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Confronting climate change and livelihood: smallholder farmers' perceptions and adaptation strategies in northeastern Burundi

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Abstract

Rain-fedagriculture is the main source of livelihood for most of Burundi's population, especially in the northeastern part of the country. This research is aimed at examining how smallholder farmers in the Northeastern region of Burundi perceive climate change and variability and at identifying the methods that are used to adapt, based on data from 200 small farmers and on actual weather data recorded between 1986 and 2017. We find that the majority of farmers (54%) perceive significant increases in temperature and unpredictability of rainfall duration and intensity and are making adjustments to adapt their agriculture in response to changes in climate. Over 80% of farmers have implemented at least one adaptation strategy among the nine evaluated. Changing crop varieties, changing fertilizers, and planting shade trees are the main adaptation strategies that were being implemented by farmers across the study area. The results of a binary regression model showed that the agricultural education and experience of farmers, as well as farm and family size, livestock ownership, climate information access, credit access, and farm income, strongly influence smallholder farmers' decisions to adapt to climate change. The main obstacles are the lack of information on climate and adaptation strategies, and poverty, which makes it difficult to cope with the increased costs of farming. Understanding farmers' perceptions of climate change and variability on a local level would provide information on how to develop adaptation strategies. The present study suggests the need for strengthening farmers' capacities and improving the policy framework for adaptation to climate change in order to improve farmers' livelihoods. Implications for policymakers will, therefore, include making flexible credit facilities, and investing in training extension agents on both climate change outreach and coping strategies.

Keywords Climate change · Smallholder farmers · Perceptions · Adaptation strategies · Northeastern Burundi

Introduction

To feed a rapidly growing population, land productivity capacity and per capita food production must increase in the coming decades (Clover 2003). The Food and Agriculture Organization of the United Nations (FAO) projects that food security must be achieved to feed the world's hungry population, which will require a 60% increase in food production by 2050 (Holmgren 2012). Yet, farmers around the world need to increase food production by increasing productivity on existing agricultural land in a sustainable manner (Pereira

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2017). Moreover, in the near future, limited agricultural land will have to compete with other services such as greenhouse gas storage, ecosystem restoration, reforestation, energy production, and urbanization. In the context of the globalized food system, options for agricultural intensification need to be considered (Struik and Kuyper 2017). However, the prospects for increased production through intensification are uncertain due to climatic issues, especially in sub-Saharan Africa (SSA), where intense rains, severe and recurrent floods, and droughts have been observed in the last decades (Oguntunde et al. 2006).

Various scientists have noted evidence of climate change in Africa since the last century, with surface temperature increases ranging from 0.72 to 0.85 °C (Nyboer et al. 2019) while projections are likely to exceed 1.5 °C by the end of the twenty-first century (Gemeda et al. 2021) and increase by 4 °C by 2100 (Masroor et al. 2020). According to a recent study by Tan et al. (2020), extreme and severe droughts and wet scenarios are expected in East Africa in the near future. Moreover, climate change impacts estimated by climate change models are expected to be greater in African regions. SSA countries are vulnerable to climate shocks and their negative impacts (Mulwa et al. 2017), especially because a large proportion of their population and economy depends directly on rain-fed agriculture and most farms are operated by smallholders (< 2 ha plot holders). Smallholder populations account for about 50 and 75% of the world's and Africa's hungry people, respectively (Sanchez and Swaminathan 2005). Among the approximately 2.6 billion people who depend directly on agriculture for their livelihoods, most are smallholder farmers in developing countries, who are unfortunately subject to unforeseen shocks that lead to crop failure and food or financial insecurity (Fan and Rue 2020). There is, therefore, no doubt that climate shocks will have a negative impact on the lives of poor and rural African farmers and will jeopardize food security and socioeconomic development (Adger et al. 2007; Gbetibouo 2009; Ringler et al. 2011).

In Burundi, agriculture is the principal source of livelihood for at least 80% of the population contributing over 28.9% of the gross domestic product (GDP) (in 2019, https://data.worldbank.org/), and nearly 90% of the households are smallholders practicing subsistence rain-fed agriculture (Nyairo et al. 2014). Different climate-related disasters are causing tremendous negative impacts on the existing fragile food security situation for both farms and pastorals. These include droughts, heat waves, floods, storms, mudslides, and landslides (Gitz et al. 2016). These events have taken lives, destroyed homes and livelihoods, displaced thousands of people, and have caused a breakdown of vegetation and farmland, especially in the northeast (Batungwanayo et al. 2020; Ndayiragije et al. 2017). In addition, climate predictions expect additional

uncertainty and extreme events for Burundi. For instance, based on CORDEX climate models, a study conducted by Rivas-López et al. (2022) has indicated that Burundi will experience an increase in annual and seasonal average temperature over in all scenarios, characterized by a significant annual rising trend along the twenty-first century and the increase in every single month, especially in the dry season (up to 5.2 °C under RCP8.5-P2). Precipitation would decrease throughout the year, particularly in the onset and offset of the rainy season in northern Burundi and during most of the year in the south of the country. These changes represent a high risk for agricultural production, on which 90% of the population depends. History has shown that famine, malnutrition, mortality, and related migration, among others, are direct consequences of such climatic events (Baramburiye et al. 2013). Government and NGO commitments have emerged in response to the adverse impacts of these disasters. For increasing the climate resilience of small-holder farmers, it is therefore imperative to understand the perceptions of farmers as regards the impact of climate change on their lives and livelihoods, as well as the outcomes that they will get from various climate adaptation and mitigation programs.

The purpose of the study is to gain insights into the adaptive potential of farmers in Kirundo and Muyinga provinces in northeastern Burundi by examining their perceptions, knowledge, and adaptation practices to climate change and variability. To do so, an in-depth survey was conducted among communities in Northeastern Burundi at risk from or affected by climate change and variability about (a) the impact of climate change on their daily lives, with particular attention to the consequences on livelihoods and economic activities and (b) the farmers' knowledge base and the perception of what needs to be done and what is being done to respond. This study uses a binary logistic model to examine the key elements that determine adaptation strategies.

Climate change perceptions, adaptation options, and barriers in agricultural systems

Although a literature review on climate change shows that more attention has been paid to climate system modeling, climate change impacts, adaptation, and risk assessment, relatively little attention has been paid to the perceptions and adaptation options of people experiencing climate change (Rahman and Hickey 2019; Holman et al. 2019). Yet, the perception of climate change and its associated impacts is an important first step for smallholder farmers to adapt (Deressa et al. 2011) in order to better cope with climate change in their environmental and agro-structural context. Indeed, adaptation will be necessary to meet the challenges associated with climate change, especially in SSA (Jiri et al. 2015).

As noted in the studies by Tittonell et al. (2010, 2011) and Alvarez et al. (2018), smallholder agricultural structures are quite complex and heterogeneous in their different characteristics, including land ownership, soil fertility, used cropping strategies, livestock ownership, off-farm sports, labor, and cash availability, socio-cultural traits, farm improvement trajectories, and livelihood techniques. Moreover, they may vary from country to country, from region to region, and even within short distances due to variations in relief and soil. The adaptive potential of smallholder farming systems to cope with climate shocks and reduce their impacts will therefore depend heavily on the type of smallholder farming (Alvarez et al. 2018).

Practices to adapt to climate change impacts and variability refer to real adaptations or changes in the decision-making environment that could ultimately improve resilience or reduce vulnerability to observed or anticipated climate risks (Adger et al. 2007; Cooper et al. 2013). Proactive strategies such as crop and livelihood diversification, seasonal climate forecasting, network-based disaster preparedness, early warning systems for famine, hedging, water storage, supplemental irrigation, and others have already been implemented to adapt to seasonal and inter-annual time scales (Adger et al. 2007). Strategies and innovations used to adapt to climate variability include adjusting planting dates, introducing new crop varieties, changing plant spacing and crop varieties, increased use of manure, water harvesting, well digging, agroforestry, crop rotation, and post-harvest monitoring (Bryan et al. 2010; Mugendi et al. 2015). These strategies are implemented by a range of stakeholders, including individuals, communities, governments, and the private sector. The strategies typically involve a mix of stakeholder actions, deployment of appropriate technologies, and development of climate-resilient infrastructure (El Raey 2004; Organisation 2004; Osman-Elasha et al. 2006). Strategies are typically proposed in response to various hazards and often as a component of existing practices or applications, including livelihood improvement, water resource monitoring, and drought assistance.

Adaptation of agriculture to the impacts of climate change and variability has therefore emerged as a priority task for various stakeholders in SSA (Jiri et al. 2015). Particular emphasis has been placed on improving the adaptation potential of smallholder farmers and increasing the adoption of adaptation strategies (Apata 2011). However, any effective adaptation policy must take into account knowledge, perception, and awareness of the impacts of climate change and variability. It follows that potential barriers and constraints to smallholder adaptation must be considered (Knittel 2016). Better information on how smallholder farmers understand climate change and climate variability and what their adaptation strategies are is essential for promoting successful adaptation (Jiri et al. 2015). However, there are still few detailed studies on farmers' perceptions of climate change and variability in their region and the adaptation methods they adopt.

Material and methods

Description of the study area

This study was conducted in Kirundo and Muyinga provinces in northeastern Burundi covering an area of 3539 km^2 (i.e., 13% of the country's surface area), located approximately between longitudes 29.92 to 30.5° E and latitudes 2.31 to 3.2° S in northeastern Burundi. This region covers a part of the agro-ecological zone of Bugesera and another part of the Bweru. That also falls in the two climatic zones: (a) the depression of the east and northeast and (b) the zone of the central plateaus. The altitude ranges between 1320 and 2000 m and is characterized by high temperatures, but especially a more pronounced drought. Average annual temperatures are around 20 °C and annual rainfall rarely exceeds 1100 mm but can drop to around 600 mm. Atmospheric humidity is never very high, with an annual average of 65 to 70% (Frenken 2005). Two rainy seasons occur in the region: the so-called season A running from mid-September to December (SOND), known as the short rainy season, and the so-called season B running from March to May (MAM), known as the long rainy season. Also, two dry seasons separate those wet seasons, the season C running from June to August (JJA), known as the long dry season, and a short dry season in January–February(JF) (Batungwanayo et al. 2020; Nkunzimana et al. 2021). Figure 1 shows the map of sample study areas located in Kirundo and Muyinga provinces.

Climatic disasters and catastrophic events have caused many problems for the local population in Burundi. Because of dryness, smallholders in the northeast of Burundi were severely hit by famine (Lawin et al. 2019). Before the climatic conditions become unfavorable, the northeastern region was the country's breadbasket for the major food crops widely present in households' food, including maize, beans, sorghum, rice, potatoes, sweet potatoes, bananas, and cassava (Nyandwi et al. 2019). Coffee is the main exportation and cash crop of the region. As there is strength in numbers, farmers in the region, as well as those in other parts of the country, have been grouping together in cooperatives for years. As a result, farmers in cooperatives have seized new financial opportunities by gaining easy access to a wide range of services, such as access to low-cost agricultural inputs, market opportunities, agricultural micro-credit, natural resources, training, and information. This also helps other organizations (e.g., NGOs) contributing to the country's development to reach the farmers easily since the national agricultural budget has not been sufficient to meet their needs (Manirakiza et al. 2020). In the

Fig. 1 Sample study communes in Northeastern region, Burundi
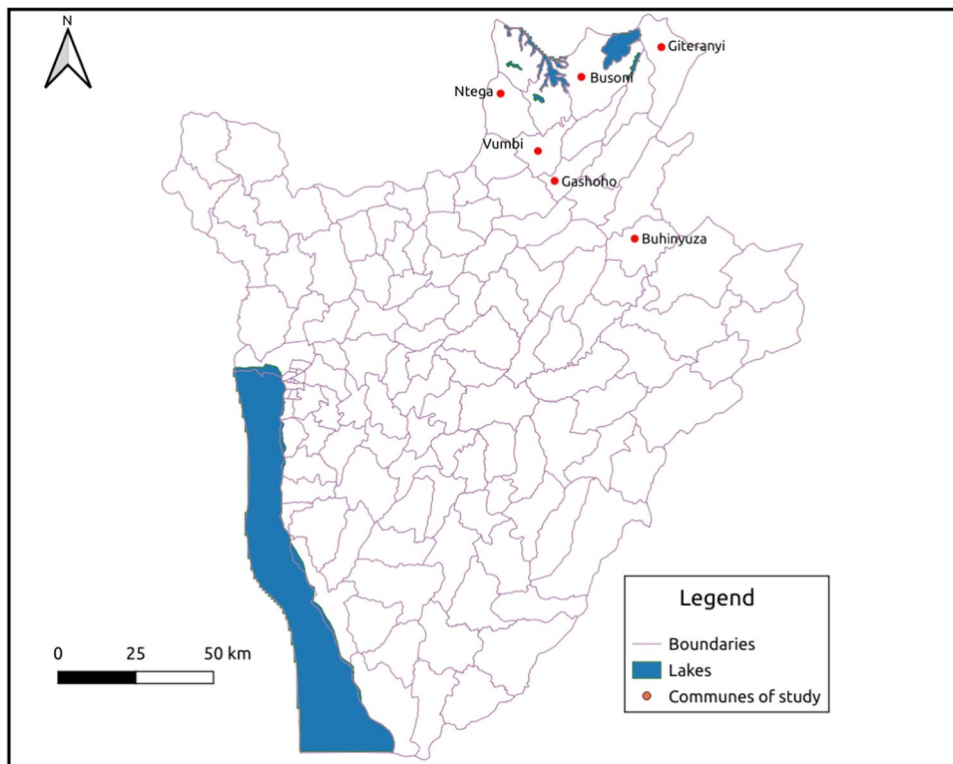
area of development, Burundi was ranked 185th out of 189 countries in the world and 49th out of 53 countries in Africa, with a Human Development Index (HDI) of 0.417 in 2017. Nearly 80% of Burundians live below the poverty line, or less than one US dollar a day (Nyandwi et al. 2019).

Sampling design and data collection

This study describes farmer's perceptions of climate change and variability as well as self-reported farm-level adaptation measures, and barriers to adaptation at their household level. It is based on primary data from a survey of household members conducted by means of face-to-face discussions, using a structured questionnaire. A total of 200 farmers were questioned during the survey between February and March 2021, in two northeastern provinces of Burundi: Kirundo and Muyinga. Multistage sampling technique was used to sample the farmers from the two provinces. Among the 14 communes (Bugabira, Busoni, Kirundo, Ntega, Vumbi, Gashoho, Bwambarangwe, Giteranyi, Butihinda, Gitobe, Gasorwe, Muyinga, Buhinyuza, and Mwakiro) of the two provinces of study, only six are selected using a simple random sampling (Lohr 2009; Mutoko et al. 2014). In each stratum (commune), a number of individuals were selected using the quota sampling method. Quota sampling is a non-random sampling method, also called non-probability sampling, often used in polls and opinion surveys where the specific size of the sample is usually decided in advance

(see details in (Sedgwick 2012)). The communes resulting from the random sample drawn as well as the proportions to be adopted are shown in Table 1.

A fully structured questionnaire used includes four main sections: (i) basic information about farmers, (ii) their perceptions of climate hazard and variability, (iii) information on their adaptive potential, coping strategies, and sensitivity, and (iv) limitations to adaptation.

Analytical techniques

Adaptation strategies to changes in climatic factors such as increased temperature and decreased precipitation can reduce agricultural losses caused by these factors. Yet, farmers decide to adapt once they recognize local changes in

Table 1 The study sample distribution

Province	Commune	No. of farmers interviewed		
		Male	Female	Total
Muyinga	Buhinyuza	13	5	18
	Gashoho	9	13	22
	Giteranyi	27	27	50
Kirundo	Busoni	29	19	48
	Ntega	16	18	34
	Vumbi	17	11	28
	Total	107	93	200

long-term climate such as temperature and precipitation patterns (Bryan et al. 2013). To empirically probe the influences on the choice of different adaptation strategies implemented by farmers in response to perceived climate change within areas of interest, many researchers typically used binomial or multinomial logit approach (Deressa et al. 2009; Onyekuru and Marchant 2017; Kumar and Sidana 2018; Funk et al. 2020), to permit an assessment of more than two categories and allow the determination of choice probabilities for these different categories (Wooldridge 2010; Destaw and Fenta 2021). However, an analysis of the available variables is needed to decide upon a model to be used. Thus, an overview of the variables selected for the study is presented.

Dependent and independent variables related to adaptation

Our preference for explanatory variables is based on an in-depth literature review but is limited by the availability of data. Consequently, there are factors that were not considered in this evaluation that could modify the findings. However, the predictors chosen cover a wide range of factors that scholars consider to influence climate adaptation. These variables are summarized in Table 2, and they encompass farmers' traits such as age (farming experience), education, and gender, as well as family size; financial components, including farm profits and livestock ownership; physical characteristics, including farm size, farmland location, and use of extension services; and awareness of climate fluctuations, as assessed through perceptions of decreased rainfall, increased temperature, and soil and water depletion.

The dependent variables used in the study are nine dummy variables including changing crop varieties (CCV): mixed cropping (MC), planting shade trees (PST), crop rotation (CR), soil conservation (SC), changing fertilizer application

(CF), pesticide application (PA), changing planting dates (CPD), and farming system shift (FSS). The outcome is equal to one if the farmer used the adaptation option and zero otherwise. The statistics summary for the identified response variables shows that there is no adaptation option that is adopted by 100% of respondents, indicating that there is a diversification of adaptation strategies (see Table 3). Therefore, it is necessary to see which of these variables are adopted with regard to the explanatory variables.

Empirical modeling

Following the literature, most of the researches on perceiving farmers' adaptation to weather alteration and variability used a multinomial logit (MNL) modeling technique (Deressa et al. 2009; Funk et al. 2020; Hisali et al. 2011; Onyekuru and Marchant 2017) where respondents are restricted to select only one from a given set of adaptation strategies. Indeed, it was common in this study for farmers to adopt more than one adaptation strategy simultaneously. This behavior pushed on the usage of the logistic regression method to study the factors that affect the selection of adaptation strategies. The theoretical framework adopted for this research is mainly based on a binary logistic model to study the influencing factors of the different adaptation strategies implemented by the farmers in the region. As previous studies have suggested, we expect farmers to implement strategies to adapt to climate change if it boosts their net farm profits or reduces the perceived risk to their agricultural production (Abid et al. 2015; Bryan et al. 2010). Consider the following model:

$$Y_{ij}^* = a + \sum \beta_k X_k + \varepsilon_{ij}, \tag{1}$$

where Y_{ij}^* is a hidden variable or unobserved variable for the farmer i who is adopting strategy j. Also, X_k indicates the

Table 2 Descriptions of explanatory variables

Explanatory variable	Description	Expected signs
Gender of farmer	Dummy takes values female and male	(±)
Education level	Dummy takes the values no education, basic, secondary, and university	(+)
Years of experience in farming	Dummy takes the values < 30, 30–39, 40–49, > 50	(±)
Access to climate information	Dummy takes the value 1 if have access and 0 otherwise	(+)
Household size (individuals)	Continuous	(+)
Landholding (in hectares)	Continuous	(+)
Access to credit	Dummy takes the value 1 if have access and 0 otherwise	(+)
On-farm income	Continuous	(+)
Off-farm income	Continuous	(+)
Farm location	Dummy takes the value on hills; near lake/river, low land; and mixed	(+)
Livestock ownership	Dummy takes the value 1 if owned and 0 otherwise	(+)
Climate awareness	Dummy takes the value 1 if the farmer is aware of climate change; 0 otherwise	(+)

vector of k explanatory variables that influence the farmer's decision to implement adjustment strategies. The symbol a is the intercept of the model, β_k is the vector of coefficients and ε_{ij} is the error term (normally distributed with zero mean and constant variance).

Given that the variable Y_{ij}^* is not directly observed, we use Y_{ij} which takes the values 0 or 1 in respect to the following rule:

$$Y_{ij} = \left\{ \begin{array}{l} 1 \text{ if } Y_{ij}^* > 0 \\ 0 \text{ otherwise} \end{array} \right\}, \tag{2}$$

where Y_{ij} is an observed variable indicating that the farmer i will adapt to perceived climate change with certain strategies $j\left(Y_{ij} = 1\right)$ if their expectations for profits are above zero $\left(Y_{ij}^* > 0\right)$. Otherwise, farmer i would not opt for the adaptation strategy j if the expectations for profits are equal or less than zero $\left(Y_{ij}^* \leq 0\right)$.

Hence, the conditional probability that Y_{ij} equals 1 is

$$Pr\left(Y_{ij} = 1|x\right) = Pr\left(Y_{ij}^* > 0|\ x\right) = \frac{\exp\left(\beta_k X_k\right)}{1 + \exp\left(\beta_k X_k\right)} = G\left(\beta_k X_k\right), \tag{3}$$

where $G(.)$ is the logistic distribution's cumulative distribution function (Fernihough 2011). $Pr\left(Y_{ij} = 1\right)$ is the probability of choosing the adaptation options j. The reference category j is the number of adaptation options to climate change in the choice set, X_k is a vector of the predictor physical and socio-economic factors (variables), and β_k is a vector of the estimated parameters. β_k describes the size and direction of the relationship between the independent variables and the dependent variable, and the statistical significance related to the effect of increasing an independent variable as do the ordinary least squares (OLS) coefficients.

Thus, the dependent variables Y_{ij} have binary output ($\left(Y_{ij} = 1\right)$ if the farmer i adopts the adaptation strategy j, and $Y_{ij} = 0$ otherwise), and we seek to explain the variations using one or more explanatory variables X_k. The independent variables (explanatory) are shown in Table 2.

The coefficients of the logit approach are not sufficient to interpret the relationship between response and explanatory variables. The only components that may be directly interpreted in a sizable manner are the signs and significance of the coefficients of the regression (Funk et al. 2020). Positive β_k shows that X_k will increase the possibility of adopting a selected adaptation strategy. However, the coefficient β_k cannot explain how lots the possibility of a farmer i adopting a specific adaptation strategy $\left(Y_{ij} = 1\right)$ will change when we change X_k consequently. Therefore, the marginal effects are computed using the coefficients by taking the derivative of the probability with respect to one element, k, of X to increase the interpretation of the results (i.e., we take the derivative of Eq. 3):

$$\frac{\partial G\left(\beta_k X_k\right)}{\partial X_k} = \frac{\exp\left(\beta_k X_k\right)}{(1 + \exp\left(\beta_k X_k\right))^2} \cdot \beta_k.$$

The marginal effects are usually calculated at the data's sample to mean and vary with the values of X. They describe the effect of changing the unit of the explanatory variable on the likelihood of the dependent variable $\left(Pr\left(Y_{ij} = 1\right)\right)$.

The derivation of marginal effects finally yields to:

$$\frac{\partial G\left(\beta_k X_k\right)}{\partial X_k} = Pr\left(Y_{ij} = 1|x\right) \cdot \left(1 - Pr\left(Y_{ij} = 1|x\right)\right)\beta_k. \tag{4}$$

As the marginal effects of dummy variables are not reported appropriately, the coefficients are interpreted in terms of marginal effects on odds ratios rather than on probabilities (Funk et al. 2020). The odds for an individual i are expressed as the ratio of the probability ρ_i to $1 - \rho_i$, where $p_i = Pr\left(Y_{ij} = 1|x\right) = \frac{\exp\left(\beta_k X_k\right)}{1 + \exp\left(\beta_k X_k\right)}$. Thus,

$$\text{odds} = \frac{p_i}{1 - p_i} = \frac{\frac{\exp\left(\beta_k X_k\right)}{1 + \exp\left(\beta_k X_k\right)}}{1 - \frac{\exp\left(\beta_k X_k\right)}{1 + \exp\left(\beta_k X_k\right)}} = \exp\left(\beta_k X_k\right); \ln \frac{p_i}{1 - p_i} = \beta_k X_k,$$

where $\frac{\rho_i}{1 - \rho_i}$ defines the probability that $Y_{ij} = 1$, against the probability that $Y_{ij} = 0$. Thus, the logit model can be interpreted intuitively, since the log-odds ratio is linear with respect to the regressors.

Thereafter, the study's empirical models were validated based on different ways before discussing the results in detail. Therefore, all estimates have been tested by means of testing the overall significance of the procedures, in addition to the goodness of fit. The general significance of the models was checked using the likelihood-ratio, with the null hypothesis technique. For this evaluation, a null hypothesis is established by assuming and placing all regression coefficients of the logistic models equal to zero, in opposition to the alternative that at least one of the regression coefficients of regression $\left(\beta_k\right)$ is not equal to zero (Lever et al. 2016; Peng et al. 2002). This test assesses the robustness of the model with predictors compared to the model with only an intercept (i.e., an intercept-only model). Thus, it follows an asymptotic chi-square distribution with degrees of freedom set as the difference between the number of variables in the model with predictors and the model with intercept only (Abid et al. 2015).

Moreover, the classification table method was used to evaluate the accuracy of our models in predicting the dependent variable. The classification table is based on a comparison of the predicted scores of the observations, from the independent variables of the model, with their actual responses given within the data (Lever et al. 2016). The predicted value is considered 1 if it is greater than the set limit value of 0.5; thus, a farmer adopts an adaptation technique; otherwise, the prediction is

considered 0 (a farmer does not adopt). The accuracy of the model, therefore, reflects the proportion of positive and negative events correctly estimated over the total number of events (Team AVC 2016). Therefore, based on these comparisons, the higher the percentages, the better the model.

Furthermore, the receiver-operating-characteristic (ROC) curves are used to evaluate the models' efficiency. This enables graphical inspection of the performance of the model, as it represents the fraction of successfully categorized adopting farmers versus incorrectly categorized farmers (which are not sincerely adapting to climate change). Therefore, a ROC curve illustrates the alternate-off between the sensitivity (i.e., the rate of true positives) and this value subtracted from 1 (i.e., the rate of false positives), since the threshold (c) varies between 0 and 1. For the threshold c = 1, all farmers are expected to adapt to climate change, so all of the farmers that successfully adapt are efficaciously precise; instead, all farmers that do not adapt are incorrectly specified (Funk et al. 2020). Therefore, the ROC curve takes on the value (0, 100). With the same reasoning, the ROC curve takes on the value (100, 0) for c = 0. For this reason, if a model has no predictive capability, its ROC curve is a direct line between those two points (Cameron and Trivedi 2005). As such, when the area under the curve (AUC) for a model's ROC is greater than the area under that line, the model has better predictive power than randomness.

Not only the computation of the ROC curves for the predictability of the sample was performed, but also the evaluation of the performance of the models by calculating out-of-sample predictions. The data set was split randomly into two groups, with two-thirds of the full data set as a training set to estimate the logit models and the remaining one-third for testing the out-of-sample performance.

Weighted average index and Henry Garret ranking method

To assess the perception and adaptation strategies to local climate change and variability in northeastern Burundi, the data collected among 200 smallholder farmers have been used. Then, information on socio-economic characteristics and respondents' perceptions of climate change and variability, adaptation methods (Table 3), and challenges are described using descriptive statistics such as percentages and frequency counts. In addition, all available adaptation options to perceived changes in climate patterns at the farm household level were ranked on a 5 or 7-point Likert scale as well as with the weighted average index (WAI) of respondents' variables using the following formula (Lone et al. 2020):

$$WAI = \frac{\sum f_i w_i}{\sum f_i}$$

where f is the frequency of variables; w the weight of each variable of the respondents evaluated on the scale; and i

Table 3 Adaptation methods employed by farmers (multiple responses)

Adaptation method	Frequency	Percentage (%)
Changing crop varieties (CCV)	138	69.00
Mixing cropping (MC)	116	58.00
Planting shade trees (PST)	135	67.50
Crop rotation (CR)	105	52.50
Soil conservation (SC)	38	19.00
Changing fertilizer (CF)	150	75.00
Pesticide application (PA)	78	39.00
Changing planting dates (CPD)	107	53.00
Farming system shift (FSS)	116	58.00
No adaptation	15	7.5
Total sample size	200	

is the response on the scale (i.e., 1, strongly disagree; 2, disagree; 3, somewhat disagree; 4, undecided/neutral; 5, somewhat agree; 6, agree; 7, strongly agree or 7, extremely severe; 6, very severe; 5, severe; 4, significant; 3, somewhat significant; 2, irrelevant; 1, I don't know).

Moreover, Henry Garrett's assessment method was used to measure the degree to which farmers are coping with specific problems while projecting adaptation techniques. To sort out the most important constraint, farmers had been invited to rank all identified concerns and the effects of this rating procedure had been transformed into scores using the percentage position in the Garrett table. Then, for every problem, the scores had been brought up and then the severity of each trouble was calculated primarily based on the general rating. The following formula was used to obtain the Garrett scores (Garrett and Woodworth 1969):

$$\text{Percent position} = 100\left(\frac{R_{ij} - 0.5}{N_j}\right),$$

where R_{ij}, rank given for the ith item by j^{th} individual; N_j, number of items ranked by j^{th} individual.

Results and discussion

Characteristics of respondents

Smallholder farmer's characteristics of our sample are assessed, with the farmer considered either as the main decision-maker in planning the household's agricultural activities or as a person involved in the follow-up (Table 4). The respondent farmers are not highly educated enough (19% have no formal education while 46% have managed to gain the basic level). Majority (61%) of the farmers were less than 45 years old while 25%, 10.5%, and 3.5% of the respondents were aged

45–54 years, 55–64 years, and 65 years or more respectively. Also, 53.5% of respondents were male while 46.5% were female. Eighty-three percent of the respondent farmers are involved only in agriculture and livestock breeding, and 63% of them can earn at least 10,000 Burundian francs (BIF) from their crops after satisfying their subsistence needs.

Farm-level perceptions about changes in climate patterns

The results reveal that most of the farmers in this region have experienced climate alterations. For instance, 54% of the farmers perceived that the temperature appeared to be higher than before while there is ambiguity about rainfall as farmers refer to short periods of time from which they highlighted the increased rainfall intensity. Furthermore, the survey showed that farmers have perceived a decrease in rainfall duration and number of rainfall events (Fig. 2). These perceptions are matching with the preceding findings of trend analysis (Batungwanayo et al. 2020). Climate uncertainty makes farming a risky business, which limits farmers' willingness to invest in it. This risk is probable to increase with climate change and variability within the area.

Impacts of climate change on agriculture perceived at farm level

The assessed impacts of climate change on agriculture activities are summarized in Table 5. The majority of the

Table 4 Socio-economic characteristics of farmers

Variables	Modalities	Frequency	Percentage (%)
Education	None	38	19
	Basic	92	46
	Secondary	56	28
	University	14	7
Farm location	Low land	7	3.5
	Mixed	87	43.5
	Near lake	5	2.5
	On hills	101	50.5
On-farm income (Burundian francs)	0–1000	9	4.5
	1000–5000	17	8.5
	5000–10,000	48	24
	>10,000	126	63
Farming experience (years)	<30	34	17
	30–39	98	49
	40–49	32	16
	>50	36	18
Family size (individuals)	0–3	18	9
	4–6	98	49
	7–10	75	37.5
	>10	9	4.5
Farm size (in hectares)	0–1	59	29.5
	1–5	124	62
	5–10	17	8.5
Have perceived changes in climate	No	14	7
	Yes	186	93
Climate information	No	64	32
	Yes	136	68
Access to credit	No	158	79
	Yes	42	21
Livestock ownership	No	38	19
	Yes	162	81
Have an off-farm source of income	No	166	83
	Yes	34	17
Gender	Female	93	46.5
	Male	107	53.5

surveyed farmers report that unexpected related climate events (i.e., floods and droughts) are indeed occurring, and that these events disrupt their agricultural activities and potentially destroy their farms. The local farmers are concerned by these changes, and the most pronounced statement is that climate change and variability lead to poverty and food shortage (MPS: 5.84, see Table 5). Farmers also express their concern about the rising costs involved in farming for coping with climate factor's effects. They need for instance to look for fertilizers to make the land fertile or to look for other selected seeds that can resist climatic stresses.

Results from Fig. 3a show that most farmers (about 73.5%) perceive that season A (short rain season, ranging from mid-September to December), has been challenged by climate events. That is due mainly to variability in starting of that short rain season as well as dry spells occurrence during that growing period. Such results are also supported by other statements related to the seasonal climate variability in Burundi. Note that agricultural drought magnitude varies more during the short rainy season (SOND) than during the long rainy season (MAM) (Nkunzimana et al. 2021). Figure 3b also suggests that climatic threats cause farming losses between 30 and 80% of respondents.

Farmers' climate change adaptation strategies and constraints impeding farm-level adaptation

The results reveal that there is a reduction in the number of farmers' responses from climate change perception to climate change adaptation. Indeed, for the 96.9% of respondents that have perceived changes in climate, only 92% of the respondents adapt to climate change and variability. This reduction may be associated with various adaptation limitations. Farmers indeed apply various adaptation strategies. Changing crop varieties, planting shade trees, and changing fertilizer application are the most reported adaptations, which are reported

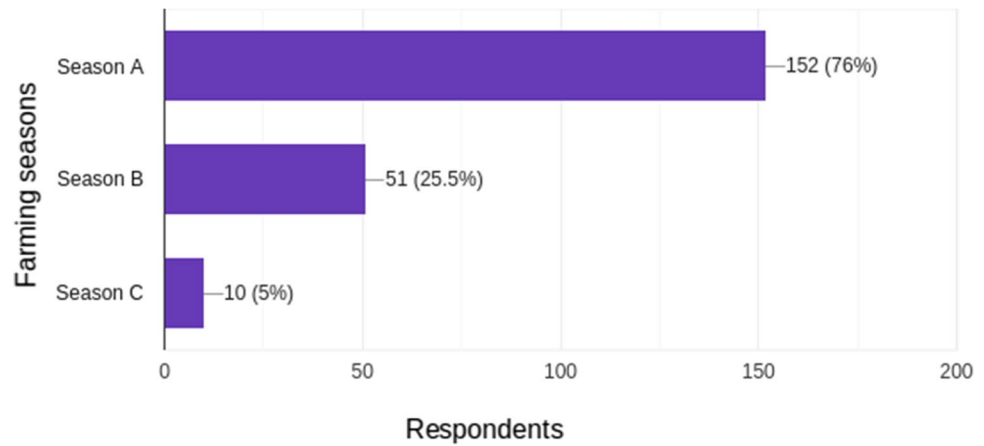Fig. 2 Perceptions of farmers on changes in climate elements/events in the study region

Table 5 Farmers' general perception of negative effects of long-term changes of climate variables on agriculture

| Statement	Extremely severe(7)	Very severe(6)	Severe(5)	Significant(4)	Somewhat significant(3)	Irrelevant(2)	I don't know(1)	WAI	Rank
Poverty and food shortage	100	31	28	28	6	5	2	5.84	1
Rising cost of farming	77	53	30	25	6	5	4	5.69	2
Frequency of floods and farm destruction's	74	35	28	28	16	17	2	5.32	3
Disappearance of vegetation cover	60	54	19	31	17	11	8	5.22	4
Post harvest losses	38	54	48	27	14	13	6	5.06	5
Pest invasion	30	48	53	34	20	7	8	4.9	6
Erosion	41	36	35	39	33	13	3	4.81	7
Prevalence of disease	32	28	51	50	20	14	5	4.7	8
Destruction of roads and homes	43	37	34	25	28	26	7	4.68	9
Death of livestock	26	44	54	25	13	23	15	4.58	10
Extinctions of crop varieties	27	20	39	44	26	26	18	4.14	11
Rural–urban migration	22	16	22	27	16	77	20	3.45	12
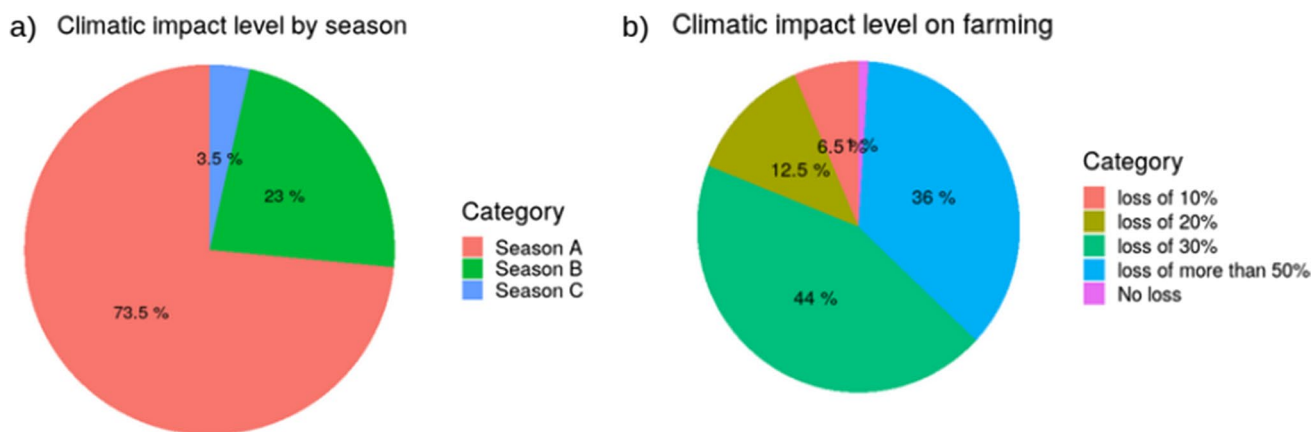
Fig. 3 Seasonal climate impact on agriculture and level of vulnerability

by 69.00, 67.00, and 75.00% of the total sample of farmers respectively (Table 2). The modification of crop variety and the use of shade tree planting as adaptation strategies can be explained by way of the benefit of access and low price of the adaptation approach for farmers, and the public endorsement of these strategies, especially through the governmental reforestation revival (such as the forestry and agroforestry project "ewe Burundi urambaye") (Kaboneka et al. 2020). The lesser use of soil conservation practices is mainly due to the fragmentation of cultivable land in the study area where most of the respondents' households have less than one hectare. Burundi's increasing population density (300 inhabitants/km^2 with an annual growth rate of 2.6%), mixed with soil degradation, has brought about a decline inside the average land vicinity from 1 ha in 1973 to 0.50 ha per family in 2009 (Ndagijimana et al. 2019). Consequently, farmers generally tend to continuously farm the plot of land through the years, resulting in land degradation.

In addition, the results of the study indicate that farmers who perceived a change in the long-term climate and intended to adapt their farms have faced a number of constraints and were therefore unable to adapt. The constraints mostly identified by the respondents were insufficient capital, compounded by high labor costs, and lack of information, followed by resource constraints, lack of knowledge, and other constraints (Table 6).

With respect to the lack of financial resources, it should be noted that the use of agricultural loans in the study region is restricted, as access to micro-credit facilities is restricted. The lack of financial resources completes the lack of access to or availability of other assets on the farm degree. Physical assets include agricultural inputs (improved seeds, fertilizers), farm tools (soil conservation tools, cultivators, harvesters, etc.), and institutional resources (water and soil analysis laboratories).

The lack of information refers to the farmers' lack of access to information, both from private and public sources, on how to change their farming activities. The lack of knowledge about technology has also been found to be relevant in

this study area. According to Simelton et al. (2013), scientists, policymakers, and other stakeholders need to be more attentive to the expertise that farmers and extension agents have so that one can enhance the system and implementation of adaptation guidelines. Building capacity at the local, national, and regional levels is, therefore, a priority for developing countries to cope with climate fluctuations.

In addition, farmers had been asked to pick out the most efficient strategies to enhance effective adaptation to uncertain climatic conditions. They recognized subsidies for agricultural inputs, up-to-date agricultural records services, and enough irrigation water delivery as a necessary manner to enhance the adaptation of agriculture to changing climatic conditions in the study area.

Model significance and goodness of fit

The results for model significance and performance of the fit are summarized in Table 7. It is shown that the overall percentage correctness from the classification table method, for all models, is above 66% confirming that all the models

Table 6 Constraints impending adaptation to climate change

Problems	Garrett score	Mean Garrett score	Rank
High cost of labor and inadequate capital	12,987	64.935	1
Poor access to credit	12,716	63.580	2
Inadequate information	12,385	61.925	3
Limited availability of land	10,896	54.48	4
Length of time required to see results	9597	47.985	5
Education level	9385	46.925	6
Old age	7688	38.440	7

Table 7 Models' significance testing and goodness of fit

Models	(Chi-squared)	Degree of freedom (df)	P-level	Log likelihood	AIC	Nagelkerke R-squared	Model correctness (%)
Changing crop varieties (CCV	45.818	23	0.002	− 94.427	189.036	0.358	78.750
Mixing cropping (MC)	74.522	23	< 0.000	− 107.76	198.653	0.438	77.639
Planting shade trees (PST)	60.037	23	< 0.0001	− 103.378	192.718	0.430	79.503
Crop rotation (CR)	34.978	23	0.03	− 111.345	233.711	0.260	68.944
Soil conservation (SC)	31.292	23	0.003	− 77.419	169.546	0.285	83.229
Changing fertilizer (CF)	66.721	23	< 0.000	− 91.350	161.979	0.500	82.608
Pesticide application (PA)	31.302	23	0.090	− 109.948	234.594	0.237	70.807
Changing planting dates (CPD	37.459	23	0.021	− 110.896	230.334	0.277	72.670
Farming system shift (FSS)	57.280	23	< 0.000	− 69.513	127.745	0.517	90.683

AIC stands for *Akaike information criterion*

are able to predict whether or not a farmer is adapting to climate change and variability. From Table 7, it can be seen that the chi-square values for all fit models are positive and range from 31.292 to 74.522. The associated *p*-values are significant at 5% apart from a model for pesticide application which is significant at a *p* value of 10% and making that the models with predictors fit significantly better than the intercept-only model. So, based on that, it can be said that the null hypothesis (that there is no relationship between the outcome variable and any of the factors) can be rejected.

In addition, the goodness of fit assessed by the use of Nagelkerke's *R*-squared, with values ranging from 0.24 to 0.41, indicates an excellent fit to explain adaptation to climate change variability, in comparison to the null model using only a constant as a regressor. Furthermore, the evaluation ROC curves for our models are shown in Fig. 4 for the 9 logit models, with the blue shaded areas representing the 95% confidence interval for the ROC curves estimated using 2000 bootstrap replications (Abid et al. 2015). The results show that all models perform well with mean values for AUC above 73%, except model (b) which appears to be less adapted to out-of-sample predictions.

Factors affecting the adoption of climate-resilient strategies

We are concerned with characterizing the impact of explanatory variables that affect farmers' choice of adaptation methods. Table 8 presents a summary of the regression results of the nine chosen adaptation strategies. A simple and intuitive interpretation of the coefficients is given here through the use of odds ratios as well as marginal effects (see Table 9).

Gender of farmers

The findings imply that the odds for a male farmer to adopt mixing cropping, planting shade trees, and soil conservation as adaptation strategies are greater than the odds for a female farmer. Moreover, we found that male farmers are less likely to use changing crop varieties, crop rotation, changing fertilizer, pesticide application, changing planting dates, and farming system shifts. These findings are consistent with previously published studies indicating that observed gender differences in coping are attributed to adoption levels and intensity rather than differences in the type of strategies embraced by different gender groups (Adzawla et al. 2019; Ume et al. 2021).

Years of experience in farming

The years of experience of a farmer are mostly dependent on his or her age. The odds ratio for years of experience of farmers is in some cases greater than one, implying that the factor is positively related to the adoption of adaptation practices. From the results in Table 8, having a high number of years of experience as a farmer significantly increases the odds of planting shade trees and rotating crops as an adaptation strategy. Nevertheless, we found significant values of less than one, for mixing crops and changing planting date's adaptation strategies, suggesting that greater age of farmers significantly decreases the odds of using these strategies. This suggests, therefore, that younger farmers are more likely to adopt technologies than their elder peers, as they may be innovative and willing to try new technologies and methods to improve farming (Ali and Erenstein 2017). Thereby, this aligns with what we expect to be an inconclusive sign of the relationship between farmers' age and adaptive strategies.

Education level

Education should be an important factor in accessing advanced information on new and improved agricultural technologies and on increasing agricultural productivity (Elahi et al. 2015; Ullah et al. 2019). However, changing
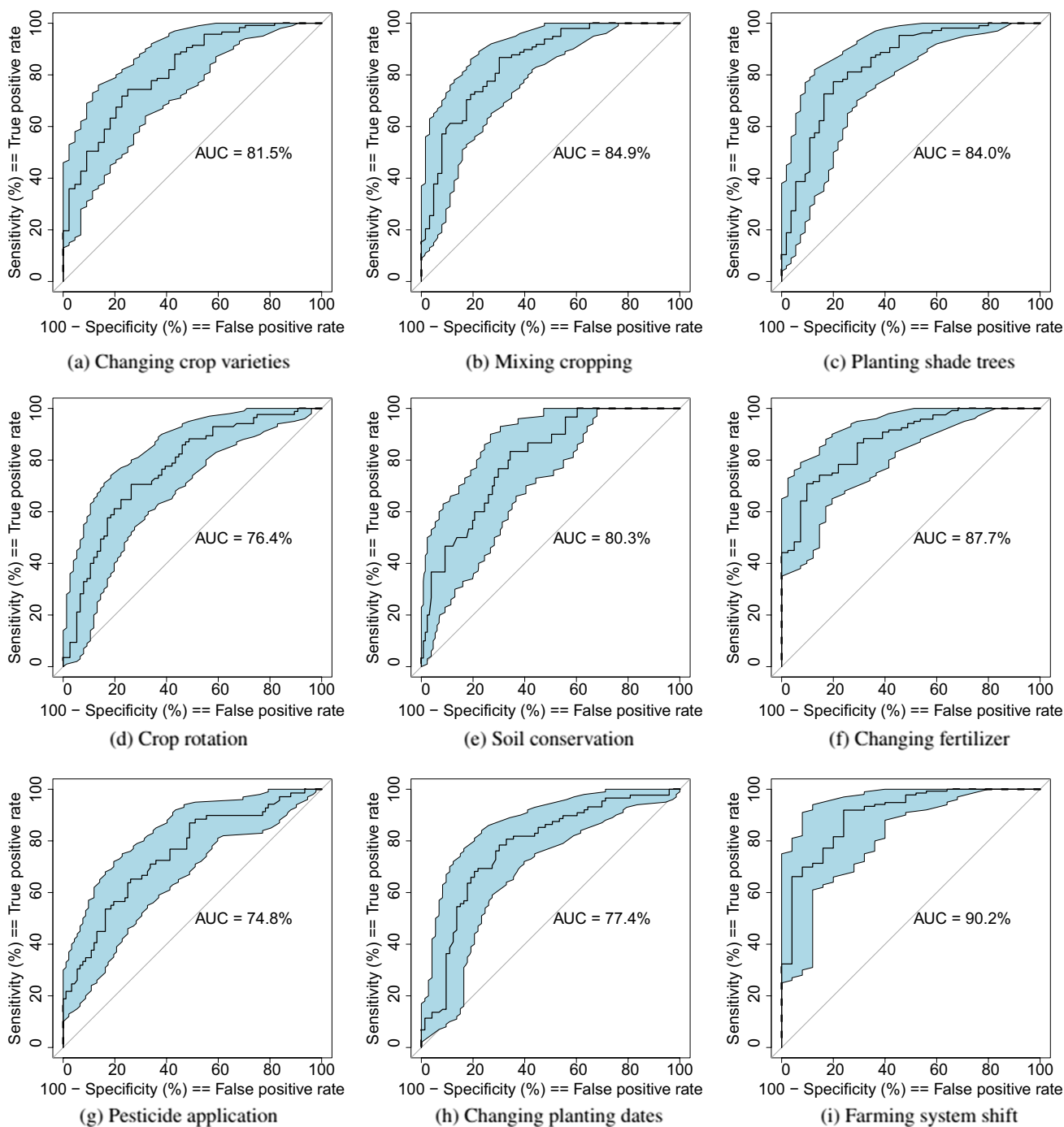
Fig. 4 ROC curves for assessed adaptation strategies. The R package pROC by Robin et al. (2011) was used for computing these graphs

fertilizer and farming system shifts are only adaptation strategies with a positive significant relationship with the education factor. The results suggest that the odds, for a farmer with a high school degree, to change fertilizer and adjust his farming system, are almost 6.5 times greater than the odds for a farmer with no degree or with basic education (Table 8). The average marginal effects indicate that increasing the number of years of schooling

per unit would increase the probability of managing fertilizer use (19.8%) and the farming system (14%) meeting improved technologies (Table 9). These results are in agreement with other studies, for instance, the studies by Deressa et al. (2009) and Ali and Erenstein (2017), according to which there is a significant positive relationship between education and adaptation to climate change and variability.

Table 8 Regression results—odds ratios

Explanatory variables	CCV	MC	PST	CR	SC	CF	PA	CPD	FSS
Gender of farmer	0.430* (0.157,1.103)	2.615** (1.059, 6.813)	1.198 (0.477, 3.022)	0.806 (0.360, 1.775)	1.413 (0.490, 4.195)	0.830 (0.282, 2.436)	0.593 (0.263, 1.297)	0.857 (0.383, 1.902)	0.495 (0.124, 11.82)
Years of experience in farm	0.583 (0.196,2.096)	0.100*** (0.020, 0.287)	4.069** (1.082, 18.71)	2.624* (0.936, 8.053)	0.525 (0.091, 2.397)	0.960 (0.262, 3.84)	1.359 (0.503, 4.031)	0.373* (0.126, 1.057)	2.000 (0.439, 11.54)
Education level	2.701 (0.338, 3.618)	5.031 (1.437, 21.513)	0.375 (0.066, 1.913)	3.798 (0.803, 28.01)	2.463 (0.414, 12.68)	6.800** (1.59, 35.469)	1.308 (0.493,3.713)	1.686 (0.589, 4.524)	6.300** (1.212, 53.00)
Access to climate information	2.292* (0.941, 7.210)	1.000 (0.342, 2.464)	2.613* (0.963, 7.121)	0.883 (0.382, 2.076)	0.482 (0.135, 1.617)	0.720 (0.223, 2.218)	0.650 (0.288, 1.583)	2.621** (1.124, 6.532)	4.600** (1.253, 23.02)
Household size (individuals)	2.067 (0.163,26.66)	0.793 (0.054, 11.108)	1.300 (1.127, 3.383)	0.598 (0.021, 6.142)	0.361 (0.024, 12.00)	4.800 (0.09, 119.25)	0.339 (0.011, 3.782)	3.917 (0.30, 106.21)	36.000** (20.29, 145.0)
Farm size (in hectares)	1.499 (0.420, 3.045)	3.455** (1.283, 9.106)	0.405 (0.068,2.185)	0.939 (0.220, 3.954)	7.148** (1.281, 45.05)	0.640 (0.194, 2.06)	1.326 (0.601, 3.341)	2.594** (1.116, 6.459)	1.700** (0.383, 7.011)
Access to credit	0.302** (0.104, 0.832)	0.688 (0.221, 1.858)	0.748 (0.259, 2.098)	2.276* (0.917, 6.25)	0.608 (1.563, 1.941)	0.750 (0.217, 2.711)	0.917 (0.363, 2.388)	0.985 (0.400, 2.516)	0.260** (0.650, 1.025)
On-Farm income	0.000 (NA, 1.4e+59)	0.332 (0.0171, 4.338)	0.000 (NA, 3.5e+57)	1.552 (0.201, 14.15)	2.703 (0.249, 82.54)	1.300 (0.021, 35.)	0.162 (0.005, 1.706)	1.656 (0.170, 20.48)	0.000 (NA, 4.5e+41)
Off-farm income	4.172* (1.382, 31.22)	1.051 (0.251, 2.722)	1.928 (0.514, 7.109)	0.454 (0.160, 1.372)	1.515 (0.344, 5.087)	4.000** (1.98, 191.80)	2.938** (1.155, 10.72)	1.289 (0.449, 4.214)	2.300 (0.411, 3.584)
Farm location	2.805 (0.201, 40.23)	0.212 (0.004, 2.868)	17.306** (1.537, 48.77)	2.113 (0.302, 14.74)	12.581* (1.143, 320.8)	3.000*** (0.876, 15.43)	6.225* (0.858,82.13)	0.634 (0.064, 5.162)	1.900 (0.067, 65.65)
Livestock ownership	6.745*** (2.447, 40.166)	3.217* (0.773, 9.945)	3.373** (1.023, 10.99)	3.805** (1.317, 13.55)	8.027* (1.035, 163.7)	3.600* (0.957, 15.56)	1.943 (0.712, 7.194)	2.218 (0.758, 7.344)	4.400* (1.068, 28.66)
Climate awareness	2.152 (0.363, 12.95)	10.357** (1.919, 125.54)	3.032 (0.568, 16.56)	2.149 (0.468, 10.40)	0.580 (0.088, 5.100)	15.000** (1.783, 158.48)	6.588* (0.99, 142.46)	0.456 (0.083, 2.197)	4.700 (0.667, 31.90)
N	200	200	200	200	200	200	200	200	200

***, **, and * are significant levels at 1, 5, and 10% probabilities, respectively. Values in brackets are 95% confidence intervals

Access to climate information

Having past, current, and forecast climate information (i.e., temperature and precipitation) available to farmers has a positive and significant effect on the likelihood of changing crop varieties, planting shade trees, changing planting dates, as well as farming system shifts as adaptation methods (Table 8). Farmer's odds of changing crop varieties, changing planting dates, changing planting dates, and farming system shift are respectively 2.29, 2.61, 2.62, and 4.6 times higher than for farmers who do not have climate information. Climate information also increases the likelihood of changing crop varieties (12.8%), planting shade trees (15.2%), changing planting dates (19%), and farming system shift (13%) (Table 9). Thus, access to climate information influences the farmer's adaptation decision. Similar results were reported by Ng'ang'a et al. (2012) and Destaw and Fenta (2021) who found that access to climate information proved to be positive and significantly influenced the implementation of adaptation strategies in East Africa.

Table 9 Marginal effects of binary logistic models for adaptation strategies at the farm level

Explanatory variables	CCV	MC	PST	CR	SC	CF	PA	CPD	FSS
Gender of farmer	−0.117	0.145	0.026	−0.042	0.041	−0.021	−0.102	−0.029	−0.054
Years of experience in farm	−0.085	−0.405	0.195	0.189	−0.074	−0.004	0.064	−0.207	0.055
Education level	0.130	0.226	−0.154	0.252	0.143	0.198	0.054	0.102	0.140
Access to climate information	0.128	0.000	0.152	−0.025	−0.091	−0.037	−0.087	0.190	0.130
Household size (individuals)	0.109	−0.034	0.043	−0.105	−0.130	0.200	−0.348	0.322	0.410
Farm size (in hectares)	0.056	0.205	−0.138	0.084	0.261	−0.052	0.056	0.195	0.390
Access to credit	−0.194	−0.059	−0.044	0.161	−0.057	−0.033	0.017	−0.002	−0.120
On-Farm income	−0.320	−0.164	−0.38	0.090	0.107	0.031	−0.347	0.098	−0.200
Off-farm income	0.175	0.007	0.093	−0.157	0.053	0.209	0.225	0.049	0.590
Farm location	0.161	−0.239	0.475	0.150	0.227	0.622	0.328	−0.089	0.043
Livestock ownership	0.318	0.183	0.199	0.274	0.172	0.162	0.131	0.153	0.140
Climate awareness	0.122	0.373	0.176	0.152	−0.073	0.362	0.305	−0.144	0.150
N	200	200	200	200	200	200	200	200	200

Moreover, extension services or other sources of diffusion that provide information regarding climate are required to accompany farmers in making adaptation decisions. Deressa et al. (2009) and Nhemachena et al. (2014) have for instance found a positive relationship between extension services and households' adoption behavior. Therefore, we can infer that the existence of services that assist and inform farmers about the changing climate is very important for implementing adaptation strategies.

Household size (individuals)

A large family is normally associated with an increased staffing workforce, which could allow a family to carry out diverse agricultural activities. Farming system shift comes out positively associated with family size given the odds ratio greater than one (Table 8), possibly indicating the supply of labor. The estimated average marginal effect for a family size of respondents for farming system shift as an adaptation option was 0.41 which means that if the family member of respondents is increased by one unit, the adoption of farming system shifts would increase by 41%. This result is relevant as we expect family size (and therefore labor supply) to be positively related to the adjustment process and is also supported by other studies, for example, the study by Deressa et al. (2009) where they found a positive relationship between family size and adoption of agricultural technologies or adaptation to climate change and variability. Yet, it is argued by Jiri et al. (2015) that the size of the respondent's household has an impact on the adaptation process. This can be seen in the idea that household size (as an indicator of labor endowment) should be positively related to adaptation, as a larger household means more available workers and, therefore, allows for better adaptation.

Farm size owned (in hectares)

Farm size refers to the total land area held by a farmer's family and can be considered an indicator of wealth, which makes it easier for a family to adapt to climate change. We found that farm size has a significant and positive effect on mixing crops, soil conservation, changing planting dates, and farming system shift as adaptation options (Table 8). Hence, increasing the farm size by 1 ha increases the odds of mixing crops, soil conservation, changing planting dates, and farming system shift by a factor of 3.45, 7.14, 2.59, and 1.7, respectively. A 1% increase in the farm size increases these probabilities of mixing crops, soil conservation, farming system shifts, and changing planting dates by 0.205, 0.261, 0.39, and 0.195%, respectively (Table 9). The results are supported by those of Kabir and Mahbubul Alam (2021) and Destaw and Fenta (2021) who showed a statistically significant association between farm size and farming system shift. As reported by Zerssa et al. (2021), farm size plays a key role in the adoption of new technologies, as farmers with larger farms are more willing to adapt their cropping systems because they can use part of the farm to test new techniques and the other part for conventional practices.

Farmers' access to credit

Access to credit helps smallholder farmers to strengthen their financial resources and they can therefore easily undertake new adaptations (Shikuku et al. 2017). The farmers interviewed confirmed that having access to credit increases the cash flow resources of affected farmers and helps them to deal with adaptation-related transaction costs. However, there are no institutions that offer them farm credit. Few farmers are grouped in cooperatives and

can take out small loans to buy small livestock or build up their farming systems. Access to credit is positively and significantly related to crop rotation and negatively related to changing crop variety and farming system shifts. These results are in agreement with other studies carried out in SSA that have shown the contribution of credit accessibility in determining smallholder adaptation strategies to climate change and variability (Coccolini et al. 2016; Hassan and Nhemachena 2008; Maddison 2007).

The different aspects of assets

On-farm income, off-farm income, and livestock ownership are used to estimate various aspects of wealth. Respondents claimed that on-farm income, as the only source of income for a household, is minimal, but the two other aspects of wealth appear to be of high importance for engaging in coping strategies. We noticed a significantly positive association between off-farm income and changing crop varieties, changing fertilizer, and pesticide application. A farmer who has other sources of income, such as trades and transportation, is more likely to adopt these adaptation options since they require financial inputs. Furthermore, the odds of creating an additional off-farm income-generating activity will increase by 4 times for changing crop varieties, 14 times for changing fertilizer, and 3 times for pesticide application.

Moreover, we found a positive association between livestock ownership and various coping strategies. The likelihood of changing crop varieties, mixing cropping, planting shade trees, crop rotation, soil conservation, changing fertilizer, and farming system shift will increase significantly by at least three times by introducing further livestock. This meets our expectations and line with other studies (Jiri et al. 2015), stating that farmers with different sources of income are more likely to make use of adaptation strategies to face the effect of changes in climate.

Farm location

Crop farms located on the hills, those on the lowlands, and those on the river banks in the marshes do not experience the same effects of climate change and variability. As reported by the respondents, agricultural valleys are formerly flooded by rivers due to extreme precipitation. Yet, farms located on the hills and lowlands are often subjected to inter-seasonal erosive and dry conditions. We have found that having farms in those three locations has a positive relationship with adopting adaptation strategies and increases the likelihood of adapting to the effect of the changing climate. In the study on gender-related variations in perceived climate change impact, vulnerability, and coping strategies in Ghana

by Bessah et al. (2021), it has also been reported that farm location plays an important role in adaptation to climate change impact as resources to be engaged are controlled regarding farm locations.

Climate awareness

Binary logistic regression results show a positive association between climate awareness and most options for adaptation to climate change and variability though some of the coefficients are insignificant. It is also positively related to mixing crops, changing fertilizer, and pesticide application (Table 8). It is also positively associated with changing crop varieties, planting shade trees, crop rotation, and farming system shift, although not significantly. Although farmers are aware of climate change and variability, some do not care about adopting adaptation strategies.
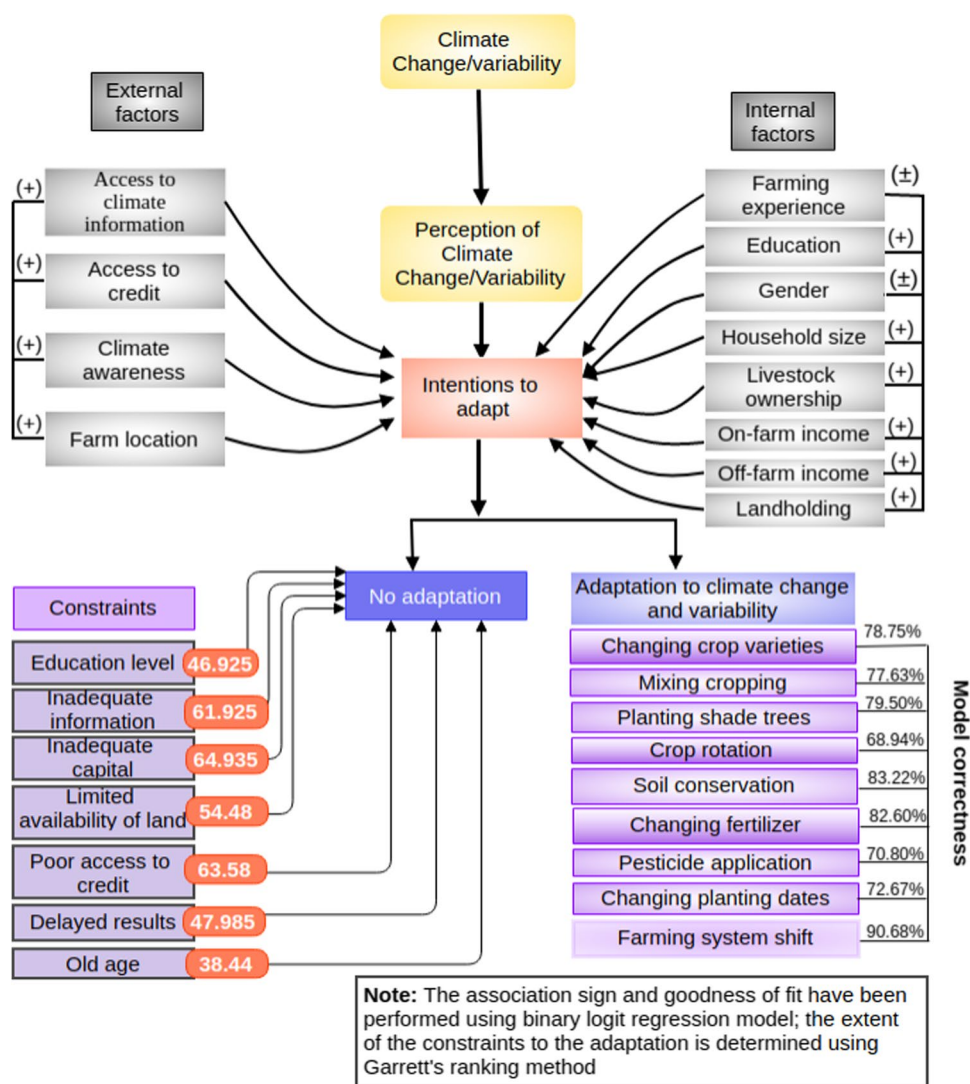
Schematic framework for the farmer adaptation process

To summarize the adaptation process at the farm level, we developed a schematic framework for the farmers' adaptation process based on the analysis of the collected field data (Fig. 5). In this framework, we described the smallholder adaptation process as a three-stage process. First, smallholders perceive the changes in climate scenarios and the associated negative impacts on their agricultural production. These perceptions are determined by a variety of internal and external factors (socioeconomic, environmental, or institutional). Second, farmers intend to take certain actions to adapt to climate change and climate variability, which in turn may be described or influenced by the factors mentioned above. Finally, farmers decide whether or not to adapt to perceived climate change and climate variability. Therefore, farmers' decision to adopt certain adaptation measures may in turn depend on various factors (Table 2). Yet, farmers' decision not to adapt to climate change and climate variability can be explained by various constraints reported by farmers, including those who did not adapt even though they intended to (Table 6).

Conclusion and policy suggestions

The study has used primary farm-level data from the northeastern region of the country to assess farmers' perceptions, adaptive capacities, and strategies taken to cope with the changing climate. The study indicates that most farmers had a perception of changing climate variables (about 96%) during the past three decades. The results also revealed that the different factors considered are significantly associated with the coping strategies adopted by farmers. For instance, farmers

Fig. 5 Schematic framework of farmers' adaptation process (Adapted from (Kumar and Sidana 2018)

Note: The association sign and goodness of fit have been performed using binary logit regression model; the extent of the constraints to the adaptation is determined using Garrett's ranking method

with advanced age, i.e., with farming experience, are less likely to change their crop varieties and planting dates but are more likely to plant shade trees and adopt a crop rotation strategy. In addition, farmers owning livestock and also engaged in off-farm activities are found to be more committed to the use of adaptation strategies to climatic fluctuations. Furthermore, the results of the binary logit model revealed that other determinants such as education, access to climate information, household size, farm size, and access to farm credit are found to be influencing factors for a farmer to engage in shifting his farming system, to cope with the changing climate. Obviously, farmers in the study area have been well aware that climate conditions are changing and that strategies should be implemented to cope with the adverse effects of these changes.

The ranking of farmers' perceptions of the negative effects of long-term changes in climate variables on agriculture highlight the most threats experienced during the last decades. These include poverty and food shortage, the rising cost of farming, and the frequency of floods and farm destruction.

Also, the Garrett method reveals that the poor financial status of farmers, in particular access to credit, is the most perceived constraint confronting adaptation options. Another significant result of this study is that the respondents' statements about the variability of temperature, rainfall, and rainy days in the region are consistent with the statistical analyses, indicating the validity of the farmers' perceptions.

The study presents valuable but primary observations for understanding farmers' perceptions and behavior. However, since the study was conducted in a relatively small geographic area, any generalization of the results would have to be made with precaution. The results from the smallholder level, however, offer both a starting point and a better basis for further research, possibly on large representative scales. Also, the list of possible factors influencing adaptation decisions, discussed in this study, is not exhaustive. Therefore, there is a need to extend the study and extend the present analysis and methodology beyond the study area and include other impacts of climate change and variability on food security.

From the results of this study, it is necessary to address the specific local constraints to adaptation at the farm level. As the main actor in the agricultural sector, the government needs to address the constraints through crop development, availability of credit, facilitation of extension services, dissemination of agronomic and climatic knowledge, improved weather forecasting, and maximum farmer participation in decision-making. As for the farmers, we propose they take more interest in cooperatives, as this will help them to put together the resources and strength to face the effects of climate change. Finally, the key policy message of this study is that decision-makers at different institutional levels are challenged to transform and reorient agricultural systems towards more resilient systems to ensure sustainable agricultural productivity in a changing climate. This requires the identification of optimal interventions so that context-specific solutions are provided at different levels (from local to global).

Declarations

Competing interests The authors declare no competing interests.

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