditional knowledge, or local knowledge essential for climate change adaptation (IPCC 2022; Taylor et al. 2023) constitutes traditional CSAPT. They refer to the skills and understanding that communities develop based on their environments (IPCC 2019) and are passed down orally from one generation to the next. Despite the importance of traditional CSAPT, the increasing risks of climate change are affecting farmers' livelihoods (Spear et al. 2019). This vulnerability, often caused by a lack of effective mitigation and limited uptake of essential innovative technologies (Ocelli et al. 2021), drives a growing demand for smallholder farmers to adopt innovative CSAPT. Innovative CSAPT are typically science-based and externally introduced, including improved seeds, scientific weather forecasting, and improved irriga-

tion techniques aimed at increasing productivity and bolstering resilience to climate shocks (Adeola et al. 2023; Patel et al. 2020).

In Togo, smallholder farmers mostly engage in low-input, subsistence agriculture, relying on traditional knowledge (Novotny et al. 2024; World Bank, 2022; Pilo et al. 2021). To improve food production and security, the Togolese National Program of Investment for Food Security Project (PNIASA) has promoted the adoption of CSAPT, including livestock vaccinations, weather education, improved seeds, and organic fertilizer. International and local NGOs have also promoted CSAPT through farmer field schools to enhance food security further (Board 2013; World Bank 2010). Despite efforts to improve food production and security through CSAPT adoption in Togo (Board 2013; World Bank 2010), concerns persist about farmers' efficiency, echoing the long-standing 'poor-but-efficient hypothesis' introduced by Schultz (1964). Evaluating farm performance goes beyond just measuring yield; it involves assessing allocative efficiency, which measures the optimal use of inputs based on prices, and technical efficiency, which compares actual output to potential output to identify performance gaps and compare outputs to those of other farms or benchmarks (Coelli et al. 2005). Improving technical efficiency is crucial for fostering productivity growth in climate-smart agriculture by optimizing resource use, reducing costs, and maximizing outputs (Carrer et al. 2022; Nin-Pratt 2016).

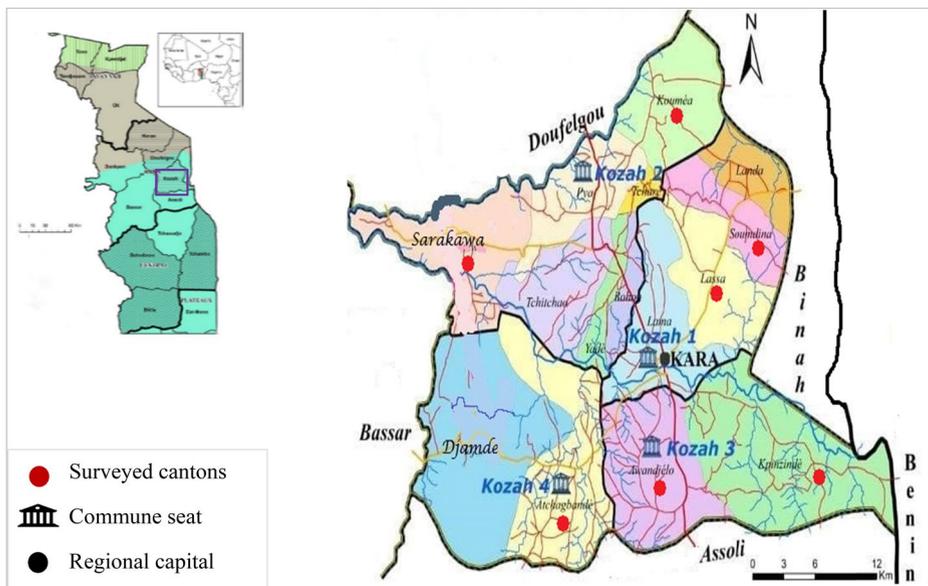
However, a significant gap remains in understanding the detailed adoption patterns of both traditional and innovative CSAPT by smallholder farmers and how these patterns vary in their effects on farm efficiency. Specifically, there is a lack of comparative analysis of their respective contributions to farm technical efficiency, especially across different local contexts. In this regard, this study directly addresses these gaps by examining the drivers behind farmers' adoption of a mix of traditional and innovative CSAPT and comparing the impacts of using both versus only traditional CSAPT on smallholder farmers' technical efficiency in Northern Togo's food production, utilizing econometric methods such as binary probit and stochastic frontier analysis on farm household survey data.

This study makes two key contributions to the existing literature. First, it identifies the factors influencing smallholder farmers' preference for a combination of traditional and innovative CSAPT. It offers valuable insights for developing effective, context-specific, climate-resilient policies that improve productivity and food security. Second, performing a comparative analysis of the production efficiency between traditional and innovative CSAPT is essential, as it empirically demonstrates the unique contribution of traditional knowledge and practices alongside innovative CSAPT in addressing climate change. This provides policymakers with concrete evidence to appraise current programs and make strategic decisions about promoting innovative CSAPT or enhancing the efficiency of existing traditional CSAPT. We find that most farmers adopt solely traditional CSAPT, which is less efficient than those who adopt both traditional and innovative CSAPT.

## 2 Materials and methods

### 2.1 Study area and data collection

This study focuses on the Kozah prefecture in northern Togo's Kara region (Fig. 1), which has a poverty rate of 56% (World Bank, 2022). The region known for its agricultural poten-



**Fig. 1** Map of the study area. Source: Map of Togo- Ali (2019); Map of Kozah (Kozah 4 city council)

tial has benefited from multiple food security intervention projects (ADB, 2016; MaEDR, 2010). Kozah spans 1,086 km<sup>2</sup> and includes 15 cantons across four communes, between 9.5876° N and 1.1737° E. It has a tropical Sudanian climate with temperatures ranging from 20 °C to 39 °C and receives 1,000 to 1,700 mm of rainfall from April to October (Ali 2019). With over 283,000 residents, the economy primarily relies on trade and agriculture, especially smallholder farming of maize, sorghum, and rice (Ali 2018).

We collected data through a survey from a representative sample of farmers to enhance our statistical power and validate our models. We randomly selected farmers from the population of smallholder farmers across all four communes in the Kozah prefecture. We employed a multistage random sampling technique. In the first stage, we randomly selected seven out of fifteen cantons in Kozah by ballot. Next, we randomly selected four villages within each canton, also by ballot. Lastly, we randomly selected 20 households from each village, depending on the farmers' willingness to participate in the survey, resulting in a total of 560 households surveyed. After reviewing the data for completeness, 26 incomplete questionnaires were excluded, leaving a final sample of 534 farm households. The use of 534 observations in regression models such as Probit and Stochastic Frontier Analysis offers adequate statistical power for robust analysis. After receiving intensive training on survey protocols, ethical conduct, and accurate data recording, enumerators familiar with local farming contexts administered questionnaires in the Kabyè language directly to farmers in their homes. It included information on household demographics, farm holdings, farming systems used, crop production inputs and outputs for the 2022–2023 farming season, as well as knowledge of CSAPT. The primary inputs used in the production process included fertilizers, seeds, and labor. We further categorized fertilizers and seeds into organic and inorganic fertilizers and traditional and improved seed varieties. We measured labor as the total number of days worked per household. To accurately capture farmers' engagement

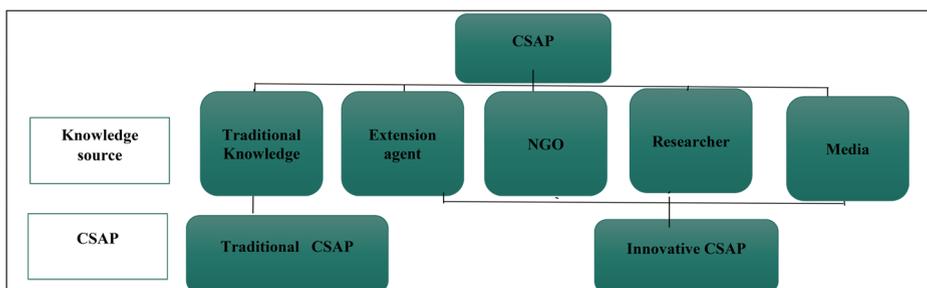
**Table 1** Portfolio of CSAPT used in the study

Soil Management	Water Management	Livestock Management	Agroforestry	Crop production
Organic fertilizer	Flood water harvesting	Improved pasture	Agri silviculture	Pollination management
Crop rotation	Weather forecasting	Animal breeding	Silvopastoral	Cover cropping
Intercropping	Adapting cropping calendar	Supplementary feeding	Agrosylvopastoral	Mulching
Mixing organic and inorganic fertilizers	Irrigation	Disease control		Integrated pest management
Little or no-till	Alternate wet and dry rice production	Vaccination		Improved varieties
Leguminous species	Crop diversification			
Integrated weed Management	Crop insurance			
Stone bunds				

with diverse CSAPT, we employed photographic elicitation to help identify the CSAPT listed in Table 1. A CSAPT was considered unfamiliar to a farmer if they neither knew its name in their local dialect nor recognized its photograph. For CSAPT, which is known to farmers, we inquired about where they first learned about it and whether they adopted it during the 2022 planting season, assigning a score of 1 for adoption and 0 for non-adoption. We categorized the sources of knowledge into five groups: traditional knowledge, government extension agents, NGOs, researchers, and the media.

### 2.2 Methodology

Based on the knowledge sources reported in the survey, we distinguish between traditional CSAPT (learned primarily from traditional knowledge) and innovative CSAPT (acquired from non-traditional sources such as extension agents, NGOs, researchers, and the media) as illustrated in Fig. 2. We observed that all sampled farmers adopted at least some traditional CSAPT. Therefore, to effectively analyze the adoption of more advanced practices, we categorized farmers into two distinct groups for analysis: those who adopted solely traditional CSAPT and those who adopted a combination of both traditional and innovative CSAPT.



**Fig. 2** CSAPT classification

## 2.3 Methods of data analysis

To achieve the research objectives, we combine descriptive and inferential statistics with econometric models. We employed a probit regression model to explore factors influencing farmers' adoption of innovative CSAPT. We estimated the production frontier (the maximum possible output a farm can produce with its inputs) and evaluated technical efficiency (how close a farm is to that maximum) using the Stochastic Frontier Approach (SFA), with an output-oriented focus. This method is particularly useful for low-input farming systems, such as those in our study area.

### 2.3.1 Probit model specification

We chose the probit model for this analysis because it effectively identifies the factors influencing agricultural technology adoption, as demonstrated in previous studies (Abate 2024; Kitole et al. 2024). This method addresses heteroscedasticity (changes in the spread of the data points) and aligns with the cumulative normal probability distribution, enhancing the robustness of the results. In this study, the dependent variable is a hybrid of innovative and traditional CSAPT, with 0 representing non-adoption and 1 indicating adoption. Key covariates include farmers' gender, education level, household size, secondary occupation, land ownership, access to credit, farm group membership, and the perceived occurrence of dry spells. We present the model as follows:

$$CSA_i = F(X_i\beta) + \varepsilon_i \quad (1)$$

Where  $CSA_i$  stands for innovative and traditional CSAPT adoption, given as 1 if they were adopted and 0 otherwise;  $X_i$  is the set of independent variables;  $\beta$  is the vector of coefficients to be estimated using maximum likelihood estimation;  $\varepsilon_i$  is the error term (unobserved factors that influence the dependent variable), assumed to be normally distributed.

Consistent with Asante et al. (2024), we calculate the marginal effects, which are the effect of a small change in an independent variable on the probability of a specific outcome, to gauge the actual change in the probability of adoption attributable to changes in the independent variables, because the standard probit model estimates provide only one direction of effect. We compute the marginal effects as follows:

$$ME = \beta_i \phi(z) \quad (2)$$

Where:  $\beta$  are the coefficients of the independent variable;  $\phi(z)$  refers to the standard cumulative normal distribution associated with the mean dependent variable.

### 2.3.2 Stochastic frontier analysis

We preferred the parametric SFA to the non-parametric Data Envelopment Analysis (DEA) because the deterministic nature of DEA assigns all deviations from the efficiency frontier to inefficiencies. However, agricultural productivity in our study area is affected by external factors like climate shocks, pests, and diseases (Dossa and Miassi 2023), making it challenging to attribute deviations solely to inefficiency (Battie and Coelli, 1995). Additionally, DEA

ignores random shocks like measurement errors and other data noise, while SFA separates the error term into two components: a two-sided random error that reflects uncontrollable factors and a one-sided inefficiency component (Coelli et al. 2005; Kumbhakar and Lovell, 2000). Nevertheless, SFA’s main limitation is its requirement for a predetermined functional form and specific distributional assumptions for technical inefficiency. We express the stochastic production frontier proposed by Aigner et al. (1977) as follows:

$$Y_i = \beta_0 + \beta X_i + \varepsilon_i \tag{3}$$

where  $Y_i$  denotes the log value of crop output in kilograms (Kg) of  $i^{th}$  farm ( $i = 1, 2, 3, 4, 5 \dots n$ ) and  $X_i$  is a vector of input quantities such as log values of land in hectares, traditional and improved seeds, organic and inorganic fertilizers,  $\beta$  is the vector of the parameter to be estimated.  $\varepsilon_i = -u_i + v_i$ .  $v_i$  is assumed to be independently and identically normally distributed  $N(0, \sigma_v^2)$  and independent of the  $u_i$  whereas  $u_i$  is a non-negative random variable related to the technical efficiency of crop production and hypothesized to be independently and identically distributed as half-normal, such that  $u_i \sim iid N^+(0, \sigma_u^2)$ . We redefined the equation as follows:

$$Y_i = f(X_i; \beta) \exp(v_i - u_i) \tag{4}$$

where  $f(\cdot)$  It can assume different functional forms, such as Cobb-Douglas or Translog functional forms. In this study, the Cobb-Douglas production function is selected over the Translog or Quadratic forms in SFA, based on theoretical, empirical, and practical considerations. The Cobb-Douglas functional form is used because it requires fewer parameters, making it easy to understand and interpret the relationships between inputs and outputs (Kumbhakar and Lovell 2000; Okoye et al. 2016). It can provide more stable estimates in situations when the dataset is small or lacks sufficient variation (Greene, 2008; Coelli et al. 2005). Even when the true production function is more complex, studies show that technical efficiency estimates from Cobb-Douglas are often highly correlated with those from Translog or Quadratic forms (O’Donnell and Coelli 2005; Ali and Kpakpabia 2019). From Eq. 3, we define the technical efficiency of farms as:

$$TE_i = \frac{Y_i}{Y_{i*}} = \frac{f(X_i; \beta) \exp(v_i - u_i)}{f(X_i; \beta) \exp v_i} \tag{5}$$

The denominator represents the observed value of the farmer’s output expressed in kg, and the numerator is the frontier output. Hence,

$$TE_i = \exp(-u_i) \tag{6}$$

Once we have computed the technical efficiency of each farmer, it is crucial to estimate the impact of traditional and innovative CSAPT on efficiency. This analysis will help us understand the factors contributing to producers’ technical inefficiency and provide valuable insights for policymakers. We, therefore, regress a set of factors on  $-u_i$  as follows:

$$-u_i = \delta_0 + \sum_{n=1}^k \delta_n Z_n + e_i \tag{7}$$

Where  $Z_i$  is a vector of factors influencing technical inefficiency, including CSAPT from various knowledge sources (traditional and innovative),  $\delta_i$  is the vector of parameters we estimated.  $\varepsilon$  is the error term that is assumed to be normally distributed. Following Battese and Coelli (1995), we use the maximum likelihood method to estimate the stochastic frontier and the inefficiency model in a single-step approach.

Empirically, we specify the output model as follows:

$$Q_i = \beta_0 + \beta_i X_i + v_i \quad (8)$$

where  $Q_i$  is the outcome variable measuring the value of output,  $X_i$  is the vector of inputs, and  $\beta_i$  the parameter to be estimated. We adopted the inefficiency model as follows:

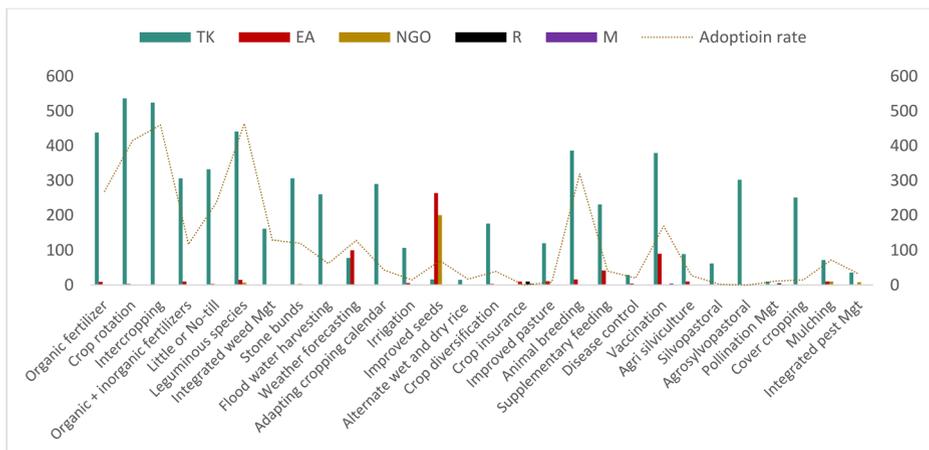
$$E_i = \delta_0 + \delta_i Z_i + e_i \quad (9)$$

where  $E_i$  stands for the inefficiency score,  $Z_i$  is the vector of covariates influencing farmers' inefficiency like climate change adaptation (traditional and innovative CSAPT), gender, education, dry spells, land ownership, membership in farmers' organizations, farming experience, and  $\delta_i$  are the parameters to be estimated.

### 3 Results and discussions

#### 3.1 Knowledge source of CSAP and adoption rates

Figure 3 illustrates the initial knowledge sources farmers reported for CSAPT, as enumerated in Table 1, along with their respective adoption rates. Traditional knowledge was identified as the primary knowledge source for all CSAPT, except for improved seeds, weather forecasting, and crop insurance, where the primary source is extension agents. These three are the innovative CSAPT in our study area, primarily disseminated through extension services.



**Fig. 3** Farmers' knowledge sources and the adoption rate of CSAPT

The low adoption rates of certain CSAPT, such as irrigation, floodwater harvesting, adapting cropping calendars, crop diversification, stone bunds, cover cropping, agro-silvopastoral systems, crop insurance, and supplementary feeding, result from a complex interplay of economic, social, institutional, and environmental challenges. For instance, practices like irrigation and floodwater harvesting, though traditionally understood, often require significant upfront investments in infrastructure, such as pumps, canals, and retention structures. Most smallholder farmers cannot afford these without external financial aid or collective efforts. This finding aligns with Chimi et al. (2023) and Barron et al. (2015), who also identified financial barriers as a significant obstacle to adopting water management technologies in similar contexts. Socially, practices such as crop diversification may be perceived as labor-intensive, making them less appealing to farmers (Giller et al. 2011). This view aligns with Giller et al. (2011) observations on the labor demands of diverse cropping systems, particularly for smallholders.

Institutional gaps also play a crucial role. The lack of organized community support or unclear land tenure for communal water resources can hinder the successful implementation of collective methods, such as floodwater harvesting and building stone bunds. This aligns with Kabubo-Mariara et al. (2010) work, highlighting the vital role of strong local institutions in enabling collective action for natural resource management. Environmentally, the increasing severity and unpredictability of droughts and floods weaken the reliability of traditional calendar-based agricultural practices. This variability often causes farmers to hesitate in adopting strategies heavily dependent on predictable rainfall patterns. Our findings support Kassie et al. (2014) conclusion that increased climate variability directly diminishes the perceived reliability and adoption of traditional, weather-dependent farming practices. Ultimately, despite its innovative potential, crop insurance faces adoption challenges rooted in economic concerns and trust issues. Farmers often see premiums as unaffordable or doubt the payout procedures, mainly when frequent and widespread climate shocks occur. This echoes the challenges documented by Ali et al. (2020) regarding the low uptake of agricultural insurance in developing countries, which is linked to affordability and distrust.

The adoption of improved seeds, such as hybrid and open-pollinated varieties of maize, soybeans, rice, groundnuts, beans, and sorghum, remains low. These seeds offer shorter growth cycles and higher yields, but require enhanced soil fertility, often achieved through the use of inorganic fertilizers (Head of the Legumes Program, ITRA-Kara, 2023; Simtowe et al. 2019). Soils in northern Togo are predominantly sandy-loamy, characterized by low organic matter and nutrients, particularly nitrogen, as well as a low cation exchange capacity, rendering them naturally infertile and prone to leaching (Diwediga et al. 2017). This condition limits farmers' ability to benefit from improved seeds without balanced nutrient management, as poor soil quality leads farmers to spend more on inorganic fertilizers, whereas richer soils facilitate better yields from improved seeds; thus, creating a significant economic barrier for resource-limited smallholder farmers. Without external support, the cost of acquiring both improved seeds and necessary inorganic fertilizers often exceeds the perceived benefits, especially considering the financial risks of low soil fertility and unpredictable rainfall. This financial burden, combined with the low-risk nature of traditional seeds, which can produce even with minimal inputs, may explain why farmers continue to favor them. This finding aligns with the concept of Integrated Soil Fertility Management (ISFM), which advocates for a combined approach of improved seeds and the balanced use of organic and inorganic fertilizers to achieve sustainable yields. Our findings support

the study by File and Nhamo (2023), which highlights that traditional seeds are perceived as having lower risk and lower input needs, despite their lower yield potential compared to improved varieties. Socioeconomic and institutional factors also influence farmers' adoption decisions (Dokyi et al. 2021).

Farmers rely on both traditional knowledge and extension agents for weather forecasting. Accurate forecasts help minimize losses from adverse weather and enhance crop yield and quality (Yegbemey et al. 2023). Extension agents advocate for scientific weather forecasting, which uses advanced technology to predict weather conditions by analyzing data from weather stations and satellites (Stull 2015). In contrast, traditional forecasting depends on observing natural phenomena, such as the behavior of plants and animals (Nyadzi et al. 2022). Farmers use both methods to adapt to climate change, which sometimes makes it difficult to determine which source most influences their decision-making during the farming season (Jiri et al. 2016).

### 3.2 Comparison of socioeconomic characteristics of traditional and innovative CSAP adopters

Table 2 presents the descriptive statistics, which summarize the characteristics of variables influencing farmers' adoption decisions, comparing households that adopted only traditional CSAPT (69%) with those that adopted both innovative and traditional practices (31%). Statistically significant differences at the 1% level (meaning these differences are highly

**Table 2** Description, summary statistics, and t-test of socioeconomic characteristics of CSAPT adopters

Variables and description	Total sample ( <i>n</i> =534)	Adopters Traditional CSAP ( <i>n</i> =371)	Adopters Innovative and Traditional CSAP ( <i>n</i> =163)	Difference in Mean (1)-(2)
	Mean (0)	Mean (1)	Mean (2)	
<b>Gender:</b> (0=male, 1=female)	0.28	0.33	0.16	0.17***
<b>Household size</b> (Number of persons in the household)	6.19	5.95	6.72	-0.77***
<b>Education</b> (Informal=1)	0.18	0.21	0.13	0.07
<b>Education</b> (up to secondary school level=1)	0.79	0.76	0.84	-0.08
<b>Education</b> (above secondary level=1)	0.03	0.03	0.02	0.01
<b>Secondary occupation</b> (non-farming occupation 0=no, 1=yes)	0.08	0.09	0.06	0.03
<b>Land ownership:</b> 0=Family land, 1=rented	0.05	0.01	0.13	-0.12***
<b>Farm land</b> (in hectares)	1.48	1.28	1.94	-0.66***
<b>Member of farmer organization:</b> 0=no, 1=yes	0.19	0.15	0.29	-0.14***
<b>Farming experience</b> (In years)	24.60	24.62	24.54	0.08
<b>Farm type</b> (0=crop farming, 1=mixed farming)	0.87	0.87	0.88	-0.01
Dry spells (0=not experienced, 1=experienced)	0.60	0.55	0.70	-0.15***
Use of organic fertilizer (kg)	256.79	149.11	499.73	-350.629
Use of inorganic fertilizer (kg)	144.67	123.79	191.77	-67.98588 ***
Crop output value	884139.9	885,612	880818.6	4793.39
<b>Credit access</b> (0=no, 1=yes)	0.13	0.10	0.20	-0.10***
<b>Labor</b> (labor available to the household)	33.61	31.68	37.97	-6.29***

\*\*\*  $p < 0.01$

unlikely due to random chance) were found in gender, household size, land ownership, farm land size, membership in farmer organizations, frequency of dry spells, access to credit, the use of inorganic fertilizers, and the number of days of labor availability in the household.

### 3.3 Probit results of determinants of traditional and innovative CSAPT adoption

Table 3 shows the results of the probit model, identifying the factors influencing the probability of farmers adopting traditional and innovative CSAPT. The likelihood ratio test is significant at the 1% level, which confirms that our model, including the various factors, provides a significantly better explanation of adoption decisions than a simpler model without these factors. This indicates a good fit for the estimated probit model.

The results show that the coefficient for gender is negatively associated with the combined adoption of innovative and traditional CSAPT. Specifically, the marginal effect of  $-0.102$  indicates that being a female-headed household decreases the probability of adopting a hybrid of innovative and traditional CSAPT by approximately 10.2% points, holding other factors constant. This implies that females are less likely to adopt a hybrid of innovative and traditional CSAPT. Women's capacity to embrace innovative CSAPT is directly hampered by their limited access to resources, including land, credit, inputs, social norms, domestic responsibilities, and mobility constraints. Women's labor constraints and mobility limitations due to domestic responsibilities can hinder their ability to receive timely and relevant information about innovative CSAPT. Additionally, women have restricted access to credit and financial services, which are often essential for procuring innovative CSAPT, such as seeds and inputs for improved crop varieties. These barriers affect agronomic activities, such as the timely fertilizer application and access to draft power. This observation is consistent with the findings of Witinok-Huber et al. (2021) and Beuchelt and Badstue (2013).

**Table 3** Determinants of innovative CSAPT adoption in Northern Togo

Innovative and Traditional CSAPT	Coefficient	Std. Err.	Marginal effect
Gender (Female = 1)	-0.352**	0.170	-0.102**
Education (Primary and below = 0)			
Up to secondary school level	0.019	0.177	0.005
Above secondary school level	0.038	0.396	0.011
Household size	-0.012	0.021	-0.003
Secondary occupation (Yes = 1)	-0.274	0.263	-0.079
Member of farmer organization	0.399***	0.157	0.116***
Land ownership (Rented = 1)	1.854***	0.343	0.539***
Credit access (Yes = 1)	0.119	0.187	0.035
Farm type (Mixed farming = 1)	-0.311	0.203	-0.090
Land size (log)	0.340***	0.069	0.099***
Dry spells (Yes = 1)	0.404***	0.129	0.112***
Constant	-0.533*	0.295	
Number of observations	534		
Log-likelihood	-275.67		
Likelihood Ratio test:	107.37***		
Chi-square(df = 11)			
Pseudo R <sup>2</sup>	0.1630		

\*\*\* $p < 0.001$ ; \*\* $p < 0.005$

Farmer organization membership enhances the adoption of innovative and traditional CSAPT, as indicated by the positive coefficient and a marginal effect of 0.116. This means that membership increases the probability of adopting a hybrid of innovative and traditional CSAPT by about 11.6% points. Farmer organizations provide their members with improved social networks, access to information, and services such as credit and markets, ultimately increasing their adaptive capacity. This aligns with previous research (Manda et al. 2020; Anang et al. 2020). Furthermore, the results indicate that land ownership, specifically family-owned land, has a significant and positive impact, with a marginal effect of 0.539. This suggests that farmers operating on family-owned land are approximately 53.9% points more likely to adopt a mixed portfolio of CSAPT compared to those on rented land. This may be attributed to having secure land tenure, which empowers farmers to invest more confidently in transformative agricultural practices and benefit from long-term advantages. Additionally, land ownership can improve a farmer's creditworthiness, allowing them to secure loans or financial support to invest in new technologies, equipment, or inputs. This finding aligns with studies by Ma and Rahut (2024) and Keovilignavong and Suhardiman (2020).

The positive coefficient associated with dry spells suggests that experiencing dry spells is linked to increased adoption of innovative and traditional CSAPT, with a marginal effect of 0.112. This indicates that farmers who have experienced dry spells are about 11.2% points more likely to adopt a hybrid of innovative and traditional CSAPT. The finding suggests that farmers may be more likely to adopt innovative CSAPT to adapt to changing climatic conditions, particularly during dry spells. The mechanism behind this is that, during dry spells, moisture stress causes farmers to recognize the importance of water management and triggers the adoption of specific practices aimed at resilience, such as switching to early-maturing varieties, which can enhance their productivity. This finding aligns with Fisher et al. (2015) and Pangapanga-Phiri and Mungatana (2021), who found that farmers' exposure to dry spells prompted them to adopt innovative farming techniques.

Farmland size is positively linked to the adoption of innovative and traditional CSAPT. The marginal effect of 0.099 shows that, on average, a 1% increase in land size results in a 9.9% point rise in the likelihood of a farmer adopting these practices. This suggests that farm size is a key factor influencing a farmer's decision to adopt new technologies. The underlying reasons for this relationship are probably connected to resource availability and risk tolerance. Larger farms may also gain from economies of scale, which can reduce relative implementation costs. Additionally, having larger farmlands can give farmers a greater ability to absorb the financial risks and uncertainties involved in adopting innovative practices. This finding aligns with the results of Kpadonou et al. (2017).

### 3.4 Production frontier estimates

In this section, we present and discuss the results of the first-stage sample selection stochastic production frontier model, which focuses on the direct impact of inputs on farm output. The findings indicate that farm land (significant at the 1% level), traditional seeds (significant at the 10% level), improved seeds (significant at the 5% level), organic and inorganic fertilizers (both significant at the 5% level) had a positive and significant impact on crop production efficiency (Table 4). Additionally, the results showed that land possesses the highest positive elasticity of 0.222, suggesting that a 1% increase in the traditional seeds would result in a 0.222% increase in crop output.

**Table 4** Maximum likelihood estimate of the stochastic production frontier model

In (Crop Output value)	Coefficient	Standard error
Household labor (log)	0.002	0.062
Land size (log)	0.222***	0.052
Improved seeds (log)	0.037**	0.017
Traditional seeds (log)	0.053*	0.030
Organic Fertilizers (log)	0.020**	0.009
Inorganic fertilizers (log)	0.032**	0.016
Constant	12.933***	0.246
Returns to scale (RTS)	0.366	
Number of observations	534	
Wald chi2(6)	43.05***	
Log pseudolikelihood	-882.29878	

\*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.10$

Furthermore, the Returns to Scale (RTS) value of 0.366 (which is less than 1) indicates decreasing returns to scale to the modeled inputs. This means that if farmers increase all their inputs proportionally (e.g., by 100%), their crop output would increase by a smaller percentage (specifically, only 36.6%). In practical terms, this suggests that simply scaling up inputs proportionally at this stage of production is inefficient and may not significantly boost crop output over the long term. To address these diminishing returns, farmers should focus on adopting practices that enhance productivity per unit of input. Additionally, the results show that having larger farm land, using improved and traditional seeds, as well as organic and inorganic fertilizers, significantly boosts farm-level productivity. However, since the overall system shows decreasing RTS, the emphasis should be on strategically and efficiently using these inputs rather than merely increasing their quantity. Farmers who overlook these inputs may face inefficiencies that limit their competitiveness in agriculture.

The significant and positive contribution of organic fertilizer to crop output demonstrates that traditional soil management practices remain effective and significantly influence productivity, even in today's modern farming. Applying organic matter enhances soil health by increasing soil organic content, buffering pH levels, facilitating nutrient cycling, and improving water infiltration (Sileshi et al. 2025), all of which are crucial for maintaining stable yields, particularly under climate stress. However, small-scale farmers often lack the resources to produce or access the large amounts of organic material required (Ouédraogo et al. 2001), making inorganic fertilizers a more attractive option. Inorganic fertilizers are crucial for maximizing seed yield potential and have played a key role in Africa's Green Revolution (Badiane et al. 2020). Promoting their use is crucial for enhancing yields. However, using inorganic fertilizers without incorporating organic amendments can lead to greenhouse gas emissions, soil degradation, water pollution, and reliance on non-renewable resources, jeopardizing sustainability (Hu et al. 2023; Lassaletta et al. 2016). Combining both organic and inorganic fertilizers effectively can create a foundation for productive and healthy farming (Sommer et al. 2018).

Improved seeds can considerably enhance crop production efficiency (Riaz et al. 2024). However, their widespread adoption is impeded by various challenges, including high costs, limited access to credit, inadequate distribution infrastructure, and a lack of trust in seed-providing institutions (Shiferaw et al. 2015). In contrast, while traditional seeds may exhibit lower productivity under optimal conditions compared to improved seeds, they offer advantages such as cost-effectiveness, promoting genetic diversity, and enhancing resilience in

agricultural systems. These attributes contribute to maintaining stable yields in fluctuating conditions. The simultaneous positive and significant elasticities for both seed types show that they play complementary roles in smallholder farming. Traditional seeds, well-adapted to local conditions, help with stress tolerance and provide a crucial baseline yield. In contrast, improved seeds offer higher yield potential in more favorable conditions. This strategic mix of high-yield potential and the low-cost, locally adapted resilience of traditional varieties allows farmers to balance risk and reward (Haug et al. 2023). Our findings confirm that the correlation between using traditional and improved seeds is low, thereby preventing multicollinearity and allowing for the unique contributions of each seed type to farm productivity, consistent with the findings of Bezabih et al. (2025).

The coefficient for farmland (0.222) indicates that a 1% increase in cultivated land area leads to a 0.22% rise in crop output. This supports agricultural production theory, as discussed by Jayne et al. (2014), which emphasizes land as a key factor in boosting output. Larger farms benefit from economies of scale by spreading high fixed costs, such as those for building floodwater harvesting channels to collect rainwater for supplementary irrigation. Additionally, access to better resources and technologies enables larger farms to achieve higher yields per hectare, enhancing overall productivity (Van Zyl et al. 1995). Larger farms also facilitate the use of specialized equipment, such as tractors, which improve labor productivity and efficiency, reducing reliance on manual labor. These findings are consistent with the research by Julien et al. (2021) in East Africa.

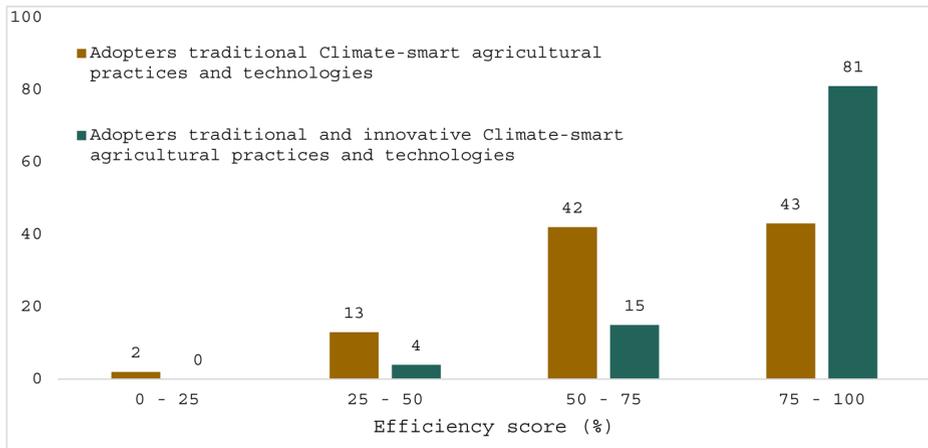
### 3.4.1 Technical efficiency scores of sample households

The SFA model results show differing efficiency scores among the two groups of adopters, as illustrated in Table 5; Fig. 4. The efficiency score ranges from 0 to 1, where 1 indicates maximum possible efficiency (producing the most output with the given inputs) and values closer to 0 indicate lower efficiency.

The maximum efficiency score recorded among all farmers is 0.999, and the median efficiency score (0.760) is higher than the mean (0.747), suggesting a left-skewed distribution. This means that most farmers are concentrated at higher efficiency levels, but there is a tail of farmers operating at much lower efficiency levels. However, the standard deviation of 0.187, coupled with the lowest efficiency score of 0.161, highlights a significant degree of variability in efficiency across the sample. Such variability suggests considerable potential for improving efficiency among farmers. These findings are consistent with prior research (Miriti et al. 2021), which demonstrates that many farmers in sub-Saharan Africa fail to attain their optimal efficiency.

**Table 5** Summary statistics of estimated technical efficiency scores of farm households

Type of sample	Estimated efficiency scores				
	Max	Min	Mean	Median	St. Dev
All farmers	0.999	0.161	0.747	0.760	0.187
Adopters Traditional CSAPT	0.999	0.161	0.711	0.756	0.192
Adopters Traditional and innovative CSAPT	0.999	0.383	0.829	0.812	0.145



**Fig. 4** Comparison of the efficiency score between the groups of CSAPT adopters

Farmers who only adopted traditional CSAPT achieved a maximum score of 0.999. The median score of 0.711 is above the mean, suggesting left skewness that may stem from a few very low efficiency scores. Adopters of solely traditional CSAPT displayed significant variability in efficiency, demonstrated by a higher standard deviation of 0.192. In contrast, adopters of a hybrid of traditional and innovative CSAPT achieved a significantly higher median score of 0.812, which is less than the mean (0.829), indicating right skewness, with most farmers concentrated around higher efficiency scores and a few of them operating at higher efficiency levels that are pulling the mean up. Moreover, their lowest standard deviation of 0.145 shows reduced variability and enhanced consistency in efficiency among this group of farmers. This observation aligns with the research by Muzari et al. (2012), which highlights the benefits of integrating traditional and innovative farming methods.

Additionally, we find that most farmers (57%) who adopt solely traditional CSAPT exhibit only moderate efficiency levels (scores below 75%), as depicted in Fig. 4. Conversely, farmers who combine traditional and innovative CSAPT demonstrate a significantly higher efficiency level, with 81% achieving performance scores between 75 and 100%. This trend suggests a reduced inefficiency among adopters of both traditional and innovative CSAPT. These observations are consistent with the findings of Pattiasina et al. (2023), who concluded that adopting only traditional CSAPT results in mostly modest efficiency improvements for farmers.

The variability observed in technical efficiency scores among farmers can be aligned with previous research on smallholder systems in Togo (Pilo 2019) and reflects the inherent biophysical and heterogeneous nature of smallholder farming systems in West African agriculture. This heterogeneity is linked to several factors, including differences in access to resources, which significantly influence efficiency. Farmers in Northern Togo, for example, have limited capital, which further restricts smallholders' ability to invest in necessary inputs, thereby reducing efficiency (Miassi et al. 2023). Additionally, water availability, which is influenced by rainfall variability, directly impacts crop yields and efficiency, underscoring the potential of irrigation to enhance output (Pilo 2019). As a result, farmers in more favorable agro-ecological zones or those with better access to resources tend to have higher

efficiency than those contending with greater environmental stresses or resource scarcity. Obstacles to market access also limit efficiency by restricting farmers' ability to source inputs and sell produce effectively (Ma et al., 2024; Kopper and Jayne 2019; Kamara 2004). On the other hand, exposure to extension services improves efficiency by encouraging the adoption and successful implementation of new technologies and practices (Jolex 2022). Ultimately, individual farmer traits, especially risk perception and management skills, greatly influence adoption and overall efficiency. Even when resources are available, differences in decision-making, knowledge utilization, and the extent of implementing CSAPT can result in notable variations in observed efficiency levels (Akter et al. 2022).

### 3.4.2 Determinants of technical inefficiency in farm-level production

Table 6 displays the findings from the second-stage sample selection stochastic production frontier model, which identifies factors that influence farmers' technical inefficiency—that is, what makes them more or less efficient in their production. In this model, a negative coefficient for a variable indicates that it reduces inefficiency and increases efficiency, while a positive coefficient indicates that it increases inefficiency and decreases efficiency. The results indicate that several factors significantly influence technical inefficiency: gender (positive effect on inefficiency, significant at 1%), membership in a farmer organization (negative effect on inefficiency, significant at 1%), and education up to secondary school level and above secondary school level (negative effect on inefficiency, significant at 5% and 1%, respectively).

The positive coefficient related to gender (1.627) indicates that female-headed farm households operate with lower efficiency compared to male-headed ones. This disparity can be attributed to various interconnected agronomic constraints. Women often have limited access to and control over vital resources, such as land, credit, draft power, and timely access to fertilizer. Additionally, mobility constraints due to domestic obligations can hinder their access to input markets and extension services. These obstacles collectively impede their

**Table 6** Maximum likelihood estimates of factors influencing technical inefficiency

Variables	Coefficient	Standard error
Education (Primary and below =0)		
Up to secondary school level	-1.132**	0.498
Above secondary school level	-26.513***	3.303
Experience	-0.022	0.028
Member of farmer organization	-25.782***	8.315
Land ownership (rented=1)	-0.889	0.718
Innovative and Traditional CSAPT (Yes=1)	-0.392	0.501
Gender (Female=1)	1.627***	0.560
Dry spells (Yes=1)	-0.349	0.390
Constant	-0.013	0.675
Number of observations	534	
Wald chi2(6)	43.05***	
Log pseudolikelihood	-882.29878	

\*\*\* $p < 0.001$ ; \*\* $p < 0.05$

ability to adopt new technologies and obtain necessary information. This finding is consistent with the research by Witinok-Huber et al. (2021) and Beuchelt and Badstue (2013).

The negative coefficients linked to the various levels of education ( $-1.132$  and  $-26.513$ ) indicate that educated farmers exhibit greater technical efficiency compared to those with informal backgrounds. This difference likely stems from education providing farmers with critical thinking abilities and knowledge of advanced farming practices, which boosts their efficiency. Such education enhances decision-making, allowing for better assessments of agricultural techniques and technologies. Educated farmers are more inclined to embrace innovative practices, which results in improved resource management, less waste, and higher yields. Furthermore, education strengthens access to and comprehension of information from extension services, aiding continuous efficiency advancements. These results align with findings from Alemayehu et al. (2024) and Agarwal et al. (2022).

Membership in farmers' organizations is significantly linked to enhanced technical efficiency, evidenced by a notable negative coefficient ( $-25.782$ ). Such organizations function as vital platforms for the dissemination of knowledge and peer learning, which contribute to higher productivity. They also facilitate access to credit and financial services, allowing farmers to make necessary investments in their farms. Furthermore, members benefit from acquiring essential resources such as high-quality seeds, fertilizers, and modern equipment, often at reduced costs through collective bargaining, thereby ensuring the availability of affordable and timely inputs. This finding corroborates the results of Olagunju et al. (2021).

## 4 Conclusion

This study examined the adoption of CSAPT and its impact on the technical efficiency of smallholder food production in Kozah Prefecture, Northern Togo. CSAPT were categorized based on their knowledge sources into traditional and innovative types. Traditional CSAPT were learned from traditional knowledge, while innovative CSAPT were acquired from non-traditional channels such as extension services, non-governmental organizations, researchers, and media. We further classified farmers into two groups: those who exclusively adopted traditional CSAPT and those who integrated both traditional and innovative CSAPT. Employing a probit model and stochastic frontier analyses, the study identified critical determinants of adoption and assessed their effects on farm productivity and efficiency.

Our findings indicate that traditional knowledge predominantly shapes agricultural practices, resulting in a high prevalence of traditional CSAPT adoption. Probit analysis demonstrated that factors such as membership in farmer organizations, secure land tenure, farmland size, and firsthand experience with droughts positively influence the adoption of a hybrid CSAPT approach. Conversely, the female gender appears to negatively affect the likelihood of adopting these integrated practices, highlighting notable gender disparities. Our analysis of technical efficiency reveals that educated farmers and farmers who are members of farmer-based organizations tend to be more efficient. The persistently lower efficiency observed in female-headed households highlights existing gender disparities. Additionally, having larger farm land, the use of traditional seeds, improved seeds, organic and inorganic fertilizers, all significantly and positively enhance crop production efficiency. The differing efficiency scores highlight the crucial role of adoption choices and diverse farm characteristics. Farmers combining both traditional and innovative CSAPT consistently showed

higher and more consistent efficiency with less variability, suggesting a combined approach optimizes resource use and enhances resilience. In contrast, those relying only on traditional CSAPT had lower average efficiency and more variability. This suggests that the combined approach optimizes resource use and provides greater resilience against climate shocks, thereby reducing inefficiency. This pattern reflects the inherent diversity of smallholder systems, which are affected by varying access to capital, water for agricultural use, and markets. Farmers with better access to these critical resources tend to achieve higher efficiency. Additionally, extension services and personal traits, such as risk management skills, significantly influence adoption and efficiency. The lower efficiency among female-headed households underscores ongoing barriers to their access to land, credit, information, and labor.

Looking beyond the immediate effects, the sustained adoption of a hybrid CSAPT package is expected to provide substantial long-term advantages for agricultural output, environmental health, and farmer resilience. The efficiency improvements suggest that persistent use will lead to more consistent and increased yields over time, directly supporting food security. Environmentally, blending traditional knowledge with modern techniques, such as improved crop varieties, is essential for preserving and enhancing soil health and conserving water resources for farming. However, attaining these long-term benefits requires addressing ongoing challenges.

Our research suggests several policy recommendations to address the ongoing challenges. First, to address the challenges posed by dry spells, governments and partners should enhance seed systems and incentives by investing in reliable, decentralized seed certification and quality assurance processes, thereby increasing farmers' efficiency and climate resilience through the adoption of innovative CSAPT. Providing direct financial support such as targeted subsidies for certified improved seeds and low-interest loans for smallholder farmers and local seed producers, potentially through a seed voucher program linked to extension services, could further promote these goals. Second, to improve farmers' access to information and social capital, it is important to promote hybrid CSAPT packages through structured, hands-on training programs and farmer field schools. These initiatives should demonstrate the synergistic benefits of combining traditional knowledge with modern innovative techniques, such as integrating traditional cover cropping with improved seed varieties. Extension services and NGOs should develop localized curricula and demonstration plots to highlight hybrid CSAPT packages effectively. Simultaneously, it is essential to strengthen farmer organizations by enhancing their capacity to enable peer-to-peer learning. This can be achieved through encouraging exchanges and learning workshops, allowing experienced members to share knowledge and best practices both within and across organizations. Additionally, supporting the development of tailored, culturally appropriate training modules and materials that address local agricultural challenges and opportunities will enhance the effectiveness of these initiatives. Third, to effectively address gender disparities and boost female farmers' adoption of a hybrid package of CSAPT, it is crucial to first secure women's land tenure rights by conducting widespread community awareness campaigns that support documentation and offer legal aid. Additionally, tailored extension programs should be scheduled at times and locations convenient for women, taking into account their domestic and caregiving responsibilities.

While this study provides valuable insights into the adoption and technical efficiency of CSAPT in Togo, it is essential to acknowledge certain limitations and potential biases that may influence the findings. First, the use of cross-sectional data from a single agricultural

season limits the ability to capture evolving adoption trends or long-term efficiency gains. Second, although a sample selection stochastic frontier model was applied, unobserved traits, such as entrepreneurial spirit, may still bias the results. Third, grouping CSAPT may obscure the distinct effects of individual practices, and adoption rates alone do not indicate intensity or consistency of use—factors that critically affect outcomes. Lastly, the stochastic frontier approach, although practical, relies on strong distributional assumptions and fails to capture changes in efficiency over time. Future research should explore the use of panel data and causal methods to enhance the robustness of findings. Investigating the influence of specific policy interventions or market dynamics on CSAPT adoption and efficiency also represents a promising direction for future studies.

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## Declarations

**Ethics approval and consent to participate** The Research Ethics Committee of the University of Applied Sciences Cologne approved this study, and all respondents consented to participate.

**Competing Interests** The corresponding author, on behalf of the other authors, declares that there are no conflicts of interest directly or indirectly related to the work submitted for publication to disclose.

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## References

- Abate TW (2024) Analysis of agricultural technology adoption: the use of improved maize seeds and its determinants in Ethiopia, evidence from Eastern Amhara. *J Innov Entrepren* 13(1):61
- Adeola O, Evans O, Ngare I (2023) African Indigenous knowledge and climate change mitigation: towards an Afro-Sensed perspective. Gender Equality, climate Action, and technological innovation for sustainable development in Africa. Springer International Publishing, Cham, pp 169–191
- Adom PK, Adams S (2020) Decomposition of technical efficiency in agricultural production in Africa into transient and persistent technical efficiency under heterogeneous technologies. *World Dev* 129:104907

- African Development Bank (2016) Togo 2016–2020 Country Strategy Paper [https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Togo\\_-\\_2016-2020\\_Country\\_Strategy\\_Paper.pdf](https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Togo_-_2016-2020_Country_Strategy_Paper.pdf)
- Agarwal T, Goel PA, Gartaula H, Rai M, Bijarniya D, Rahut DB, Jat ML (2022) Gendered impacts of climate-smart agriculture on household food security and labor migration: insights from Bihar, India. *Int J Clim Change Strateg Manag* 14(1):1–19
- Aigner D, Lovell CK, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. *Journal of econometrics* 6(1):21–37
- Akter A, Mwalupaso GE, Wang S, Jahan MS, Geng X (2022) Towards climate action at farm-level: distinguishing complements and substitutes among climate-smart agricultural practices (CSAPs) in flood prone areas. *Clim Risk Manage* 40:100491. <https://doi.org/10.1016/j.crm.2023.100491>
- Alemayehu S, Ayalew Z, Sileshi M, Zeleke F (2024) Determinants of the adoption of climate smart agriculture practices by smallholder wheat farmers in Northwestern Ethiopia. *Heliyon*. <https://doi.org/10.1016/j.heliyon.2024.e34233>
- Ali E (2018) Impact of climate variability on staple food crops production in Northern Togo. *J Agric Environ Int Dev* 12(2):321–341
- Ali E (2019) Farmers' attitudes towards climate risks and effects of farmers' risk aversion behavior on inputs use in Northern Togo. *Sarhad J Agric* 35(3):663–674. <https://doi.org/10.17582/journal.sja/2019/35.3.663.674>
- Ali E (2021) Farm households' adoption of climate-smart practices in subsistence agriculture: evidence from Northern Togo. *Environ Manage* 67(5):949–962
- Ali E, Awume AN (2025) The nexus between credit rationing and the adoption of climate-smart agricultural practices: implications for agricultural household revenue in Togo. *Dev Sustain Econ Finance* 6:100052. <https://doi.org/10.1016/j.dsef.2025.100052>
- Ali E, Kpakpabia KT (2019) Determinants of technical efficiency of cotton farmers in Togo. *Rev Agricultural Appl Econ* 22(2):88–95. <https://doi.org/10.15414/raae.2019.22.02.88-95>
- Ali E, Egbendewe AYG, Abdoulaye T, Sarpong DB (2020) Willingness to pay for weather index-based insurance in semi-subsistence agriculture: evidence from Northern Togo. *Clim Policy* 20(5):534–547
- Anang BT, Bäckman S, Sipiläinen T (2020) Adoption and income effects of agricultural extension in northern Ghana. *Scientific African* 7:e00219
- Andersson JA, D'Souza S (2014) From adoption claims to understanding farmers and contexts: a literature review of conservation agriculture (CA) adoption among smallholder farmers in Southern Africa. *Agric Ecosyst Environ* 187:116–132
- Arslan A, McCarthy N, Lipper L, Asfaw S, Cattaneo A, Kokwe M (2015) Climate-smart agriculture? Assessing the adaptation implications in Zambia. *J Agric Econ* 66(3):753–780
- Asante BO, Ma W, Prah S, Temoso O (2024) Farmers' adoption of multiple climate-smart agricultural technologies in Ghana: determinants and impacts on maize yields and net farm income. *Mitig Adapt Strat Glob Change* 29(16). <https://doi.org/10.1007/s11027-024-10114-8>
- Asfaw S, Lipper L (2016) Determinants of adoption of climate-smart agricultural practices: evidence from Ethiopia. *J Agric Econ* 67(2):481–500
- Badiane O, Odjo SP, Collins J (2020) Africa agriculture status report: feeding Africa's cities: opportunities, challenges, and policies for linking African farmers with growing urban food markets. Alliance for a Green Revolution in Africa (AGRA).
- Barron J, Kemp-Benedict E, Morris J, de Bruin A, Wang G, Fencel A (2015) Mapping the potential success of agricultural water management interventions for smallholders: where are the best opportunities? *Water Resources and Rural Development* 6:24–49
- Battese GE, Coelli TJ (1995) A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empir Econ* 20:325–332
- Bekuma T, Mamo G, Regassa A (2023) Indigenous and improved adaptation technologies in response to climate change adaptation and barriers among smallholder farmers in the East Wollega zone of Oromia, Ethiopia. *Res Glob* 6:100110
- Beuchelt TD, Badstue L (2013) Gender, nutrition-and climate-smart food production: opportunities and trade-offs. *Food Secur* 5:709–721
- Bezabih M, Tarp F, Teklewold H, Mekonnen A, Gebrehiwot T (2025) Traditional versus improved varieties of seed: is there a trade-off between productivity and risk? *Rev Dev Econ* 29(3):1921–1939
- Board, Adaptation Fund (2013) Request for project/programme funding from the adaptation fund, promoting climate-smart agriculture in West Africa available at [https://www.adaptationfund.org/wpcontent/uploads/2015/08/BOAD\\_Benin\\_BurkinaFaso\\_Ghana\\_Niger\\_Togo\\_proposal\\_combined.pdf](https://www.adaptationfund.org/wpcontent/uploads/2015/08/BOAD_Benin_BurkinaFaso_Ghana_Niger_Togo_proposal_combined.pdf)
- Carrer MJ, de Souza Filho HM, Vinhols MDMB, Mozambani CI (2022) Precision agriculture adoption and technical efficiency: an analysis of sugarcane farms in Brazil. *Technol Forecast Soc Chang* 177:121510

- Chimi PM, Mala WA, Abdel KN, Fobane JL, Essouma FM, Matick JH, Bell JM (2023) Vulnerability of family farming systems to climate change: the case of the forest-savannah transition zone, centre region of Cameroon. *Res Glob* 7:100138
- Coelli TJ, Rao DSP, O'donnell CJ, Battese GE (2005) Productivity and efficiency measurement concepts. An introduction to efficiency and productivity analysis. Springer, Boston, MA. [https://doi.org/10.1007/0-387-25895-7\\_3](https://doi.org/10.1007/0-387-25895-7_3)
- Diwediga B, Le QB, Agodzo S, Wala K (2017) Potential storages and drivers of soil organic carbon and total nitrogen across river basin landscape: the case of Mo River basin (Togo) in West Africa. *Ecol Eng* 99:298–309
- Dokyi E, Anang BT, Owusu V (2021) Impacts of improved seed maize technology adoption on productivity and technical efficiency in Northern Ghana. *Open Econ* 4(1):118–132
- Dossa KE, Miassi YE (2023) Exploring the nexus of climate variability, population dynamics, and maize production in Togo: implications for global warming and food security. *Farming System* 1(3):100053
- FAO (2013) Climate-Smart agriculture sourcebook. FAO pp, Rome, Italy
- File DJMB, Nhamo G (2023) Farmers' choice for indigenous practices and implications for climate-smart agriculture in Northern Ghana. *Heliyon* 9(11):e22162. <https://doi.org/10.1016/j.heliyon.2023.e22162>
- Fisher M, Abate T, Lunduka RW, Asnake W, Alemayehu Y, Madulu RB (2015) Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climatic Change* 133(2):283–299
- Giller KE, Titttonell P, Rufino MC, Van Wijk MT, Zingore S, Mapfumo P, Vanlauwe B (2011) Communicating complexity: integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agric Syst* 104(2):191–203
- Greene WH (2008) The econometric approach to efficiency analysis. In H. O. Fried, C. A. Knox Lovell, & S. S. Schmidt (Eds) *The measurement of Productive Efficiency and Productivity Growth*. Oxford Academic. pp 92–250. <https://doi.org/10.1093/acprof:oso/9780195183528.003.0002>
- Haug R, Hella JP, Mulesa TH, Kakwera MN, Westengen OT (2023) Seed systems development to navigate multiple expectations in Ethiopia, Malawi and Tanzania. *World Development Sustainability* 3:100092
- Hu Y, Li D, Wu Y, Liu S, Li L, Chen W, Siddique KH (2023) Mitigating greenhouse gas emissions by replacing inorganic fertilizer with organic fertilizer in wheat–maize rotation systems in China. *J Environ Manage* 344:118494
- IPCC (2022) *Climate change 2022: Impacts, adaptation and Vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK and New York, NY, USA, p 3056. <https://doi.org/10.1017/9781009325844>
- IPCC (2019) *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* In press
- Jayne TS, Chamberlin J, Headey DD (2014) Land pressures, the evolution of farming systems, and development strategies in Africa: a synthesis. *Food Policy* 48:1–17
- Jayne TS, Yeboah FK, Henry C (2017) The future of work in African agriculture: Trends and drivers of change. (Working Paper No. 25) International Labor Organization. [https://www.canr.msu.edu/fsg/publications/research-papers/wcms\\_624872.pdf](https://www.canr.msu.edu/fsg/publications/research-papers/wcms_624872.pdf)
- Jiri O, Mafongoya PL, Mubaya C, Mafongoya O (2016) Seasonal climate prediction and adaptation using Indigenous knowledge systems in agriculture systems in Southern Africa: a review. *J Agric Sci* 8(5):156–172
- Jolex A (2022) Influence of agricultural extension services on technical efficiency of maize farmers in Malawi. *Afr J Agric Resour Econ* 17(1):92–105
- Julien JC, Bravo-Ureta BE, Rada NE (2021) Productive efficiency and farm size in East Africa. *Agrekon* 60(3):209–226
- Kabubo-Mariara J, Linderhof V, Kruseman G (2010) Does land tenure security matter for investment in soil and water conservation? Evidence from Kenya. *Afr J Agric Resour Econ* 4(2):123–139
- Kamara AB (2004) The impact of market access on input use and agricultural productivity: evidence from Machakos District, Kenya. *Agrekon* 43(2):202–216
- Kassie BT, Rötter RP, Hengsdijk H, Asseng S, Van Ittersum MK, Kahiluoto H, van Keulen HJTJ, O.A., .S (2014) Climate variability and change in the central rift Valley of Ethiopia: challenges for rainfed crop production. *J Agricultural Sci* 152(1):58–74
- Keovilignavong O, Suhardiman D (2020) Linking land tenure security with food security: unpacking farm households' perceptions and strategies in the rural uplands of Laos. *Land Use Policy* 90:104260
- Kitole FA, Tibamanya FY, Sesabo JK (2024) Exploring the nexus between health status, technical efficiency, and welfare of small-scale cereal farmers in Tanzania: a stochastic frontier analysis. *J Agric Food Res* 15:100996

- Kopper SA, Jayne TS (2019) Market access, agro-ecological conditions, and Boserupian agricultural intensification patterns in Kenya: implications for agricultural programs and research. *World Dev* 124:104649
- Kpadonou RAB, Owiyi T, Barbier B, Denton F, Rutabingwa F, Kiema A (2017) Advancing climate-smart agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. *Land use policy* 61:196–207
- Kumbhakar SC, Lovell CAK (2000) *Stochastic frontier analysis*. Cambridge University Press
- Lassaletta L, Billen G, Garnier J, Bouwman L, Velazquez E, Mueller ND, Gerber JS (2016) Nitrogen use in the global food system: past trends and future trajectories of agronomic performance, pollution, trade, and dietary demand. *Environ Res Lett* 11(9):095007
- Lipper L, Zilberman D (2018) A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. *Clim Smart Agriculture: Building Resil Clim Change*, 13–30
- Ma W, Rahut DB (2024) Climate-smart agriculture: adoption, impacts, and implications for sustainable development. *Mitig Adapt Strateg Glob Change* 29(5):44
- Ma W, Rahut DB, Sonobe T, Gong B (2024) Linking farmers to markets: barriers, solutions, and policy options. *Econ Anal Policy* 82:1102–1112
- Manda J, Khonje MG, Alene AD, Tufa AH, Abdoulaye T, Mutenje M, Setimela P, Manyong V (2020) Does cooperative membership increase and accelerate agricultural technology adoption? Evidence from Zambia. *Technol Forecast Soc Chang* 158:120160: 1–12. <https://doi.org/10.1016/j.techfore.2020.120160>
- Miassi YE, Akdemir Ş, Dossa KF, Omotayo AO (2023) Technical efficiency and constraints related to rice production in West Africa: the case of Benin Republic. *Cogent Food Agric* 9(1):2191881
- Ministry of Agriculture, Livestock and Rural Development (MAERD), Togo (2010) [Proposal/Source Document for GAFSP Fund]. Retrieved from: [https://gafspfund.org/sites/default/files/inline-files/Togo\\_proposal.pdf](https://gafspfund.org/sites/default/files/inline-files/Togo_proposal.pdf). Accessed 20 Feb 2025
- Miriti P, Otieno DJ, Chimoita E, Bikketi E, Njuguna E, Ojiewo CO (2021) Technical efficiency and technology gaps of sorghum plots in Uganda: a gendered stochastic metafrontier analysis. *Heliyon*. <https://doi.org/10.1016/j.heliyon.2020.e05845>
- Modi R (2019) The role of agriculture for food security and poverty reduction in sub-Saharan Africa. *Palgrave Handb Contemp Int Political Econ* 391–410. [https://doi.org/10.1057/978-1-137-45443-0\\_25](https://doi.org/10.1057/978-1-137-45443-0_25)
- Muzari W, Gatsi W, Muvhunzi S (2012) The impacts of technology adoption on smallholder agricultural productivity in sub-Saharan Africa: a review. *J Sustain Dev* 5(8):69
- Nin-Pratt A (2016) Inputs, Productivity and Agricultural Growth in Sub-Saharan Africa. In: Greene, W., Khalaf, L., Sickles, R., Veall, M., Voia, MC. (eds) *Productivity and Efficiency Analysis*. Springer Proceedings in Business and Economics. Springer, Cham. [https://doi.org/10.1007/978-3-319-23228-7\\_11](https://doi.org/10.1007/978-3-319-23228-7_11)
- Novotny IP, Lefevre NB, Attiogbé KS, Wouyo A, Fousseni F, Dray A, Waeber PO (2024) Exploring farmer choices in Southern Togo: utilizing a strategy game to understand decision-making in agricultural practices. *Agric Syst* 218:103960
- Nyadzi E, Werners SE, Biesbroek R, Ludwig F (2022) Towards weather and climate services that integrate indigenous and scientific forecasts to improve forecast reliability and acceptability in Ghana. *Environmental Development* 42:100698
- Ocelli M, Mantino A, Ragaglini G et al (2021) Traditional knowledge affects soil management ability of smallholder farmers in marginal areas. *Agron Sustain Dev* 41:9. <https://doi.org/10.1007/s13593-020-00664-x>
- O'Donnell CJ, Coelli TJ (2005) A bayesian approach to imposing curvature on distance functions. *J Econ* 126(2):493–523
- Okoye BC, Abass A, Bachwenkizi B, Asumugha G, Alenkhe B, Ranaivoson R, Ralimanana I (2016) Differentials in technical efficiency among smallholder cassava farmers in Central Madagascar: A Cobb Douglas stochastic frontier production approach. *Cogent Economics & Finance* 4(1):1143345
- Olagunju KO, Ogunniyi AI, Oyetunde-Usman Z, Omotayo AO, Awotide BA (2021) Does agricultural cooperative membership impact technical efficiency of maize production in nigeria: an analysis correcting for biases from observed and unobserved attributes. *PLoS ONE* 16(1):e0245426
- Ouédraogo E, Mando A, Zombré NP (2001) Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agric Ecosyst Environ* 84(3):259–266
- Pangapanga-Phiri I, Mungatana ED (2021) Adoption of climate-smart agricultural practices and their influence on the technical efficiency of maize production under extreme weather events. *International Journal of Disaster Risk Reduction* 61:102322
- Patel SK, Sharma A, Singh GS (2020) Traditional agricultural practices in India: an approach for environmental sustainability and food security. *Energy Ecol Environ* 5(4):253–271. <https://doi.org/10.1007/s40974-020-00158-2>

- Pattiasina TA, Nurmalina R, Harianto, Fariyanti A (2023) Technical efficiency of traditional agriculture based on local knowledge of smallholder farmers. *Asian Journal Agric Rural Development* 13(3):206–214. <https://doi.org/10.55493/5005.v13i3.4844>
- Pilo M (2019) Dynamics of agricultural productivity and technical efficiency in Togo: the role of technological change. *Afr Dev Rev* 31(4):462–475
- Pilo M, Gerber N, Wünscher T (2021) Impacts of adaptation to climate change on farmers' income in the savanna region of Togo. *Revue Économique* 72(3):421–442
- Riaz M, Rehman S, Boz I (2024) Factors influencing the adoption of certified potato seeds among the farmers operating in Punjab, Pakistan. *Environ Dev Sustain* 26(7):16847–16861
- Richards M, Bruun TB, Campbell B, Gregersen LE, Huyer S, Kuntze V, Vasileiou I (2016) How countries plan to address agricultural adaptation and mitigation: An analysis of Intended Nationally Determined Contributions. CCAFS dataset
- Schultz TW (1964) Transforming traditional agriculture. Yale University Press, New Haven, CT
- Shiferaw B, Kebede T, Kassie M, Fisher M (2015) Market imperfections, access to information and technology adoption in Uganda: challenges of overcoming multiple constraints. *Agricultural Economics* 46(4):475–488
- Sileshi GW, Drinkwater LE, Marenja P, Snapp S (2025) Localized application of manure and fertilizers increases productivity of cereals, resource use efficiency and profitability in sub-Saharan Africa. *Agric Ecosyst Environ* 379:109347
- Simtowe F, Amondo E, Marenja P, Sonder K, Erenstein O (2019) Impacts of drought-tolerant maize varieties on productivity, risk, and resource use: evidence from Uganda. *Land Use Policy* 88:104091
- Sommer R, Paul BK, Mukalama J, Kihara J (2018) Reducing losses but failing to sequester carbon in soils—the case of conservation agriculture and integrated soil fertility management in the humid tropical agroecosystem of Western Kenya. *Agric Ecosyst Environ* 254:82–91
- Spear D, Selato JC, Mosime B, Nyamwanza AM (2019) Harnessing diverse knowledge and belief systems to adapt to climate change in semi-arid rural Africa. *Clim Serv* 14:31–36
- Stull RB (2015) Practical meteorology: an algebra-based survey of atmospheric science. University of British Columbia. [bd21e3a7-19e8-4476-8ac8-04e5ea4247ce](https://doi.org/10.1007/978-1-4939-9424-7)
- Taylor JE, Poleacovschi C, Perez MA (2023) Climate change adaptation trends among Indigenous peoples: a systematic review of the empirical research focus over the last 2 decades. *Mitig Adapt Strateg Glob Change* 28(6):29
- Van Zyl J, Binswanger-Mkhize HP, Binswanger HP, Thirtle CG (1995) The relationship between farm size and efficiency in South African agriculture, vol 1548. World Bank
- Witinok-Huber R, Radil S, Sarathchandra D, Nyaplue-Daywhea C (2021) Gender, place, and agricultural extension: a mixed-methods approach to understand farmer needs in Liberia. *J Agricultural Educ Ext* 27(4):553–572. <https://doi.org/10.1080/1389224X.2021.1880453>
- World Bank (2010) Togo - Projet d'appui au secteur agricole: plan de gestion sociale et environnementale (Vol. 2) : Plan de lutte antiparasitaire. (n.d.). Accessed 23 February 2025, from World Bank website: <http://documents.worldbank.org/curated/en/306751468173957943/Pest-management-plan>
- World Bank Togo - country economic memorandum 2022: Toward sustainable and included growth. Retrieved 3 June 2024, from World Bank website: <http://documents.worldbank.org/curated/en/099715006162211825/P174741091bbc700a089000336ea46bdd3f>. Accessed 19 March 2025
- Yegbemey RN, Bensch G, Vance C (2023) Weather information and agricultural outcomes: evidence from a pilot field experiment in Benin. *World Dev* 167:106178
- Zougmore R, Jalloh A, Tioro A (2014) Climate-smart soil water and nutrient management options in semiarid West africa: a review of evidence and analysis of stone bunds and zai techniques. *Agric Food Secur* 3:1–8

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