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Climate change adaptation strategies among smallholder farmers in Senegal's semi-arid zone: role of socio-economic factors and institutional supports

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In dryland agricultural systems, developing appropriate climate-smart technology (CST) options is important to adapt agriculture to climate change and transition toward sustainability, as well as increasing productivity and incomes. This study examines the impact of socio-economic and institutional support on community responses to climate change and the impact of changes in three selected regions of Senegal (Meouane, Thiel, and Daga Birame), which fall within different rainfall gradients. It captures community perceptions of climate change, compares them to long-term meteorological data, and identifies site-specific response strategies. Communities are randomly selected from a list of communities within the target sites. We used a two-stage stratified sampling method to select sample households. First, purposive sampling was conducted to select at least six (6) villages as a cluster within each rainfall gradient. Likewise, the selection of households in each cluster was based on the main value chains of crops grown in the study area, namely groundnut, millet, black pea, and livestock. A total of 145 households participated in this study. Data from surveys conducted during the 2022 post-harvest season were analyzed using descriptive statistics and logit models. The analysis found that smallholders have a comprehensive understanding of climate indicators, including annual rainfall, shortened crop seasons, and rising temperatures, compared to historical data trends. Additionally, the results highlight how farmers view the negative impacts of seasonal rainfall deficiencies (72%), delayed start of the growing season (88%), frequent dry spells (68%), and longer dry spells (76%), which ultimately lead to decreased grain and fodder yields. The logit model also highlights the importance of socio-economic and institutional factors such as access to credit, extension services, agricultural experience, frequency of interaction with extension workers, and access to government subsidies. These factors play a crucial role in farmers' decision to adopt CST. Given the specificity of community contexts, these insights have important implications for guiding policymakers and making it easier to reduce climate risk among smallholder farmers.

KEYWORDS

climate-smart technology, policies, farmers perception, logit-model, climate variability

1 Introduction

Sub-Saharan Africa (SSA) is one of the areas that is most susceptible to climate change and unpredictability (Arneth et al., 2019). These regions currently experience high levels of climate variability and unpredictable rainfall patterns, high reliance on climate-sensitive activities, frequent food shortages and water scarcity, rapid population growth, and a lack of institutional and economic resources to deal with and adapt to climate change and variability (Perez et al., 2015). Climate variability induced by climate change, especially in SSA, is a significant source of danger for smallholder farmers and pastoralists (Fisher et al., 2015; van Ittersum et al., 2016; Stewart et al., 2020). This environmental challenge leads to an increase in mean annual temperatures, more unpredictable rainfall that will likely make water shortages worse, high productivity declines for cereal crops, and an increase in disease, pest, and weed burden on livestock and crop systems (Panthou et al., 2018). Indeed, it had a negative impact on the livelihoods of the rural community since the agricultural system in this region relies heavily on rainfed and smallholder farming systems and offers little investment alternatives such as fertilizers, herbicides, machinery, and irrigation technologies (Haile, 2005; Muzari et al., 2012; Waongo et al., 2015; Hansen et al., 2019; Namatsheve et al., 2020). Crop and livestock production are not being left out of the global effects of climate change, which are pronounced. In these areas, the annual rainfall varies greatly (Araya et al., 2022; Joseph et al., 2023). The country is susceptible to food insecurity since smallholding farming predominated in these areas, which were characterized by low input, less mechanization, and sensitivity to climate changes (Salack et al., 2011; Adiku et al., 2015; Diouf et al., 2019). Numerous variables, such as water stress, poor soil fertility, climate variability and change, and lack of access to better seeds and varieties, inputs, credit, and markets, limit crop productivity (Faye et al., 2018; Ouedraogo et al., 2018; Diouf et al., 2019; Housseini Malam Laminou et al., 2020).

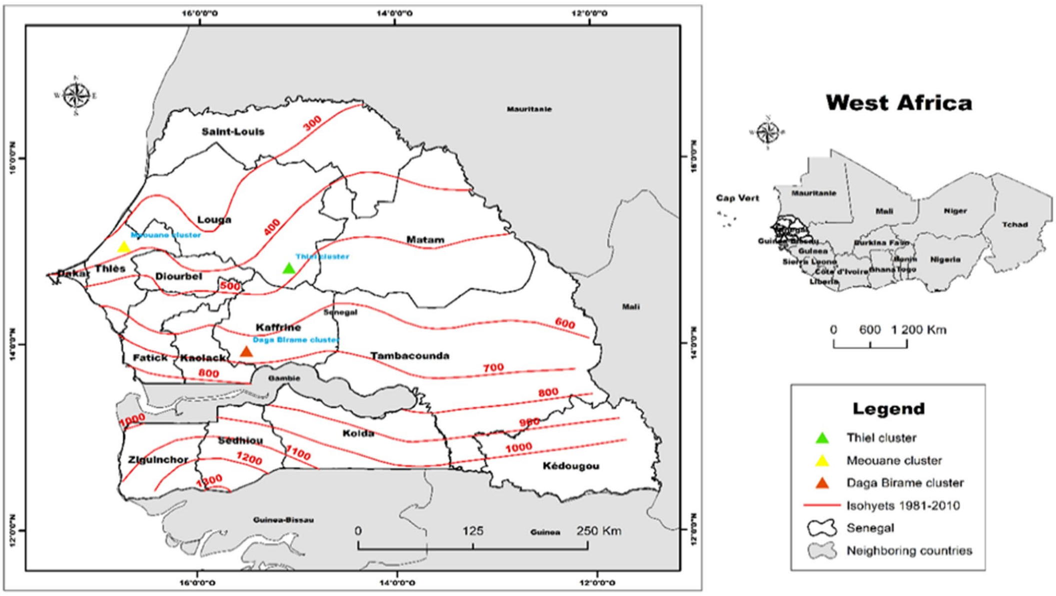
In that, vulnerable households adopt a variety of climate-smart management techniques to deal with crop loss during the rainy season, including millet-cowpea intercropping, millet-groundnut crop rotation, low-cost fertilizer use, such as organic manure, early maturity seed, climate service information, etc. (Adiku et al., 2015; Thornton et al., 2018). Nevertheless, despite the proven effectiveness of certain crop management technologies and approaches, some socioeconomic and institutional determinants influence their adoption from one farmer to another (Liu et al., 2016; Ouédraogo et al., 2023). Indeed, the adoption of innovative technology in the agriculture field to face environmental constraints and climate effects by farmers and their understanding is a theory that combines multidisciplinary factors that influence their decision in an effort to shed light on why certain farmers are capable of utilizing modern technologies while others are not (Ouédraogo et al., 2023). Thus, understanding the reaction and factors that influence farmers' decisions on adaptation strategies may therefore offer a sustainable solution to manage the impact of climate shock on agriculture and livestock systems. Clements et al. (2011) demonstrated how economic, social, and institutional forces interact to influence decisions such as improved seeds or cropping techniques to face climate change. Technologies are given to users with insufficient knowledge of the regional environment in which they function, omitting crucial concerns like market access, credit, extension services, and climate information services (Bosello et al., 2018; Owusu and Yiridomoh, 2021) can reduce the purpose of scaling up within the community. To inform policymakers and decision-makers, in-depth analyses are required to model socioeconomic and institutional aspects. Therefore, several authors have demonstrated that farmers assisting in combined climate service mainstreaming (Nordey et al., 2017; Bedeke et al., 2019; Naab et al., 2019) improved farmers' capacity to cope with climate effects. The key question is do these socioeconomic and institutional elements have an effect on the adoption and comprehension of climate-smart management practices?

Potential chances for efficient scaling choices can be found by considering the strategy for promoting climate-smart technologies while taking into account socio-economic aspects, integrating technological packages, and institutional enabling factors (Kassa, 2013; Totin et al., 2018; Gebru et al., 2020). While several earlier studies (West et al., 2008; Akponikpe et al., 2010; Traore et al., 2014; Alvar-Beltrán et al., 2020; Sraku-Lartey et al., 2020; Diarra et al., 2021) have provided evidence for community perception and their adaptation strategies throughout SSA, this paper aims to advance knowledge by examining the impact of socioeconomic and institutional factors on household coping strategies in three locations of semi-arid area in Senegal. It further assesses farmers' perception of climate variability and change compared to historical weather data as well as its impacts on crop and livestock systems. The right understanding of climate indicators within the community might be one of the key factors that can drive their decisions in cropping and livestock systems. This however explains the importance of this study which aims to complement efforts made so far, (i) to compare farmers' understanding of climate variability and change at the community scale for better farm-level interventions and (ii) to investigate the adaptation strategies and determinants which drive smallholder farmers decisions on CST adoption.

2 Materials and methods

2.1 Study area

The study locations include Meouane (15° 3′ 59.76" N/16° 45′ 26.28" W) and Daga Birame (13° 56′ 39.84"N/15° 30′ 47.88" W) located within the peanut basin while Thiel (14° 52′ 12" N/15° 5′ 0.24" W) is located in the pastoralism-dominated transition zone (Figure 1). For Meouane and Thiel locations, the rainy season begins in late June or early July and ends in late September or early October. Daga Birame location begins in early June and ends in late October. In a good year, the Meouane community often receives at least 300 mm of precipitation, and in a below-average year, less than 250 mm. For Thiel, the yearly average varies between 300 and 500 mm in a good year and a below-average year, respectively. The annual average for the last study area, Daga Birame, ranges between 400 and 600 mm in good year and below-average years. All these three areas fall within the semi-arid zone with the Sahelo-Sudanian climate conditions primarily used for livestock and crop systems such as millet, peanut, and cowpea being common. Globally, climate change is having a great influence and impact on crop and livestock production in those areas (Joseph et al., 2023). The natural vegetation is a tree and shrub savannah with an understory of annual and perennial grasses in a complex mosaic. Soils are poor, of sandy texture, commonly called *Dior* soils (Araya et al., 2022; Faye et al., 2023). The community is made up of mainly



Source: ANAT / ANACIM / FIELD SURVEY
Project: WGS 84 Lat/Long
Produced by Inoussa ZAGRE
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FIGURE 1
Map of Senegal showing the study area.

farmers who practice a small-scale mixed farming system raising livestock and growing food and cash crops on small plots of land (McClintock and Diop, 2005). The major crops grown in the area include pearl millet, groundnuts, and cowpea. Monoculture is the dominant farming system (Adiku et al., 2015). Also, the agroforestry system growing crops and preserving several acacia trees (bushes) such as *Faidherbia albida*, *Guiera senegalensis*, *Piliostigma reticulatum* and Caju nut, especially in the old peanut basin where is located Meouane cluster, one of the study areas (Badiane et al., 2001).

2.2 Sampling procedure and sample size

The current study is based on data from a cross-sectional household survey of farmers who raised crops and livestock in the three rainfall gradients areas during the post-harvest season (November and December 2022). This study considered the definition of a household as "a group of people living in the same dwelling space who have at least one common plot together or one income-generating activity together and who acknowledge the authority of a man or woman who is the head of household" given by Beaman and Dillon (2012).

These locations were defined based on the different rainfall patterns and land use systems. Furthermore, the choice of these locations was motivated by the implementation of a technologies package by the national research institute, national extension office, and AICCRA project (Accelerating Impacts of CGIAR Climate Research for Africa) to showcase the performance of climate-smart management practices such as of improved varieties, efficient use of fertilizer (micro-dose) and climate service information (CSI). These three locations are therefore located in a transition zone between the sylvo-pastoral zone (Thiel) and the peanut basin-new zone of intensive peanut farming (Daga birame) with the old peanut basin (Meouane) migrants in a pastoralist context taking into account both concerns, namely the difference in rainfall pattern and land use system. The communities were randomly selected from a list of communities located within the target locations. In that case, two-stage stratified sampling techniques were used to select sample households. First, purposive sampling was applied to select at least six (6) villages in each rainfall gradient considered as a cluster. In fact, in the Daga Birame cluster, the concerned villages were Nandjigui, Darou Nandjigui, Keur Sawely, Simbara, Mbeuleup, Diatta Fakha, and Daga Birame (Ndjognik district). In Meouane cluster, it was Meouane Meghor, Ndiane, Mborine, Ainoumane, Ndombil, and Ndiouffene (Meouane district). In the last cluster Thiel, Thiel Serere, Darou Nahim Danedji, Touba Danedji, Mola, Touba Ndiagne, and Hodiolde-3 (Thiel district) were concerned. Yet again, from among each cluster, the selection of households was based on the main crop values chain grown across the study areas namely peanut, millet, cowpea, and livestock. This information was carried out based on the workshops with the various stakeholders (two lead farmers per village, extension agents, and researchers) which were prior held in each cluster before the beginning of the rainy season 2022 by the AICCRA project. These workshops raise the main crop grown in these locations. The sample size for each cluster was purposely selected for this study based on a study by Ouedraogo et al. (2018) entitled "*Closing the Gap between Climate Information Producers and Users: Assessment of Needs and Uptake in Senegal.*" In this study, they came out with 100 surveyed to assess CIS in two regions (Louga and Diourbel). Also, this size is based on the studies of Ouédraogo et al. (2019) in Burkina Faso and Moutouama et al. (2022) in northern Benin where the sample was 30 smallholder farmers per district to assess their perceptions and adaptation strategies. Furthermore, the sampling size was deeply discussed by Waha et al. (2016) where they raised that to minimize the sampling errors, the number of sampling units per district should be between 30 and 60. Following the sampling approach for the assessment of climate adaptation strategy and climate information service at the community scale by the previous studies mentioned above, the sample size was first set to 90 households for the three clusters considered in this study. Oversampling was done to increase the sample to 145 households over the three clusters. Roughly 48, 49, and 48 households were, respectively, selected in the Daga Birame, Meouane, and Thiel clusters taking into account our logistic capacity.

2.3 Data collection

2.3.1 Survey data

The sample data was gathered based on several socioeconomic and environmental characteristics, and it contained important details on farmers' perceptions of climatic variability and change as well as their coping strategies. Climate variability is one of the factors influencing the variation in crop growth, development, and yields from year to year (Soler et al., 2008; Akinseye et al., 2023). To capture the perception of this variability by farmers, questions about their observations of climatic indicators over the previous 30 years, including annual rainfall, temperature, the onset and cessation of the growing season, and its length were asked. In fact, the good understanding of climate changes and its impacts could be a key for leading the adaptation of the majority of farming methods. To address that, questions about climate-smart management practices' adoption were adequately asked. As a definition, climate smart-smart management involves a range of practices aimed at enhancing agricultural productivity, improving resilience to climate change, and reducing greenhouse gas emissions (Partey et al., 2018). These practices help farmers cope with changing climate conditions and improve their resilience to climate change. The practices recorded in SSA are various and vary from one area to another based on farmers knowledge and environmental conditions (Moutouama et al., 2022). The common set addressed in this study are related to crop operation, improved crop varieties, improved soil management, and water-harvesting techniques. Therefore, to test the quality and farmers' understanding of the questionnaire, one village was previously selected with 10 heads of households in each location to ascertain and validate the effectiveness of the questionnaire.

2.3.2 Climate data

Long-term daily rainfall, minimum and maximum temperatures, and other climate indicators were downloaded for the research areas between 1981 and 2021 in order to validate farmers' observations and common experience of the indicators. The MERRA2-Land (NASA's Modern-Era Retrospective Analysis for Research and Applications) meteorological data were downscaled for each location (Rienecker et al., 2011; Kumar et al., 2021). The dataset is saved with a horizontal resolution of 0.25° 0.25° (~25 km), which is deemed appropriate because the variation in weather data over a limited area is generally minimal. Additionally, this resolution range is appropriate for our investigation because it includes all relevant villages in each location. To access this dataset, the Google Earth Engine user interface[1] and geographic coordinates were used.

2.4 Conceptual framework

To appreciate the influence of the factors (Table 1) on farmers' decisions, the different types of models namely linear probability, Logit, and Probit models were used by early studies (Ibitoye, 2011; Kassa, 2013; Gadédjisso-Tossou, 2015; Diallo et al., 2020; Gebru et al., 2020; Sanfo et al., 2022). Therefore, according to Greene (2012), the Logit model is more robust and more explanatory since it does not follow the normal distribution which is suitable for adoption studies in our case. In that, by using the Binomial Logit model, we focused on social, economic, and institutional factors at the household and community level (Patnaik, 2021) to understand their impact on farmers' perceptions of climate change, adoption of improved variety as a climate-smart practice, and ability to adjust crop operation during the growing season. Thereby, the questions were asked to get the binary responses. Related to climate-smart management practices, we targeted the adoption of improved varieties. In that, the question was addressed to know 1 = if farmers use improved varieties in their farming system to cope with climate variability or 0 = if otherwise. Furthermore, crop operation adjustment during the growing season by farmers was defined 1 = if the farmers agree that they adjusted the crop operation according to any information or support compared to their first plan at the beginning of the growing season and 0 = if they do not. On the other hand, the climate change perception of farmers was also categorized as 1 = if farmers agree based on their experience that there is a change in climate conditions and 0 = if they do not agree (Ntim-Amo et al., 2022).

2.5 Data analysis

The primary analyses were conducted in this study using StataCorp (2021) were descriptive statistics such as percentages and modeling analysis. The household was seen as a random variable. The Logit model was used to examine farmers' perceptions of climate change and their adoption of smart management practices. It examined whether farmers perceived change or not, adopted improved varieties as a climate-smart strategy or not, and adjusted their crop operation over the growing season or not.

The farmers' perception and adoption of adaptation practices will likely be influenced by household, farm, and institutional variables. The Logit model takes into account the link between a set of binary or continuous independent variables and a binary dependent variable. The statistical significance of the Logit model's coefficients is necessary for their interpretation. The corresponding explanatory (independent) variables in Table 1 and the dependent variables were (i) improved variety adoption as a climate-smart practice, (ii) adjustment of crop operation during the growing season as a climate-smart practice, and (iii) Farmers' perception of climate change. For these dependent

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[1] https://app.climateengine.com/data

TABLE 1 The factors determined as likely to have an impact on the decision to adopt climate-smart management practices and understand climate change.

Variables	Type	Description
Age	Quantitative	Respondent's age (years)
Gender	Qualitative	Gender of the respondent—male or female
Education level	Qualitative	Respondent's years of formal education (years)
Credit access	Qualitative	The farmer benefits from credit for investment
Access to extension service	Qualitative	Respondent has access to the extension agent's advice
Farmland erosion	Qualitative	Respondent perceives the state of erosion of a farm
Soil fertility	Qualitative	Respondent perceives the state of the fertility of a farm
Farmer association membership	Qualitative	The farmer belongs to a local association.
Experience in farming	Quantitative	Years that the respondent has worked in agriculture
Number of contacts with an extension agent	Quantitative	Number of farm visits of extension agent
Distance to extension office (km)	Quantitative	The distance from the farmer to the extension agent's office
Rainfall gradient	Quantitative	The three locations with their average rainfall amount
Access to Government subsidies	Qualitative	Respondent has access to Government subsidies such as improved seeds
Access to climate information	Qualitative	Respondent has access to climate information from the meteorological agency during the growing season

variables, the questions were set to get the closed response (1 = yes or 0 = no) which implies the use of the binary logit model. The direction and severity of the influence are reflected in the coefficient's magnitude. A positive correlation with the likelihood of adoption is indicated by positive coefficients, whereas a negative correlation is indicated by negative coefficients. The formula is given by Greene (2003):

$$\log\left(\frac{1}{1-P}\right) = \beta_0 + \beta_1 x \quad . \tag{1}$$

Where log represents the natural logarithm.

p is the probability of the event (with 1 = yes, 0 = no) and x is an independent variable listed in Table 1. β_0 is the intercept (constant). β_1 is the coefficient associated with the predictor variable x. log (1/1−p), is the log-odds or logit of the probability p.

Furthermore, Instat+ software, version 3.36, was used to statistically analyze daily rainfall and temperature data to determine the onset and the cessation of the rainy season as well as the length of the growing season. The onset was determined by Sivakumar, (1988) to be the day following May 1st with 20 mm of rain totaled over three straight days when no dry spell within the following 30 days surpassed 7 days, which is appropriate for the Sahelian zone (Akinseye et al., 2016). The cessation was defined as the first day after the first of September when the climatic water balance is less than or equal to 0.5 mm, or when the soil has no water in it down to a depth of 100 cm with daily potential evapotranspiration of 5 mm given by previous studies which has been widely used over Sahelian zones (Lodoun et al., 2013; Akinseye et al., 2016). The length of the rainy season for a particular year is calculated from the difference between the cessation and onset of that year. Sivakumar (1992) states that a threshold rainfall of 0.85 mm was utilized in these computations to identify a rainy day. In addition, the Heavy Rain Days (HRD) were computed for a better understanding of rainfall trends across the three locations and defined as days with at least 20 mm of precipitation (Alvar-Beltrán et al., 2020). To further understand the trends in rainfall, maximum and minimum temperature, cropping season onset, cessation, and length during the previous 41 years, the T-test analysis of regression in R software was performed.

3 Results

3.1 Socio-economic characteristics and farm typology

The results of the survey in Table 2 showed that the majority of farmers in the three locations (Daga Birame, Meouane, Thiel) were men. Most of them are doing crop and livestock farming (97.93%). The main crops grown in these locations are peanuts (97%), followed by millet (95%) and cowpea (64%). Maize, cassava, rice, water melon, sesame, sorghum and garden (Bell pepper, sweet eggplant, bitter eggplant, tomato, sorrel) are grown by less than 50% of the farmers. Most of them aged between 41 and 75 years (76.55%) and the average household size was 14 members. Their level of education was satisfactory for the study area (11.04% have a primary, secondary, or university education, and 74.48% have other forms of education). Furthermore, 48.96% of them claimed to be affiliated with a group of organizations and 93.79% are landowners.

3.2 The perception of farmers toward changes in temperature, wind speed, and rainfall patterns

Table 3 displays farmers' opinions on how various climate indicators have changed across the three zones. The findings revealed that 62% of farmers' respondents across the three research areas had noticed an increase in rainfall. 68% of farmers' respondents agreed that the rainy season starts late and 67% agreed the rainy season stops early. Only 37% of farmers who responded to the survey confirmed a rising tendency, whereas 60% of farmers confirmed the shortening of the rainy season over time. Most respondents noticed changes in the temperature; across the study areas, 84% of farmers who

TABLE 2 Socio-economic characteristics of respondents.

Characteristic	Modalities	Value
Gender	Male	89.66%
	Female	10.34%
Major Activity	Agriculture/Breeding	97.93%
Secondary activity	Masonry	1.38%
	livestock trade	0.69%
Crops grown	Peanut	97%
	Millet	95%
	Cowpea	64%
	Maize	48%
	Cassava	33.1%
	Rice	4.82%
	Watermelon	4.82%
	Garden (Bell pepper, sweet eggplant, bitter eggplant, tomato, sorrel)	3.44%
	Sesame	0.68%
	Sorghum	0.68%
Education level	Illiterate	14.48%
	Primary school	8.28%
	Secondary school	2.07%
	University	0.69%
	No formal education	74.48%
Age (Years)	25–40	23.45%
	41–50	31.72%
	51–60	33.11%
	> 60	11.72%
	Average age	49.02
Affiliation to organization	Yes	48.96%
	No	51.04%
Landowner	Yes	93.79%
	No	6.21%
Size of the household	Average Daga Birame	15
	Average Thiel	14
	Average Meouane	13
	Average over the three locations	14

responded to the survey confirmed that the temperature has risen in recent years. Furthermore, 72% of farmers' respondents claimed increased wind intensity. The investigation within each rainfall gradient revealed that in Daga Birame location, farmers perceived an increased trend of annual rainfall amount (84%), rainy season length (77%), temperature (92%), and wind intensity (50%). The majority of these farmers (90%) concurred that the rainy season started early and ended late (96%). In Thiel, farmers highlighted an increased trend of annual rainfall amount (100%), temperature (98%), and wind intensity (75%) while they agreed that the trend of rainy season length is decreasing (68%). In fact, they asserted a delayed trend for the start of the rainy season (100%) and an early stop (100%). The farmers in Meouane noticed that both the amount of yearly rainfall (96%) and the length of the rainy season (94%) were trending downward. Related to temperature and wind intensity, they claimed an increasing trend, respectively, 67 and 96%. A majority of them (96%) also concurred that the rainy season started later than usual and ended earlier than expected (96%).

3.3 Farmers' perspectives on the weather variabilities on livestock and crop systems

These weather anomalies, which included a late or earlier start to the rainy season, low seasonal rainfall, and the occurrence of dry spells at any point during the crop growing season, strong winds, and high temperatures, were connected to the seasonal pattern of rainfall (Table 4). The findings demonstrated that farmers understood how various weather-related scenarios might affect their crops and livestock systems. Table 4 below lists the common impacts emphasized by farmers. The main effects of weather anomaly scenarios on crop and livestock systems are what farmers along the three rainfall gradients observe.

3.4 Validation of farmers' perception of climate indices using long-term meteorological data

To support farmers' perceptions of climate indices, a T-test analysis of regression of climatic parameters data over the previous 41 years was performed (Table 5). The seasonal rainfall varied with higher inter-annual variability observed in Thiel (CV = 27%), followed by Meouane (CV = 26%) while the lowest value was observed in Daga Birame (CV = 22%). Moreover, Figure 2 displayed this variability across the three locations. The start and end of the rainy season were calculated using the number of days in the year (DOY). This suggests that a rise in DOY causes the onset to be delayed and a fall in DOY causes the onset to be earlier. In terms of cessation, an increase in DOY results in a later rainy season cessation, and a decrease in DOY results in a rainy season that ends sooner. Except for the maximum temperature, which exhibited negative tendencies but no statistically significant trend, Daga Birame location showed positive trends for onset, cessation, minimum temperature, mean temperature, rainfall amount, and length of the rainy season. The minimum temperature and the end of the rainy season were among the positive trends that at a 95% confidence level were statistically significant. The Meouane (Table 5), onset, cessation, minimum temperature, amount of rainfall, and length of the rainy season all exhibited positive tendencies in the analysis. The maximum and mean temperatures showed a downward trend. However, neither a positive nor a negative trend is statistically significant. The results for the final location, Thiel, revealed positive trends for all the parameters, and a statistically significant trend was noted for the minimum temperature and the amount of rainfall (Table 5). These findings showed that even if the tendency is not statistically significant, the positive trend of onset and cessation across the three locations indicates that the rainy season tends to be short. Figure 3 displayed the pronounced variability of onset, cessation, and

TABLE 3 Perceptions of farmers in Meouane, Thiel, and Daga Birame (%) regarding changes to several climate indices.

Daga Birame				
Climate indicators	Increase	No change	Decrease	No opinion
Annual precipitation	84	6	10	0
Length of cropping season	77	6	17	0
Temperature	92	6	2	0
Variation in wind speed	50	15	33	2
	Late	No change	Early	No opinion
Onset of the rainy season	8	2	90	0
Cessation of the rainy season	96	2	2	0
Thiel				
Climate indicators	Increase	No change	Decrease	No opinion
Annual precipitation	100	0	0	0
Length of cropping season	30	2	68	0
Temperature	98	2	0	0
Variation in wind speed	75	15	10	0
	Late	No change	Early	No opinion
Onset of the rainy season	100	0	0	0
Cessation of the rainy season	0	0	100	0
Meouane				
Climate indicators	Increase	No change	Decrease	No opinion
Annual precipitation	4	0	96	0
Length of cropping season	6	0	94	0
Temperature	67	2	31	0
Variation in wind speed	96	0	4	0
	Late	No change	Early	No opinion
Onset of the rainy season	96	0	4	0
Cessation of the rainy season	4	0	96	0
Over the three locations				
Climate indicators	Increase	No change	Decrease	No opinion
Annual precipitation	62	1	37	0
Length of cropping season	37	3	60	0
Temperature	84	4	12	0
Variation in wind speed	72	10	17	1
	Late	No change	Early	No opinion
Onset of the rainy season	68	0	32	0
Cessation of the rainy season	33	0	67	0

length of rain over 41 years for all three locations. Furthermore, the coefficients of variation (CV) of these climate indicators were computed and highlighted all the CV ranks between moderate to high variability. Indeed, across the three clusters, the CV of onset was medium, respectively, in Daga Birame (8.06), Meouane (8.3), and Thiel (9.45). Regarding the CV of cessation, they were also a medium in Daga Birame (4.93), Meouane (7.27), and Thiel (6.55). Consequently, the results indicated substantial variability in Daga Birame (20.04), Meouane (40.68), and Thiel (30.15) with regard to the CV of the length of the rainy season.

3.5 Adoption measures in response to change

Table 6 shows that the farmers in the three locations used different adaptation measures to deal with climate unpredictability. This includes the use of improved varieties, rotation with leguminous, shifting the date of sowing, crop diversification, use of organic manure, improved animal race, efficient use of inorganic fertilizer, Farmer Managed Natural Regeneration (FMNR), mulching, and irrigation. Farmers in the Daga Birame primarily use improved varieties (65%),

TABLE 4 Farmers in the Meouane, Thiel, and Daga Birame zones' assessments of how weather anomalies affect crop and livestock systems.

Weather indicators	Scenario	Impact	Frequency
Amount of seasonal precipitation	Deficit	Crop water shortage leading to decreased yield	72%
Onset	Delayed	Loss of yield due to late sowing	88%
		Lack of grain maturation and filling	90%
Dry spells near the end of the season or an early cessation of the season	Frequent	Loss of productivity due to crop drying out and insufficient grain filling and maturation	68%
		fodder shortage	36%
Extended dry spells in the early stages of the rainy season	Prolonged	Loss of seedlings due to a lack of water	39%
		Crop growth delay leading to decreased yield	76%
Strong wind	Strong	Causes soil erosion, which reduces soil fertility	44%
		Crop fall resulting in yield loss	49%
High temperature	High	Crop drying out, which reduces yield	30%
		More crop water is required, and pastoral boreholes are drying up earlier	39%
		Lead of animal disease	32%

rotate with leguminous (55%), and alter planting dates (55%). In the Thiel, farmers primarily used rotation with leguminous (98%) and crop diversification (76%) as well as shifting the date of sowing (46%). In Meouane, the findings revealed that farmers use more Farmer Managed Natural Regeneration (FMNR; 96%) than any other strategy, along with shifting the date of planting (71%), to deal with weather fluctuation during the cropping season. Otherwise, more analysis was conducted to quickly record farmers' responses when they learn about a climatic occurrence, such as an increasing dry spell. According to the findings, 60% of farmers in all three areas reported that they had adjusted their crop operations as a result of the climatic information they received during the rainy season. However, apart a few farmers (5%) who mentioned utilized irrigation with solar energy systems, none of them have claimed to practice rainwater harvesting practices such as half-moon, *zaï*, and runoff water collection basin.

3.6 Small-scale farmers' expectations and the variables influencing their demand for climate-smart management techniques

The Logit model described in equation (1) was used to analyze how socioeconomic and institutional factors affected farmers' perceptions of the need for smart management practices as described in Table 7. The dependent variables in this model were the household's adoption of improved varieties as a climate-smart management method, adjustment of crop operation during the growing season, and perception of climate change, in that order. The probability estimates of the results of the logit model demonstrate that the adoption of improved varieties as a climate-smart management technique has been strongly influenced by six factors at 1, 5, and 10%. The likelihood is influenced by access to credit, extension service, the frequency of extension agent visits, and access to government subsidies. Farmers' perceptions of soil erosion and the distance to the extension office have an unlikely negative impact at a 5% significance level. The model showed that a farmer's perception of soil erosion level, and farming experience effect positively the changing of crop operation at a 5% significant level with regard to a farmer's ability to adjust crop operation during the growing season. Farmers' knowledge was positively correlated with access to government subsidies in relation to farmers' impression of the changing climate at a 1% significance level.

4 Discussion

4.1 Comparison of farmers perception on changes in temperature and rainfall patterns with meteorological observations

Climate observations are reflected in survey results on how certain farmers perceive historical climatic changes. The majority (62%) of farmers in the three locations agreed that the amount of rainfall was increasing. Although the trends were not statistically significant, the meteorological data showed a slightly increased amount of rainfall, which supported this perception. This slight increase in rainfall amount might be due to the increase in number of heavy rain days (HRD) recorded across the three locations (Ibrahim et al., 2012). In Daga Birame, the trend was statistically significant ($p = 0.027$) while in Meaoune and Thiel, there were not statistically significant. This is in line with Ibrahim et al. (2012), who predicted an average 15% increase in the number of intense rainfall events. Toukal Assoumana et al. (2016) and Traore et al. (2013) reported a slight increase in rainfall during the past decades, respectively, in Niger and Mali. This finding highlighted that in Sahel zones, the key constraint of farmers is not usually the amount of rainfall declining over time, but rather the great year-to-year unpredictability of rainfall in this area (Traore et al., 2013; Akinseye et al., 2016). This view is consistent with time series daily rainfall data analysis, which demonstrated the highest variability. For each location (Daga Birame, Meouane, and Thiel), the coefficient of variation (CV) values was 22, 26, and 27%, respectively (Table 4). Additionally, Figure 2 illustrates this variation along the three rainfall

TABLE 5 T-test analysis of the slope of climatic parameter regression from 1981 to 2021 for the locations in Daga Birame, Meouane, and Thiel.

Parameters/Area	Unit	Mean (1981–2021)	Trend Unit (slope)	*p*-value
Daga Birame				
Maximum temperature	°C	35.2	−0.003	0.65
Minimum temperature	°C	21.3	0.012	**0.01**
Mean temperature	°C	28.2	0.004	0.50
Onset	DOY	181	0.01	0.95
Cessation	DOY	295	0.4	**0.03**
Rainfall	mm	716	3.119	0.13
Length of the cropping season	Days	114	0.004	0.50
Number of Heavy Rainy Days (HRD)	Days	4.46	0.09	**0.02**
Coefficient of variation of rainfall	Constant	22%		
Meouane				
Maximum temperature	°C	32.2	−0.01	0.12
Minimum temperature	°C	21.0	0.007	0.13
Mean temperature	°C	26.6	−0.001	0.78
Onset	DOY	205	0.19	0.39
Cessation	DOY	277	0.43	0.10
Rainfall	mm	473	2.134	0.18
Length of the cropping season	Days	72	0.2361	0.54
Number of Heavy Rainy Days (HRD)	Days	3.04	0.0439	0.24
Coefficient of variation (rainfall)	Constant	26%		
Thiel				
Maximum temperature	°C	36.2	0.001	0.86
Minimum temperature	°C	21.7	0.019	**0.0003**
Mean temperature	°C	29.0	0.01	0.08
Onset	DOY	194	0.28	0.25
Cessation	DOY	282	0.38	0.12
Rainfall	mm	533	4.156	**0.02**
Length of the cropping season	Days	88	0.1	0.77
Number of Heavy Rainy Days (HRD)	Days	3.07	0.038	0.18
Coefficient of variation (rainfall)	Constant	27%		

The statistically significant values are in bold.

gradients. The three locations' greatest CV values suggest a more pronounced inter-annual variability based on these highest values. As a result, earlier research has demonstrated that the Sahelian zone recorded a high degree of rainfall variability (Akinseye et al., 2013, 2016). This indicates that one of the major challenges that is becoming increasingly evident in the Sahelian zone and harms agriculture, and livestock systems is rainfall variability.

Additionally, the findings indicated that farmers have a proper awareness of when the cropping season begins and ends. Analysis of long-term rainfall data on the onset over the previous 41 years revealed a positive pattern that indicates a late start to the rainy season. In all three sites, 68% of farmers felt that the rainy season had been delayed. The positive trend indicates that the end of the cropping season occurred earlier than expected. This result supports what farmers believe (67%). Even though both patterns of the onset and cessation

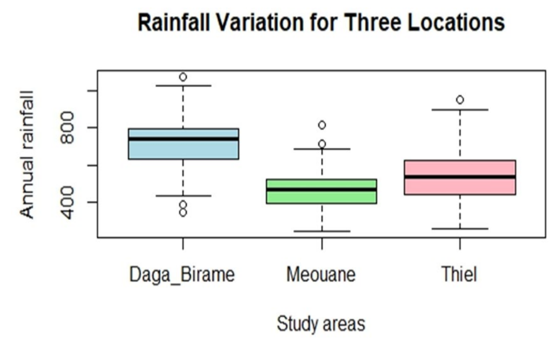

FIGURE 2
Rainfall variability across the three locations.

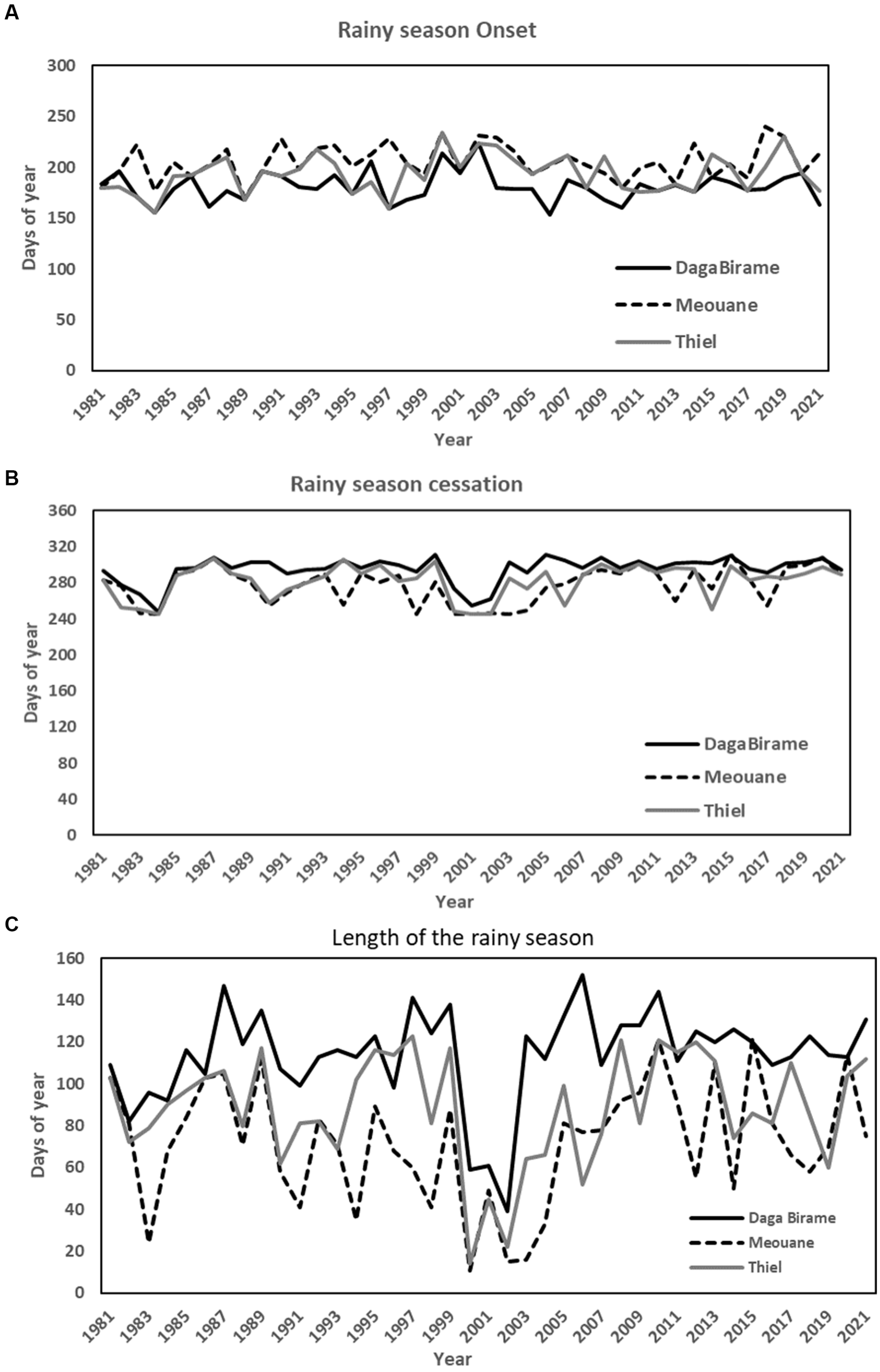

FIGURE 3
Variability in the onset **(A)**, cessation **(B)**, and length **(C)** of the rainy season in the Daga Birame, Meouane, and Thiel between 1981 and 2021.

of the rainy season tend to shorten the growing season, which is consistent with farmers' perceptions, they were not statistically significant. Therefore, the previous findings (Traore et al., 2014; Toukal Assoumana et al., 2016) supported our results, in which most farmers acknowledged a delayed start and an early cessation of the rainy season. Indigenous knowledge (Traore et al., 2014), which is the key to scaling up climate-smart management practices in those areas, is the bulk of how farmers perceive the rainy season deficit. The results further showed that within the location, farmers' perceptions of rainfall trends differed from one to another following the rainfall gradient. In both Daga Birame and Thiel, farmers perceived an increase in rainfall amount, respectively, 84 and 100% were supported by the meteorological data which highlighted the slight increase in Daga Birame and the significant increase ($p < 0.05$) in Thiel of annual rainfall amount. However, in the Meouane, there was a contrast with farmers' perceptions (96%) which indicated a decreasing trend of

TABLE 6 Farmer's adoption measures in Daga Birame, Thiel, and Meouane locations in percentage (%).

Smart management practices	Daga Birame (%)	Thiel (%)	Meouane (%)
Improved varieties	65	17	63
Rotation with leguminous	55	98	43
Change of planting date	55	46	71
Crop diversification	15	76	41
Use of organic manure	25	24	10
Improved animal breed	25	12	14
Efficiency use of inorganic fertilizer	30	27	11
Farmer Managed Natural Regeneration (FMNR)	45	2	96
Mulching	5	29	0
Irrigation	0	5	6
Rainwater harvesting (Runoff water collection basin, Half-moon, *Zaï*)	0	0	0

rainfall while meteorological data showed a slight increase. The great spatiotemporal unpredictability of the rainfall patterns could make it difficult for people in Meouane to remember past events, which could account for the reported shifts in rainfall patterns there (Moron et al., 2013; Toukal Assoumana et al., 2016). The farmers in Thiel and Meouane agreed that the rainy season tended to be shorter, which is compatible with meteorological data analysis, however, in Daga Birame there was a disagreement between the meteorological data and farmers' perceptions. Many studies (Amadou et al., 2015; Toukal Assoumana et al., 2016) in the Sahel region on farmers' perceptions of climate change continually failed to find a clear correspondence between climatic data observations and the farmers' judgments of the onset and cessation of the rainy season. Farmers agreed with an increase in temperature in the areas of Daga Birame, Thiel, and Meouane by 92, 98, and 67%, respectively. Sub-Saharan Africa, which already has a severely damaged ecosystem, is predicted to see a temperature increase that is 1.5 times greater than the global average, according to Arneth et al. (2019). Additional research has demonstrated that the signal is not homogeneous for specific locations (IPCC, 2014). In that line, Gadédjisso-Tossou (2015) and Traore et al. (2014) also show the accurate perception of temperature trends in Togo and Mali, respectively. The comments from farmers are consistent when it comes to the examination of long-term minimum and maximum temperature data for each zone. In fact, during 41 years, there was a statistically significant increase in the minimum temperature at the localities of Daga Birame ($p = 0.0183$) and Thiel ($p = 0.0002$). Previous research has demonstrated that a major factor contributing to increased heat is the rising minimum temperature (Alexander et al., 2006; Schlenker and Roberts, 2009). Regarding rainfall, only the Thiel location saw a significant rise over 41 years ($p = 0.02$). Therefore, Daga Birame alone found that heavy rainy days had a substantial p-value (0.0274). In several other countries, there were likewise significant connections between observations and farmers' views of climate change (Traore et al., 2014; Gadédjisso-Tossou, 2015; Toukal Assoumana et al., 2016). The analysis of long-term climate data, which showed a slight increase for all three locations over the last four decades, supported the perception of an increase in annual rainfall by most farmers. Traore et al. (2013) found a similar slight increase in annual rainfall amount over five decades in southern Mali. The findings have also shown that farmers across the three locations perceived strongly the change in wind intensity (72%). That means farmers have a good perception according to the change of wind intensity following the rainfall gradient since this weather anomaly causes an impact such as crop fall and soil erosion on their cropping system.

4.2 Farmer's perception of weather anomalies impact on crop and livestock production and coping measures

In the mid-21st century, climate change is expected to reduce average crop yields by 22% across Sub-Saharan Africa, which could threaten food security in low-income and agriculture-based economies (IPCC, 2014). Small farmers should be motivated to adopt climate-smart management strategies to deal with the effects by having a proper understanding of rainfall unpredictability and temperature increase, which are the key constraints in the Sahelian zone (Akinseye et al., 2012). The primary meteorological anomalies identified by earlier research in the Sahelian region (Traore et al., 2014) were incorporated into this survey to capture farmers' awareness of their impact on crop and livestock systems. The survey has further highlighted those farmers perceived most of the impact of weather anomalies on crop and livestock systems. This is consistent with Traore et al. (2014), who discovered that farmers in southern Mali believe weather anomalies have an impact on crop productivity. The farmers in this survey agreed that there is a connection between weather anomalies and crop and livestock productivity. Farmers across the three locations claimed clearly that the late start and early end of the rainy season led to late sowing which reduced yields and prevented the grain from filling up and maturing demonstrated by previous research (Bedeke et al., 2019). This can be explained probably by the lack of moisture during the grain filling and maturation phases (Sultan et al., 2005). The regional monsoon tends to strengthen the link between water supply and plant water use, possibly leading to increased crop water demand (Sultan et al., 2005). Several studies on the effects of climate variability on crop production have shown that irregular rainfall distributions may subject the crop to a variety of mild to severe intra-seasonal water stresses, which could then affect the yield, especially during the crucial stages of flowering and grain-filling (Akinseye et al., 2012, 2016, 2023; Traore et al., 2014). The best sowing window is one of the key aspects to avoiding yield loss. They also

TABLE 7 Adoption of climate-smart practices and farmer perception using Binomial logit model.

Variables	Improved variety adoption as a climate-smart practice	Adjustment of crop operation during the growing season as a climate-smart practice	Perception of climate change
Age	−0.08 (0.06)	−0.07 (0.05)	0.04 (0.16)
Gender	2.61 (1.63)	0.91 (0.96)	20.77 (2.47)
Education level	−0.21 (0.22)	−0.01 (0.22)	−17.28 (2.14)
Credit access	**3.05* (1.76)**	−0.26 (0.8)	−0.07 (1.77)
Access to extension service	**1.84* (1.07)**	0.37 (0.95)	0.46 (2.46)
Farmland erosion	**−1.59** (0.69)**	**2.27** (0.97)**	0.58 (1.46)
Soil fertility	0.99 (1.06)	−0.46 (0.42)	0.66 (0.93)
Farmers' group membership	0.67 (0.55)	−0.41 (0.4)	−1.4 (1.25)
Farming experience	0.02 (0.05)	**0.10** (0.04)**	−0.06 (0.14)
Number of contacts with an extension agent	**0.41*** (0.14)**	−0.01 (0.13)	0.45 (0.58)
Distance to extension office (km)	**−0.26** (0.1)**	0.06 (0.05)	0.03 (0.13)
Access to Government subsidies	**2.03* (1.06)**	1.39 (0.93)	**2.98* (1.77)**
Rainfall gradient	−0.52 (0.70)	**1.53** (0.60)**	0.77 (0.41)
Access to climate information	−2.29 (1.62)	1.11 (0.88)	1.26 (0.34)
Constant	**9.93* (5.19)**	**−5.20* (3.11)**	57.55 (8.589)
Observations	136	136	136

Survey data collected in post-harvest 2022, Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$, the values in bold are statically significant.

raised that different weather anomalies mentioned in Table 3 led either to crop or livestock loss which is in line with the IPCC (2014) forecast that by 2050, crop and fodder growing seasons in Western Africa may be shortened by an average of 20%, leading to a 40% reduction in grain yields and biomass for livestock. Moreover, Mohamed et al. (2023) predicted that the impacts of sowing dates on production could lead to millet yield reductions of up to 50% in the Sahel zone.

In addition to animal illnesses and water scarcity, warming trends are one of the factors contributing to increased damage to livestock farms in the Sahelian region (Traore and Owiyo, 2013; Sylla et al., 2018). Furthermore, Rhodes et al. (2014) emphasized that the intensity and distribution of animal diseases, changes in pasture yield, changes in plant species composition, and changes in water availability are all likely to have a significant influence on livestock.

Our study revealed the potential of a number of adaptive strategies to deal with the weather's unpredictability across three rainfall gradients, farmers agreed that rotation with leguminous crops is a frequent practice. This is consistent with previous studies (Araya et al., 2022; Vieira Junior et al., 2023) which highlighted that the Senegal cropping system is dominated by monocropping with rotation from 1 year to another. Their rotation cropping system is dominated by the groundnut-millet and millet-cowpea cycle with groundnuts often occupying a larger area (Salack et al., 2011; Adiku et al., 2015; Faye et al., 2018; Housseini Malam Laminou et al., 2020). They also mentioned that crop diversification, using an improved variety, shifting the planting date, and Farmer Management Natural Regeneration (FMNR) are their main coping strategies. Previous research has demonstrated that these practices were mostly employed in the Sahelian region to mitigate the consequences of climate variability and change (Akponikpè et al., 2010; Rhodes et al., 2014; Danso et al., 2018). The Farmer Management Natural Regeneration (FMNR) which refers to the agroforestry system to restore the land degraded was mainly used in Meaoune located in the old peanut basin. The land is more degraded in this part than in the new peanut basin, Daga Birame, and the agro-pastoralism zone (Thiel). Also, the Meouane location recorded less average amount of rainfall compared two others. In fact, by doing FMNR, contributes more to restoring degraded land and establishing a favorable micro-climate which can reduce the effects of climate change such as temperature increase. The result showed that across the rainfall, there is still more effort to do since the uptake of smart fertility management practices such as the use of organic manure. This might be due to a lack of input for composting since crop residues are mostly used in those areas to feed animals. Therefore, using more rotation with leguminous across the three rainfall gradients demonstrates that this practice is mainly used by farmers in those areas to cope with soil fertility depletion. On the other hand, the high percentage of farmers who use improved varieties and change the planting date depending on the rainy season pattern emphasizes their understanding and capacity across the rainfall gradient to cope with climate variability and change. However, regarding the rainwater harvesting practices such as runoff collect basin, half-moon, and *zai* which are common in Sahel zone, the results revealed that those practices are underscored across the three locations where the study was carried out. Indeed, Faye et al. (2022) have mentioned that the rainwater harvest practices that are common in Sahel countries are not observable everywhere in Senegal. This deficiency may stem from the prevalent soil's sandy texture which is not favorable to those practices (Zougmoré et al., 2014) due to low capacity of water holding (Fatondji et al., 2012). According to that, Yameogo et al. (2011) emphasized that the soil type is a required condition for the success of rainwater harvest practices. They added that practices such as half-moon and *zai* practices are suitable in crusted soil which can explain why the farmers have not claimed these practices. Hence, it can be also due to a lack of knowledge related to rainwater harvest techniques. Hence, the overall results revealed that smallholder farmers have real knowledge about the state of their environment which could be an opportunity to strengthen their resilience to climate effects through participatory actions.

4.3 Socio-economic and institutional influence on Farmer's perception and smart management practices adoption

Interventions for accelerating adaptation on a community scale are primarily influenced by socio-economic and institutional factors (Tesfaye et al., 2019). On the other hand, the findings indicate that some of the socioeconomic and institutional variables mentioned in this study had an impact on farmers' perceptions of climate change, their ability to implement improved variety as a climate-smart management strategy, and their capacity to modify crop operations during the growing season.

As expected, having *access to credit* considerably increases the possibility of improved variety adoption as a climate-smart management practice across the three locations. These results support the findings of Bedeke et al. (2019), Fonta et al. (2018), and Diallo et al. (2020), who discovered that having access to finance increases the likelihood of coping with climate change. Access to financing should actually be the best option to assist the poorest farmers in making investments in their fields to combat climate variability, increase crop yield, and guarantee food security. By 2030, developing countries' adaptation costs are predicted to reach up to US$ 340 billion annually, according to IFAD (2021). In this report, the annual cost of mitigation might reach US$ 850 billion. This IFAD study highlight the value of funding at the national, regional, and local levels for least-developed countries to deal with the effects of climate change effectively. This explains that access to credit as an expectation might increase farmers' capacity to adopt improved variety as a smart technology in this study. Therefore, sustainable financial resources and investments are required to increase farmers' adaptability to climate change. According to Rhodes et al. (2014), the impact of climate change is lessened by factors including access to land, resources, financing, and markets which emphasizes the importance of learning more about socioeconomic and institutional aspects in coping with climate change.

They were statistically more likely to adopt improved variety as a climate-smart management strategy if they had *access to extension services.* This result adds to the evidence that getting assistance from extension agents promotes the adoption of adaptation strategies to increase crop production in response to the effects of climate change (Theriault et al., 2017). This is consistent with earlier research (Ngigi et al., 2017; Bedeke et al., 2019; Gebru et al., 2020) that found farmers' access to extension services significantly increases their awareness of cropping technology packages.

According to our expectations, *farmers' perceptions of the severity of their farmland erosion* reduce the likelihood of using improved variety as climate-smart management practice. Indeed, a number of studies (Harr et al., 2014; Mwase et al., 2015; Jamala et al., 2021) have shown that in the Sahel region, farmers typically prefer to keep their land in a fallow system for a while when they notice how severely their land is eroding. Then, until soil fertility is restored, they make fewer investments in this degraded property. When farmers perceive advanced erosion of farms, this should be the main factor explaining the negative impact of climate-smart management practice uptake in this study. Therefore, the model showed that farmers' ability to change crop operation during the growing season, when they have a good knowledge of farmland erosion, which can still be a smart practice.

Crop operation adjustments during the growing season are more likely when a farmer has more *experience.* Experienced farmers are more likely to adjust crop operation during the growing season to deal with climate effects like dry spells in the study location. These findings support those of Ibitoye (2011), Yegbemey et al. (2014), Gadédjisso-Tossou (2015), and Fonta et al. (2018), who have underlined the importance of farming experience in coping with climate unpredictability. This demonstrates that a farmer's ability to adapt to climate unpredictability and change is greatly influenced by their level of agricultural experience.

Many *contacts with extension agents* raise the likelihood of adopting improved variety as a climate-smart management practice. Farmers' awareness and the frequency of extension agent visits increase their ability to use the innovation packages and success (Yegbemey et al., 2014). One of the key elements that can increase farmers' knowledge and capacity to use smart management technology is frequent contact with extension agents. According to Partey et al. (2020), crop management would benefit from extension partnerships in the creation and national service of early warning systems and the continued refinement of the current climate projections, resulting in information that is useful for nearby farmers. Ngigi et al. (2017) have found that the adoption of innovation packages is improved in Kenya by the number of farm visits by extension agents.

The findings indicate that the improved variety's adoption as a climate-smart management strategy was adversely impacted by the *farmer's distance to the extension office*. Kassa (2013) discovered that distance is a factor that negatively affects how innovation packages are adopted, which is consistent with our findings. Farmers are expected to make the adoption of the measures easier since they trust extension agents to promote climate change adaptation (Bedeke et al., 2019). As a result, farmers' capacity for adaptability may be lowered by the distance preventing extension agents from visiting them as frequently during the growing season. Toukal Assoumana et al. (2016) indicated in the prior study that farmers had a poor ability to adjust to climate variability due to a lack of help from extension services, which corroborates that distance has a negative effect in this study.

Additionally, *access to government subsidies* raises the likelihood that farmers will adopt improved variety as a climate-smart management practice and have a more positive attitude toward climate change. Crop inputs like improved varieties, fertilizer, climate service information, etc. are the major factors that allow farmers to realize the accuracy of innovation packages, which are the main targets of government subsidies. In such instances, government subsidies are a factor that boosts farmers' confidence in innovation packages and their uptake. By supplying enough information and relevant experience regarding the negative effects of climate change, this confidence increases farmers' and extension workers' capacity to employ adaptation measures (Bedeke et al., 2019).

The *rainfall gradient* (study location) positively influenced farmers' decision to adjust their crop operations. This can be explained by the different magnitudes between the three locations in terms of onset, cessation, and length of rainy season emphasized in Figure 3. This implies that the variability of the rainy season across the three locations led farmers to adjust crop operation, which emphasizes their good perception of climate indicators shown in Table 3. Therefore, for Africa's smallholder farming, climate information services (CIS) are still very useful (Zougmoré et al., 2014; Ramaraj et al., 2023) to enhance their resilience vis-a-vis climate effects. Gadédjisso-Tossou (2015) discovered that the usage of short-duration varieties and changes in planting dates were both influenced by climate information for farmers in Togo. In Senegal, the national meteorological agency and many projects have worked great to release CIS close to the community. The results raise that climate-based agro advisory was implemented within many communities in Senegal through the platform via SMS and voice messages in different local languages. So, this could be the main reason that the climate information service did not influence farmers' decisions in this study since they are already well-informed about climate information which might reduce the variability of decisions taken from one farmer to another within the community.

5 Conclusion

Our research examined the perception of climate variability and change among farmers in semi-arid regions of Senegal, as well as the factors influencing their adoption of climate-smart management practices. The findings revealed that smallholder farmers possess a comprehensive understanding of climate indicators, such as annual precipitation, changes in cropping seasons, and rising temperatures when compared to historical data trends. Additionally, the results highlighted how farmers are acutely aware of the detrimental effects of insufficient seasonal rainfall (72%), delayed onset of the growing season (88%), frequent dry spells (68%), and prolonged dry spells (76%), all of which led to decreased grain and fodder yields. Through the implementation of the Logit model, we identified the significant ($p < 0.05$) influence of socioeconomic and institutional factors on farmers' decisions to adopt Climate-Smart Technology (CST). These factors include access to credit, extension services, farming experience, frequency of interaction with extension agents, and access to government subsidies. These factors play a crucial role in shaping farmers' choices in these areas. Furthermore, the study underscored the negative impact of distance from extension offices, highlighting the urgent need to enhance the accessibility of extension services, particularly in rural regions.

Smallholder farmers in three different locations have utilized various Climate-Smart Technologies (CST) to mitigate the effects of climate change. These technologies include the use of improved crop varieties, crop rotation with leguminous plants, adjusting planting dates, practicing Farmer Managed Natural Regeneration (FMNR), and diversifying crops. However, it is important to conduct a more detailed analysis by incorporating comprehensive climate-smart indices to assess the effectiveness of each technology. Additionally, exploring the carbon parameters associated with these technologies can yield more robust findings. Although the sample size used in this study may not be fully representative of Senegal, the results can still contribute to the identification and promotion of practices that enhance the sustainability of smallholder farming in semi-arid regions. Ultimately, these findings can inform rural development policies aimed at achieving adaptation strategies in the face of changing climatic conditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

IZ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. FA: Conceptualization, Funding acquisition, Resources, Supervision, Validation, Writing – review & editing. OW: Funding acquisition, Resources, Validation, Writing – review & editing. MK: Validation, Writing – review & editing. AF: Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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