



Regular Article

Smallholders' coping strategies in response to climate variability in semi-arid agro-ecozones of Upper Eastern Kenya

Felix K. Ngetich^{a,b,*}, Franklin S. Mairura^c, Collins M. Musafiri^b, Milka N. Kiboi^{b,d},
Chris A. Shisanya^e

^a Jaramogi Oginga Odinga University of Science and Technology (JOUST), School of Agricultural and Food Sciences, P.O. Box 210, 40601, Bondo, Kenya

^b Cortile Scientific Limited, PO BOX 34991, 00100, Nairobi, Kenya

^c University of Embu, Department of Water and Agricultural Resource Management, P.O. Box 6-601100, Embu, Kenya

^d Division of Research, Innovations, and Outreach, KCA University, PO BOX 56808, 00200, Nairobi, Kenya

^e Kenyatta University, Department of Geography, P.O. Box 43844, 00100, Nairobi, Kenya

ARTICLE INFO

Keywords:

Adaptation
Soil and water conservation
Rainfall variability
Rainfed farming
Arid and semi-arid lands

ABSTRACT

Rainfed agriculture dominates food production systems in arid and semi-arid agro-ecozones. Water is a key limiting factor to crop growth in the small-scale farming systems of the Sub-Saharan Africa (SSA) region. Climate adaptation is a fundamental and necessary response to the threat posed by the current and future climatic changes in semi-arid farming systems of the SSA region. This study was implemented to identify the socioeconomic drivers and determinants of adaptation to rainfall variability at the farm level in contrasting agro-ecological zones of Kenya. Two hundred and seventy (270) farmers were selected. The survey was implemented in Mbeere South, Meru South, and Maara Sub-Counties in Kenya to determine farmers' perceptions of climate variation during the decade that preceded the survey and climate adaptation strategies that farmers implemented. The most common climate adaptation strategies included the use of terraces (89%), early maturity crop varieties (82%), and intercropping (79%). In comparison, the least common strategies included water-harvesting strategies (29%), trenches (35%), and staggering planting dates (46%). Farmers in low potential agro-ecological zones recorded lower education levels, less secure land tenure systems, and poor access to training, extension, and credit facilities necessary for successful climatic adaptation strategies. The study findings indicated that farmers in low potential zones, including Mbeere South Sub-County, faced more risks due to the nature of climatic variation in this agro-ecozone. Farm socioeconomic characteristics were important factors that influenced farmer adaptation, including gender and age differentials, education attainments and agricultural training, farm labor availability, household food security status, and preceding annual occurrences of crop failure. There is a need to develop holistic approaches that incorporate scientific findings from the researchers and the local household-based strategies that can enhance risk assessment and management, coping and adaption strategies, and decision-making by multiple stakeholders.

1. Introduction

Climate variability is more remarkable in the Arid and Semi-Arid Lands (ASALs) than high potential agro-ecozones (Omoyo et al., 2015). Rain-fed agriculture dominates food production systems in ASALs, and water is a key limiting factor to crop growth. The realization of the inevitability of climate change has reinvigorated adaptation research (Berrang-ford et al., 2010). Hence, it has been universally accepted that climate influences development and must be integrated

into the African development agenda (NEPAD, 2004; Simbanegavi & Arndt, 2014). However, the exact nature and extent of the impacts of climate change on temperature and rainfall distribution patterns remain uncertain. Most key investors and stakeholders in agricultural development in the Third World agree that it is the poor and vulnerable who will bear the brunt of changes in climate as they occur (Aseyehgn et al., 2017; Cooper et al., 2008). This has led to wide recognition of adaptation as a fundamental and necessary response to the threat posed by the current and future climatic changes (IPCC, 2007; Mavhura et al., 2017)

* Corresponding author. Jaramogi Oginga Odinga University of Science and Technology (JOUST), School of Agricultural and Food Sciences, P.O. Box 210, 40601, Bondo, Kenya.

E-mail address: felixngetich@gmail.com (F.K. Ngetich).

<https://doi.org/10.1016/j.ssaho.2022.100319>

Received 18 January 2022; Received in revised form 6 May 2022; Accepted 14 July 2022

Available online 21 July 2022

2590-2911/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

and that many of the most threatened countries (developing and least developed) have inadequate capacity to adapt (Twomlow et al., 2008).

East Africa and Kenya, in particular, is characterized by high rainfall variability (Camberlin et al., 2001; Shisanya, 1996). Most of Kenya's agriculture is rainfed (98%) and is mostly dependent on the seasonal rainfall pattern. Approximately 16% of Kenya's land area receives sufficient and reliable rainfall considered suitable for cropping. The remaining 84% are classified ASALs, receiving an average yearly rainfall of 400 mm (Kalele et al., 2021). Despite the climatic and environmental challenges witnessed in the ASAL counties of Kenya, agriculture is integral, contributing to livelihood strategies and up to 70 percent of household incomes.

Dry spell analysis of weather data from a site in Machakos Sub-County in Kenya, representative of drier agro-ecological zones, showed that maize on sandy soil is exposed to a dry spell exceeding 15 days in more than three out of five seasons (Barron et al., 2003). Results of analysis of rainfall data from Murang'a County in Central Kenya, representative of humid agro-climatic conditions, showed that farmers' perception that rainfall has decreased over the last 40 years is not reflected in a decrease in the total rainfall amounts. Still, there were indications for more frequent dry spells towards the end of the short rains (Ovuka & Lindqvist, 2000). Less is known about the possible impacts on rainfall extremes, specific to Africa, in either models or observations (IPCC, 2007). However, the general expectation is that more intense and heavy rainfall events interspersed with longer, relatively dry periods and increased evapotranspiration (Meehl et al., 2007). The trends in climate variability are expected to be different in ASAL ecosystems compared to the highland eco-regions (Njoka et al., 2016). Increases in both minimum and maximum temperatures have been documented across Kenya, while actual observed temperature trends indicate significant warming in the ASAL regions of Kenya (USGS and USAID, 2010).

Climate variability has negatively affected Kenya's socioeconomic development. The 2008–2011 drought's economic impacts in Kenya were approximated to be Kshs 968.6 billion (\$12.1 billion) (Republic of Kenya, 2012). In Kenya, maize is both a staple food and cash crop that is now a popular and cultural cereal, virtually replacing the traditional sorghum (*Sorghum bicolor*) and millet (*Pennisetum americanum* L.) (Jaetzold et al., 2007). The increased food demand sets tremendous pressure on production even in less suitable climatic zones, intensifying competition for the available water. Competition for water increases the cost of production, leading to higher maize prices, which raises food prices in general. Improving the water use efficiency for maize production through adaptive farm management strategies in response to rainfall variability is thus of paramount importance to obtain "more crop per drop of rain" with uncertainty in precipitation due to climate variability.

Rockström et al. (2009) have shown enormous potential for improving green water use in food production in the SSA and other regions. Hence, food security in Africa critically hinges on investments in agricultural water management, emphasizing locally adapted rainwater management measures (Hoff et al., 2010). Adaptation is a process of deliberate change, often in response to multiple pressures and changes that affect people's lives (Stringer et al., 2009). The Intergovernmental Panel on Climate Change (IPCC, 2014a, 2014b, p. 1132) defines adaptation as an adjustment in ecological, social, or economic systems to actual or expected climatic stimuli and their effects or impacts. In the context of climate change, Smit et al. (2001) define adaptation as the adjustments in ecological, social, or economic systems to moderate potential and anticipated damages or to benefit from opportunities associated with climatic changes. Successful adaptations can be considered actions that decrease vulnerability and increase overall resilience in response to a range of community's immediate needs, risks, and aspirations (van Aalst et al., 2008).

Defining successful adaptation is complicated because criteria for success are generally contested and context-specific (Dessai et al., 2009). Adger et al. (2005) suggested that effectiveness is one of the important

elements, besides efficiency, equity, and legitimacy, in assessing successful adaptation. Cooper et al. (2008) believed that adaptation strategies are those approaches that have evolved over time through peoples' long experience in dealing with the known and understood natural variation that they expect in seasons combined with their specific responses to the season as it unfolds. Adaptive strategies are long-term (beyond a single season) interventions that are needed for people to respond to a new set of evolving conditions (biophysical, social, and economic) that they have not previously experienced (Mortimer & Manvel, 2006, p. 8).

The challenge then is to form alliances with communities that help to connect the issues concerning livelihoods and everyday survival with the risks from extreme events (van Aalst et al., 2008). There are considerable knowledge gaps concerning the interacting and multiple stresses on the vulnerability of the poor in Africa (Thornton et al., 2010). Research on climate adaptation by small-scale farmers has yet to become a high priority issue in ASALs compared to high potential agricultural zones in the Central Highlands of Kenya and the SSA region as a whole. There is little evidence, policy support, and concerted effort to facilitate the adaptation at the farm level. Additionally, farmers' low adoption of climate coping strategies in ASALs contributes to exposing smallholders to climatic risks, including food insecurity in these fragile socio-ecological systems (Mutua-Mutuku et al., 2017). As Twomlow et al. (2008) pointed out, there is a need to evaluate the rural poor's coping strategies concerning climate, especially in ASALs.

Considerably, the studies justify need for in-depth understanding of the determinants of adopting climate variability coping strategies to aid in the formulation of pro-farmer policies that could enhance their adoption. Despite the potential of smallholders to harness the enormous potential of climate variability adaptation, the literature on climate coping practices in semi-arid agro-ecozones of Upper Eastern Kenya of Kenya is limited. In particular, there is lack of knowledge relating to the nature of climatic variability in different agroclimatic zones in Kenya. This knowledge is necessary to improve climate adaptation strategies in different agro-ecological zones and socioeconomic settings of small-scale farm households. The local farming practices may help scientists and farmers to explore new opportunities availed in a participatory manner that will enable the adaptation of the farming systems to rainfall variability. To increase overall agricultural productivity, stabilize yields over time and encourage the otherwise risk-averse farmers to invest more in agriculture, there is a need for deliberate effort to identify the precise drivers and determinants of adaptation to rainfall variability at the farm level. Therefore, the study's objective was to provide empirical insights into farmers' climate variability adaptation practices to rainfall variability in contrasting agro-ecological zones of central Kenya's small-scale farming systems. The study hypothesized that climate variability adaptation is influenced by farmer, farm, environmental and institutional factors. The study's main objective was to determine farm characteristics in contrasting agro-ecological zones of Kenya that influenced farmers potential to cope with climatic variability.

2. Review of empirical studies

Assuming perfect awareness of climatic variability, reliable early warning systems, and without socioeconomic constraints, small-scale farmers in the ASAL regions are likely to make timely and rational decisions and achieve optimal adaptation to climate variability (Waldman et al., 2020). However, assumptions about perfect adaptation capacity do not hold when examining empirical adaptation responses among small-scale farmers. Farmer adaptation decisions are often influenced by several factors, including the perception of climate risks, natural capital, financial capital, human capital, social capital, and institutional capital, which introduce a bias to rational decision making (Schlüter et al., 2017).

Climate variability is a major hurdle to enhanced crop productivity in most developing countries. Small-scale farmers adopt a bundle of

climate variability coping strategies to improve their welfare (Mairura et al., 2022; Mugi-Ngenga et al., 2021; Musafiri et al., 2022a, 2022b). Small-scale farming households are risk-averse and will only adopt a technology if the gains outweigh the traditional practices. However, the decision to adopt a specific climate variability coping strategy is a complex process that is influenced by factors including farm and farmer, institutional and environmental dimensions (Mairura et al., 2022; Oyetunde-Uzman et al., 2021). In this study, we highlight the interactions of the farmer and farm, institutional and environmental factors as stated in previous literature in the context of this study.

Regarding farmer and farm characteristics, gender is a key characteristic that could drive or restrain the adoption of climate variability coping practices. Past studies revealed mixed results on the influence of gender on the adoption of technologies (Mairura et al., 2022; Musafiri et al., 2022b; Mwaura et al., 2021; Oyetunde-Uzman et al., 2021). Gendered differences in technology adoption are attributed to male farmers' greater resource control and decision-making than their female counterparts (Ndeke et al., 2021; Ndiritu et al., 2014). Age is an important factor in the adoption of climate variability coping practices. Older farmers are risk-averse and have a higher propensity to practice traditional practices than new ones (Macharia et al., 2014; Musafiri et al., 2020). Farm size is a proxy for both natural and financial capital and defines the availability of land for experimenting with new technologies. Smallholder farmers with larger farm sizes are more likely to adopt new agricultural practices. However, Martey and Kuwornu (2021) found that farm size positively influenced the adoption of mineral fertilizer and negatively influenced mulch and manure. Education is an essential determinant of new technology adoption as it defines the small-scale farmers' ability to comprehend (O'Donoghue & Heanue, 2018). The application of manure on small land size was attributed to the amount of manure and mulch that is required. Additionally, the practices are labor-intensive and mostly applicable to smaller landholdings. Hired labor enhances the adoption of labor-intensive technologies (Mugwe et al., 2009). Larger tropical livestock units (TLU) ownership in a farm is associated with the increased application of manure (Oyetunde-Uzman et al., 2021), which is a climate coping strategy. Ownership of title deeds is a proxy for land tenure security, thus the long-term ability to adopt new technologies (Mugwe et al., 2009). Food insecure farming households have a higher propensity to adopt new technologies to enhance their food production. Finally, diversification with fodder crops increases the tendency to adopt new technologies to minimize the vagaries of climate variability.

Institutional factors offer supportive services for the adoption of climate adaptation strategies. It is noteworthy that institutional factors such as extension access, group membership, and agricultural credits improve small-scale farmers' financial and human resource capacity thus enhancing the adoption of innovations (Amadu et al., 2020; Mairura et al., 2021). Past studies revealed that access to extension services, group membership, and farm credits positively influences agricultural innovation adoption (Ndiritu et al., 2014; Otieno et al., 2021; Oyetunde-Uzman et al., 2021).

Environmental factors such as perceptions of climate change, soil fertility, and incidences of crop failure influence the adoption of climate variability coping practices. Perceptions about the local climate can influence farmers' potential to cope with climate variability. Past studies have highlighted various indicators of climate variability, including the increase in temperature, reduced rainfall amounts, and short cropping calendars (Mairura et al., 2021; Mugi-Ngenga et al., 2021). It is noteworthy that perception of climate change can motivate small-scale farmers to adopt coping, mitigation, and adaptation practices. Soil fertility plays an essential role in enhancing crop productivity. Small-scale farmers' perception of low soil fertility will improve the adoption of soil productivity, ameliorating practices for enhanced crop yields. Otieno et al. (2021) found that small-scale farming households that experienced low soil fertility were more likely to uptake integrated soil fertility management practices. Total or partial crop failure could be

attributed to small-scale farmers' vagaries of climate variability (Rapholo & Makia, 2020; Tarchiani et al., 2017). Therefore, crop failure could be a determinant of adopting climate variability coping strategies. Small-scale farm technology options to alleviate crop failure include drought-resistant crop varieties, crop diversification, changing planting dates, and soil water conservation (Marie et al., 2020).

3. Methodology

3.1. Study area

Kenya is divided into seven agro-ecological zones (FAO, 1978) using a moisture index based on annual rainfall expressed as a percentage of potential evaporation (Jaetzold et al., 2007; Sombroek et al., 1982). The zones are roughly parallel with Braun's climatic zones of the Precipitation/Evaporation Index (Jaetzold et al., 2007; Kenya Soil Survey, 1982). Still, there are differences according to the influence of the length and intensity of arid periods (Jaetzold, 2007). Areas with an index greater than 50% and a mean annual rainfall of more than 1100 mm have a high potential for cropping and are designated zones I, II and III. These zones account for about 16% of Kenya's land area and fall within humid to semi-humid climates. The semi-humid to arid regions (zones IV, V, VI and VII) have less than 50% indexes and a mean annual rainfall of less than 1100 mm. These zones are generally referred to as the Kenyan rangelands and account for about 80% of the land area (Kabubo-Mariara & Karanja, 2007). The seven zones starting from I to VII is equivalent to Tropical Alpine Zones (T.A.), Upper Highland Zones (U.H.), Lower Highland Zones (L.H.), Upper Midland Zones (U.M.), Lower Midland Zones (L.M.), Inner Lowland Zones (I.L.), and Coastal Lowland Zones according to Jaetzold et al. (2007). Based on this classification, the dominant agro-ecological zones in Mbeere South are Lower Midland 3, 4 and 5 (L.M. 3, L.M. 4, L.M. 5, respectively) and Inner lowland 5 (IL5). Meru South and Maara Sub-Counties are dominated by Upper Midland 1 to 4 (UM1, UM2, UM3, UM4) and Lower Midland 3 to 5 (LM3, LM4 and LM5) agro-ecological zones (Fig. 1).

The study was carried out in Maara and Meru South Sub-Counties in Tharaka Nithi County and in Mbeere Sub-County, Embu County, in the Central Highlands of Kenya. The Central Highlands of Kenya cover both areas with high potential for crop production on inherently fertile soils and relatively moderate rainfall, and areas with lower potential due to lower rainfall and less-fertile soils, following the agro-climatic gradient defined by the Mount Kenya system topography. The three Sub-Counties represent the whole of the central highlands of Kenya and the highlands of East Africa in general. The rainfall pattern in all the sites is bimodal with long rains (L.R.) being received from mid-March to June and short rains (S.R.) from late October to December. Further details of the study area are shown in Fig. 1.

Mbeere Sub-County which lies on the south-eastern slopes of Mount Kenya is now experiencing an influx of immigrants from the overpopulated high-potential areas. The Kenya 2019 census showed that Mbeere has a population of 163,476 persons comprising 46,065 households covering an area of 1312.1 km² (KNBS, 2019). The LM3 is a cotton (*Gossypium hirsutum*) zone while LM4 and LM5 are Marginal Cotton and livestock-millet zones, respectively, characterized by a short to very short cropping seasons. These zones are suitable for common beans (*Phaseolus vulgaris*), dry land composite and hybrid maize (*Zea mays*), sorghum (*Sorghum bicolor*), green grams (*Vigna radiata*), cowpeas (*Vigna unguiculata*), chickpeas (*Cicer arietinum*), among other pulses (Jaetzold et al., 2007). They are representative of semi-arid agro-climatic conditions with relatively low agricultural production potential. Although the region is more suitable for drought-tolerant crops and livestock rearing (Jaetzold et al., 2007), major crops grown by most households are maize (*Zea mays*), cowpeas (*Vigna unguiculata*), pigeon peas (*Cajanus cajan*) and common beans (*Phaseolus vulgaris*). Mbeere Sub-County has an annual average rainfall of 700–900 mm, a temperature of 21.7–22.5 °C, while the altitude ranges from 500 to 1800 masl

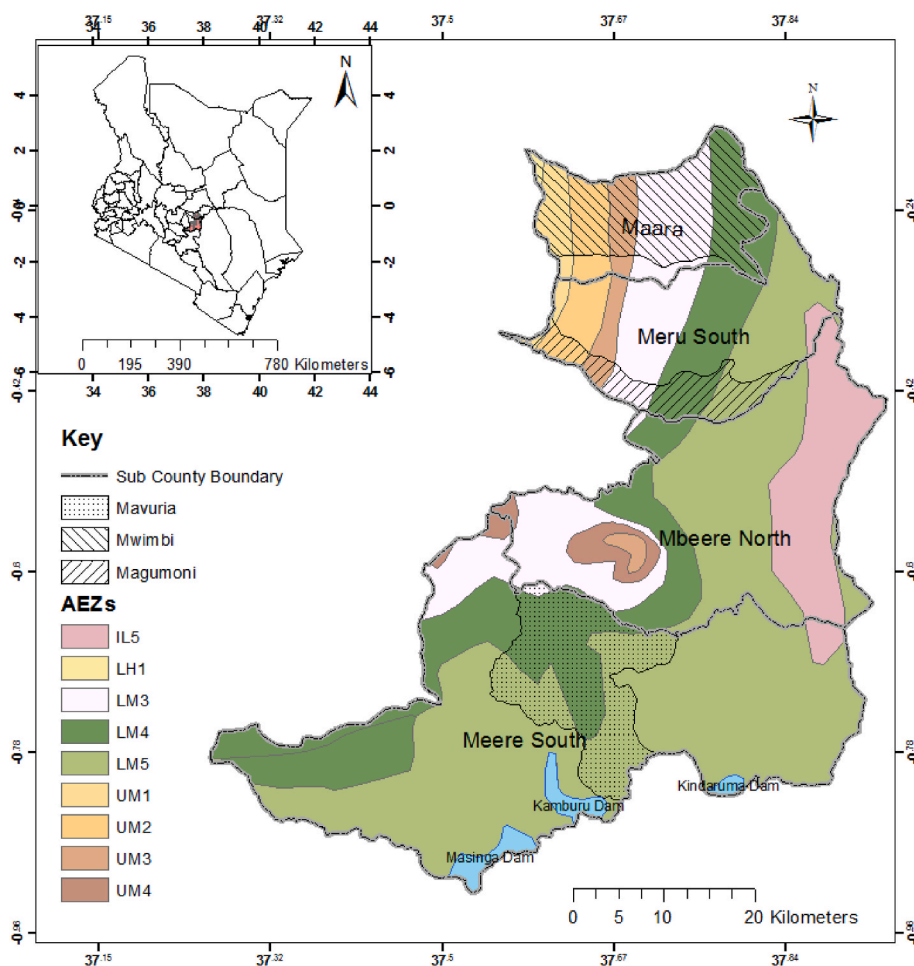


Fig. 1. Map showing the study area; sampled divisions, agro-ecological zones and Sub-County boundaries.

(Jaetzold et al., 2007).

Maara and Meru South Sub-Counties lie on the eastern slopes of Mount Kenya and are representative of the densely populated high potential humid area. According to the 2019 Kenya census, Maara has a population of 114,894 persons comprising 30051 households, covering an area of 265 km², while Meru South has a population of 91,080 persons comprising 28,249 households covering an area of 139 km² (KNBS, 2019). Major crops grown are beans (*Phaseolus vulgaris*), irish potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cabbages (*Brassica oleracea*), kales (*Brassica oleracea* L.), tomatoes (*Solanum lycopersicum*), onions (*Allium Cepa*), maize (*Zea mays*). The farmers in the region primarily rely on small-scale rainfed farming, which is mostly non-mechanized and involves minimal use of external inputs. Although the two sub-Counties are within the same administrative region (Tharaka Nithi County), there are specific agro-ecological and demographic differences, especially the land topography, population density (125, 433 and 656 persons per km² for Mbeere South, Maara and Meru South, respectively) and culture that might influence the farming practices. Meru South Sub-County falls within the upper midland zone two (UM2) and upper midland zone three (UM3) and lies at an altitude of 1500 m above sea level, with a total annual rainfall of 1200–1400 mm and an average annual temperature of 20 °C (Jaetzold et al., 2007). Maara sub-County represents a sub-humid climate with an altitude ranging between 910 and 1300 masl, an annual temperature of 21. to –23.5 °C and a bimodal rainfall pattern totalling 1000–1600 mm (Jaetzold et al., 2007).

3.2. Sampling strategy

Purposive sampling of the study sites was based on the differences in agro-ecological and demographic characteristics. Within the Sub-Counties (Mavuria in Mbeere South, Magumoni in Meru South, and Mwimbi in Meru South), households were sampled randomly from the household list obtained from the local administration offices (ward officers) that constituted the sampling frame. The number of households sampled per site was calculated as the number n required to estimate population proportions π with 95% confidence intervals around observed sample proportions P with an interval no larger than $P \pm 0.103$ (Wonacott & Wonacott, 1977, p. 650, Equation (1)):

$$n = \frac{1.96^2 \pi(1 - \pi)}{c^2} = \frac{1.96^2 0.5(1 - 0.5)}{0.103^2} = 90 \tag{1a}$$

where 1.96 was the z-value for a 2-sided 95% confidence interval, $c = 0.103$ was the desired maximal half-width of the confidence interval, and $\pi = 0.5$ was the population proportion that results in the widest confidence interval for a given sample size (worst-case for a conservative estimate of sample size). Hence 90 households were randomly sampled per Sub-County, giving a total sample size of 270 households in the 3 Sub-Counties (Table 1).

3.3. Recruitment and training of enumerators

Six enumerators per site composed of undergraduates were used to conduct the household interviews. The enumerators were recruited from the localities where the survey was conducted to ensure that they were

Table 1
Sample size distribution in Sub-Counties and wards.

Ward	Maara	Mbeere South	Meru South	Total
Ganga	90	-	-	90
Mavuria	-	90	-	90
Mukuuni	-	-	47	47
Thuita	-	-	43	43
Total	90	90	90	270
Population density (persons km ⁻²)	433	125	656	

Population density data was sourced from KNBS, 2019.

proficient in the local dialect’s oral/diction, translation, and knowledge of their local farming systems. The enumerators were trained before the survey to ensure consistency and reliability in administering the questionnaires. The training included interpreting and translating the questions; from English to the local language (*Ki-Mbeere* in Mbeere South Sub-County and *Ki-Chuka* in Maara and Meru South Sub-Counties). After the training, their competencies were tested using a questionnaire administered between the enumerators before pretesting it on a sample of farmers, which helped minimize sampling errors. After pretesting of the questionnaires with a sample of farmers, an expert panel meeting between the researchers (Authors) and the enumerators was held to evaluate the content and face validity of the results of the pretesting and the equivalence with the original (conceptual, item, semantic). Appropriate adjustments and corrections to the questionnaire were done accordingly based on expert panel recommendations guided by the pretesting results.

3.4. Field survey strategies

Face-to-face interviews were conducted in the sampled households using the pretested questionnaire between August and October 2009. Households that had participated in the pretesting exercise were excluded from the study. Information was collected on the household’s demographic characteristics and socioeconomic conditions (all the members living under the same roof and whose labor, income, and expenditures were considered part of the household’s economic conditions). Structured questions were asked about their understanding and perception of agriculturally related climatic phenomena, such as the direction of the change of seasonal rainfall, temperature, weather-related hazards like droughts and prolonged dry spells, and available on-farm soil and water conservation strategies. Impact of climate change and farmers’ adaptation strategies, food security and farmers’ soil and water conservation practices, and farm management decision rules in response to rainfall distribution were also inquired. Farmers’ adaptation strategies were ascertained by asking questions about the various influential factors and the actions to counteract the perceived change in climatic patterns, especially erratic rainfall. Some questions, including changing planting dates, were framed. The planting dates were identified as early, normal and late planting concerning rainfall onset versus planting time by farmers.

3.5. Statistical data analysis

Data were analyzed using SPSS (IBM Corp, 2020) and R statistical procedures (R Core Team, 2020). Descriptive statistics were performed to summarise the data and to test relationships between variables. These statistics included frequencies, students’ t-tests for pair-wise comparisons, and Pearson Chi Square-test statistics. For categorical variables, cross-tabulation was done, while for quantitative variables, mean comparisons of quantitative dependent variables were carried out using one-way analysis of variance (ANOVA). Regarding farmers’ drought risk adaptation strategies, farmers rated their effectiveness in coping with drought risks using a scale of 1–10.

Conversion TLU (Tropical Livestock Unit) factors were established for animal species that farmers reared. A mature cattle was assigned a TLU value of 1 per head, while 0.2 TLU per head was allocated for shoats, 0.3 for pigs, 0.8 for donkeys, 0.02 for poultry and rabbits, and 0.3 for pigs (Njuki et al., 2011). Binary logistic regression modeling was used to estimate the effects of household and farm factors effects on the farmers’ adoption of climate adaptation strategies. The climate adaptation models included 11 different regressions for farm-level adoption of early maturing varieties, use of cover crops, changing planting dates, changing crop types, changing crop varieties, staggering of planting dates, terracing, digging of infiltration trenches, intercropping, in-situ water-harvesting structures, agroforestry and reducing plant populations (Eq (1)) using SPSS procedures (IBM Corp, 2020). The parameter descriptions for the regression models are included in Table 2, while the binary regression model specification is shown in Equation (1).

$$\ln \left[\frac{p}{1-p} \right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_j x_j \tag{1b}$$

where *p* was the probability of a farmer adopting an adaptation measure, *1-p* represented the probability of not adopting an adaptation strategy. β_0 was the intercept, $\beta_1, \beta_2 \dots \beta_j$ represented the regression coefficients of farm factors, and $X_1, X_2 \dots X_j$ were the farm household explanatory variables.

Table 2
Factors influencing farmer adoption for 11 different climate adaptation measures.

Parameter	Description	Measure
Dependent variables	Adoption of 11 different climate adaptation strategies in arid and semi-arid farming systems	Binary:1 = if adopted, 0 = not adopted
Independent variables		
Gender	Gender of household head	Binary:1 = male, 0 = female
Age	Age of household head	Numeric (years)
Farm size	Total farm size of the household	Numeric (ha)
Education	Education qualifications of head	Binary:0 = below primary education, 1 = above primary education Numeric: TLUha ⁻¹
Farm TLU	Tropical livestock units per hectare	
Has title	Whether farmer holds secure land title	Binary:0 = without title, 1 = has title
Household food insecurity	Family faces food insecurity	Binary:0 = no, 1 = yes
Farmer cultivates fodder	Family cultivates fodder	Binary:0 = no, 1 = yes
Hired labor	Number of farm activities that household uses hired labor	Numeric
Credit	Farmer has access to credit facilities	Binary:0 = no, 1 = yes
Group	Farmer is a member of agricultural groups	Binary:0 = no, 1 = yes
Extension/ NGO	Number of adaptation strategies that farmer accessed extension and NGO intervention	Numeric
Climate change	Farmer has experienced climate change during the last 10 years	Binary:0 = no, 1 = yes
Farm with poor soils	Proportion of farm with poor soils	Numeric (% of farm)
Farm with good soils	Proportion of farm with good soils	Numeric (% of farm)
Crop failure	Number of instances (seasons) farmer has experienced a total crop failure in the last 5 years	Numeric

4. Results and discussions

4.1. Household socio-demographic characteristics

Table 2 shows the general demographic and socioeconomic characteristics of households in the Central Highlands of Kenya. There were significant associations between study sites and all household socioeconomic characteristics. Regarding gender, there were 82% males in Maara, while they comprised 47% and 91% of the farmers in Mbeere South and Meru South Sub-County, respectively. The educational characteristics indicated that most farmers had acquired secondary education (62%) while 20% had completed primary school and 17% had tertiary education across the counties. The findings indicated that only 1% of the respondents did not acquire any formal education. However, Maara Sub-County had the highest (62%) proportion of smallholders who had acquired secondary school education than the 18% and 23% in Mbeere South and Meru South, respectively. Both Mbeere and Meru South recorded a higher proportion of respondents who completed secondary school education. The land tenure distribution indicated that a higher proportion of farmers owned titled land in Maara and Meru South (>70%) compared to Mbeere South (39%). Similarly, there was a higher level of credit access by farmers in Maara and Meru South (>70%) than Mbeere-South Sub-County. The survey found that most farmers had not experienced climatic changes (57%), while 43% of the farmers recorded changes in the climate. In comparison, a higher proportion of farmers in Mbeere recorded various experiences of climatic changes (62%), compared to other locations (<30% of farmers). Fodder cultivation was more prominent in highland agroecosystems, with 80% and 69% of farmers cultivating the crops in Maara and Meru South Sub-Counties, respectively (Table 3). There were significant differences in farm TLU intensity between Sub-Counties. TLU intensity was higher in Maara and Meru-South than Mbeere South Sub-County. At the same time, there was significantly higher labour use in more farm operations and training for more farm activities in Maara and Meru South, compared to Mbeere South Sub-County (Table 3).

Education attainments were distinctly higher in Maara Sub-County, followed by Meru South, while in Mbeere South Sub-County, it was comparatively the lowest (Table 3). This was based on the number of household heads who had attained secondary education and above than those without any formal education. Farm sizes and their utilization status were significantly higher in Mbeere South Sub-County than in the other two Sub-Counties. In both Meru South and Maara Sub-Counties, the land under cultivation was over 80% of the total farm size, while in Mbeere South, about 50% of the total farm size per household was cultivated (Table 3). Also, Mbeere South had a higher proportion of the farmland under the pasture.

Almost all the cattle in Mbeere South Sub-County were local breeds with an average of 2.5 cattle per household, while the cross-bred (improved) cows were negligible in the site (original data has been expressed as TLU). In Meru-South and Maara Sub-Counties, the average proportions of cross-bred (improved) cows were substantially higher than local breeds. Stall feeding (zero-grazing, tethered) was the main system of animal production in Maara (94%) and Meru-South (100%) Sub-Counties. In contrast, in Mbeere South Sub-County, 30% of farmers used stall feeding, 26% used free-range feeding in a private (own) grazing land, while 44% of farms used communal (open) grazing land (data not shown).

The household characteristics may influence the day-to-day farm operations and decision-making, including climate adaptation strategies by farmers in semi-arid agro-ecozones. The results indicated that Mbeere South Sub-County, a drier agro-ecological zone, recorded lower educational attainments and less secure land tenure than high potential zones in Maara and Meru South. Farmers in low potential and semi-arid zones also recorded lower access to credit facilities and training, which can support farmers as human and financial capital to cope with climate variability. There was a higher reporting of climate variability in Mbeere

Table 3

Characteristics of the households in Maara, Mbeere South and Meru South Sub-Counties.

Parameters	Sub-County				X ² , T-test Sig
	Mbeere South	Maara	Meru South	Total	
<i>Gender of head</i>					
Male	42(46.7)	74 (82.2)	82 (91.1)	198 (73.3)	0.000
Female	48(53.3)	16 (17.8)	8(8.9)	72 (26.7)	
<i>Education level</i>					
None	14(15.6)	1(1.1)	9(10.0)	1(1.1)	0.000
Primary	51(56.7)	18 (20.0)	41 (45.6)	18 (20.0)	
Secondary	16(17.8)	56 (62.2)	21 (23.3)	56 (62.2)	
Tertiary	9(10.0)	15 (16.7)	19 (21.1)	15 (16.7)	
<i>Land tenure</i>					
Farmer has no title	55(61.1)	26 (28.9)	20 (22.2)	198 (73.3)	0.000
Farmer has title	35(38.9)	64 (71.1)	70 (77.8)	72 (26.7)	
<i>Access to credit</i>					
Farmer has no access	57(64.8)	26 (29.5)	25 (28.1)	108 (40.8)	0.000
Farmer has access	31(35.2)	62 (70.5)	64 (71.9)	157 (59.2)	
<i>Experienced changes in climate</i>					
Has not experienced change	34(37.8)	60 (69.8)	56 (64.4)	150 (57.0)	0.000
Has experienced change	56(62.2)	26 (30.2)	31 (35.6)	113 (43.0)	
<i>Farmer cultivates fodder</i>					
Does not cultivate fodder	85(97.7)	18 (20.2)	27 (30.7)	130 (49.2)	0.000
Cultivates fodder	2(2.3)	71 (79.8)	61 (69.3)	134 (50.8)	
<i>Farm characteristics</i>					
Age of head	44.3 ± 12.7	47.8 ± 10.6	50.1 ± 12.3	47.4 ± 12.1	0.005
Farm size (ha)	6.2 ± 6.7	2.2 ± 1.5	3.5 ± 8.6	4.0 ± 6.5	0.000
Pasture (ha)	2.2 ± 6.5	0.2 ± 0.4	0.6 ± 2.6	1.0 ± 4	0.003
Farm TLU intensity (per ha)	4.2 ± 6.0	6.4 ± 5.2	6.5 ± 8.4	5.7 ± 6.7	0.039
Number of farm operations hired labour was used	1.6 ± 2.1	3.0 ± 2.6	3.9 ± 2.0	2.8 ± 2.3	0.000
Technologies learnt from extension/NGO agents	2.9 ± 2.9 (90)	0.5 ± 0.7	3.2 ± 2.7(90)	2.2 ± 2.6	0.000
Number of seasons with total crop failure instances (in 5 years)	4.7 ± 2.1	2.1 ± 2.1	0.8 ± 0.4	2.4 ± 2.5	0.000

Values in parenthesis are column percentages calculated within Counties. Means ± are followed by standard errors of means.

South Sub-County than high potential agro-ecological zones, including Meru South and Maara Sub-Counties. The survey findings have highlighted major socio-demographic differences among farmers in high-potential and low-potential agro-ecological zones in Central Kenya, which can influence climatic adaptation potential. In semi-arid farming systems, increasing vulnerability to climate change, coupled with several factors such as widespread land degradation, reducing soil fertility, high levels of poverty, declining farm sizes, inadequate access to knowledge, and poor technology adoption have greatly hindered the potential for farmers to adapt to climate variability (IPCC, 2014a, 2014b, p. 1132).

The study findings indicate that farmers in semi-arid zones of Mbeere South Sub-County were more vulnerable to the effects of climatic variability due to a higher incidence of reported climate changes and several

socioeconomic factors, including less secure land tenure, lower educational attainments, poor access to agricultural credit and training and poor access to labor. The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5) showed that farming systems in the ASALs are experiencing increased vulnerability due to the interaction of climate change factors with non-climate drivers and stressors (IPCC, 2014a, 2014b, p. 1132). Several studies have shown that socio-demographic factors influence farmers coping potential with climate variability. Aryal et al. (2021) found that household assets, land ownership, and livestock influenced farmers' choices of different climate adaptation strategies. Farmers with large land areas are more likely to change farming practices to adapt to climatic risks than those with smaller land areas (Aryal et al., 2021). Additionally, farmers with more livestock can rely on savings and borrowing as an adaptation strategy because livestock act as an insurance mechanism, thus enhancing their relative potential to cope with climatic variation (financial and natural capital). Gichangi et al. (2015) observed that erratic and poor rainfall occurs in 7 out of 10 seasons in some regions of Kenya. These climatic conditions make the farmers in semi-arid regions more vulnerable to climate change impacts than their counterparts in high potential zones. Poor social and economic conditions increase farmer vulnerability in semi-arid areas to the negative impacts of climate variability.

4.2. Farmer perception of climate change

A substantially high percentage of the farmer respondents in all the sites noted that the average temperatures had increased during the last ten years (Fig. 2). Although there was an almost unanimous (100%) agreement that rainfall patterns had changed, the nature of the change differed per site. Most farmers agreed (60–82%) that climate change had affected crop choice in all sites, although the proportions were higher in Mbeere South and Meru South Sub-Countries (Fig. 2A). There was a

significant response that climate change influenced farm management decisions in Meru-South and Mbeere-South Sub-Countries, while in Maara Sub-County, the influence was significantly lower (Pearson Chi-Square 0.01) (Fig. 2A).

High rainfall incidences were reported in Mbeere South, compared to Maara and Meru-South Sub-Countries (Fig. 2B), while most farmers reported temperature increases in all sites (Fig. 2C). Changes in rainfall patterns indicated that most farmers experienced erratic rainfall, late rainfall onsets, and more extended seasonal droughts. There were significant chi-square associations between sites and reported changes in rainfall patterns. Rainfall patterns were more erratic in Mbeere-South and Meru-South Sub Counties than in Maara Sub County. The results showed that the rains had become more erratic with late onsets at the beginning of the planting season, while prolonged dry spells became more frequent than in the past seasons.

Regarding the most probable rainfall onset dates, March 15th plus or minus two days was the most likely rainfall onset date for Meru South and Maara Sub-Countries, while in Mbeere South, the period ranged from 13th to March 22nd during the long rains season (Table 4). The short rain season also followed the same trend, with October 15th being the onset date in Meru South and Maara Sub-Countries. In Mbeere South Sub-County, the respondents identified a range of dates starting from 13th up to and beyond October 25th. Incidences of abnormally high rainfall have been observed, with Mbeere South having 71%, followed by Meru South Sub-County with 56%, and lastly Maara Sub-County with 52%. The years/periods identified with abnormally high rainfall incidences were: 1982, 1997, 1998, long rains (L.R.) 2005 across all the divisions. Where MAM was the long rains season of March April May, while OND was the short rains season of October November December. There was a general agreement that there had been other climatic changes that the respondents have observed over time, including abnormal cold and hot night temperatures, changes in wind patterns, changes in weed infestation, and reduced cloud cover. There were also changes in the July

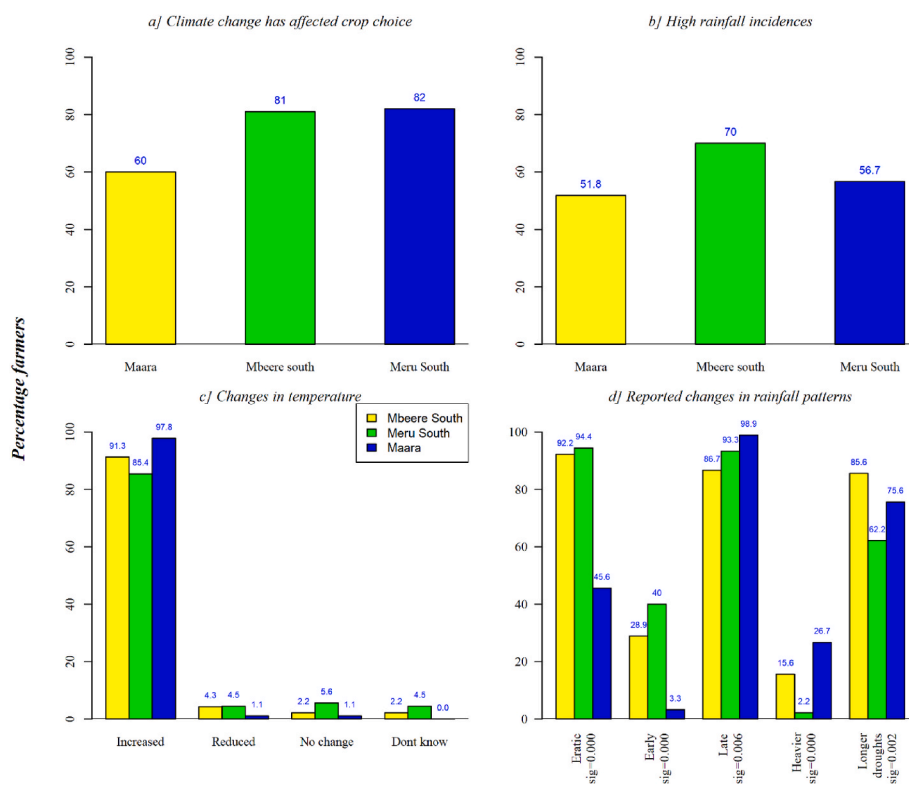


Fig. 2. Farmers' perceptions of climate change, including farmers whose crop choice was affected by climate change (2A), incidences of high rainfall events (2B), changes in temperature (2C), and changes in rainfall patterns (2D), showing significant X^2 tests (site x change in rainfall pattern). Values are percentages calculated based on Sub-County sample sizes (90 each).

Table 4
Most likely rainfall onset dates and seasons that drought is likely to occur.

Most likely rainfall onset dates (% respondents)				
Season	Dates	Maara	Mbeere South	Meru South
Long Rains (MAM)	<12	5	9	2
	13–17	89	29	53
	18–22	4	30	2
	23–31	1	32	36
Short Rains (OND)	<12	7	3	6
	13–17	88	16	46
	18–22	3	41	26
	>23	1	36	13
Season that drought is likely to occur (% respondents, frequencies in parenthesis)				
LR only		43.5 (40)	13.5 (12)	15.4 (14)
SR only		23.9 (22)	22.5 (20)	29.7 (27)
Both seasons		32.6 (30)	64 (57)	54.9 (50)
Number of seasons with a total crop failure (% respondents)				
0		41	0	71
1		6	0	19
2		11	10	8
3		9	11	1
4		24	17	1
5		7	33	0
>5		3	28	0

weather, i.e., from a cold, wet season to a dry one, lasting dry spells/strong winds, and reduced rainfall events characterized by hailstones like in the past.

It was necessary to establish whether the respondents had ever experienced droughts or prolonged dry spells in the investigated sites. The response showed that drought or prolonged dry spells were reported in the research areas as all the respondents in Meru-South and Mbeere-South and 97% in Maara had experienced drought (Table 4). Droughts were frequently experienced in both LR and SR seasons in Meru-South and Maara Sub-Counties, while in Mbeere-South Sub-County, although both seasons were still affected, it was more rampant during the LR.

In the last five years (i.e., ten seasons before the survey), 41 and 71% of the Maara and Meru-South Sub-County respondents had not experienced total crop failures (Table 4). Crop failure was frequent in Mbeere South Sub-County, ranging as low as two seasons to as high as 28% of the respondents experiencing it more than five times in 10 seasons (five years) under consideration (Table 4). Compared to Meru-South, Maara was more susceptible to crop failure with a high of 24% who had experienced four seasons of total crop failure. In Mbeere South, there were higher proportions of farmers who reported more than four seasons of total crop failure (78%) compared to all study sites. Farmers in Meru-South experienced lesser uncertainties related to rainfall variability than the other sites.

The perceived general increase in average temperatures (Fig. 2) could lead to undesirable effects for semi-arid agroecosystems, including increased evapotranspiration and frequent drought spells leading to severe soil moisture stress and hence increased risk of crop failure. The unanimous agreement on the temperature observation in all the research sites over time was an indication that the reported changes in temperature transcended temporal and spatial boundaries and were not necessarily of the same magnitude. The respondents' concern about the temperature increase was mainly in line with its impact on agriculture, a concern shared by Stige et al. (2006). They predicted a sharp fall in yields with a 1–2 °C increase in temperature for staple cereal crops in the SSA region.

Mbeere-South (drier agro-ecozone) was more susceptible to rainfall variability compared to Meru-South and Maara Sub-Counties (wetter agroecozone), especially in terms of mid-season gaps (prolonged dry spells). This could be attributed to the geographical location and climatic conditions of Mbeere-South, an indication that changing rainfall amounts and patterns and the generally increasing temperatures may

vary by location and time. According to the current study results, the rainfall variability is likely to be worse in dry areas than in high-potential agro-ecological zones (Thornton, 2010). The findings were consistent with Kisaka et al. (2015), who found that probabilities of experiencing dry spells exceeding 15 days were relatively higher in low-potential zones compared to high potential zones in the study area during both SR and LR seasons.

The dates of the onset and cessation of the rainy season are important for rain-fed agriculture in semi-arid agro-ecozones of the SSA region because of the marked seasonal nature of rainfall. The observed shift in onset dates and the frequency of droughts (Table 3 and Fig. 2) are in agreement with the findings of Ovuka and Lindqvist (2000) and (Meehl et al., 2007). A study in Murang'a Sub-County, central Kenya, which showed that farmers had observed rainfall decreases over the last 40 years, was not reflected in a decrease in the total rainfall amounts. Still, there were indications for more frequent dry spells towards the end of the short rains (Ovuka & Lindqvist, 2000). The dry spells are in line with the general expectation that, in a warmer world, there will be more intense and heavy rainfall events interspersed with more extended, relatively dry periods with increased evapotranspiration (Meehl et al., 2007).

Between long and short rain seasons, Mbeere South and Meru-South showed similar trends with indications of more erratic rainfall during the long rain seasons (Table 4). In Mbeere South Sub-County, the onset dates cover a more extended period, as early as late February and as late as mid-April in the short rains season. This could be attributed to the prevailing climatic conditions in the region, with annual average rainfall amounts that are generally low (Jaetzold et al., 2007). There was a general perception that the short rain seasons were comparatively more reliable than the long season. These observations call for different adaptive field management strategies, including changing planting dates, crop varieties, and crop types grown.

The observation that the rainfall onset date had shifted from the "normal" period in both seasons and that the incidences of drought had become more frequent in all the sites was a clear indication that the farmers were aware of the local climatic variation. This awareness is critical in initiating action to remedy the situation. van Aalst et al. (2008) pointed out that awareness of trends, regardless of the many causes, can be a first step in addressing changing risks. The findings suggested that small-scale farmers were cognizant of the vagaries of climate variability. The study findings were consistent with Musafiri et al. (2022a), who found that the main indicators of climate change included an increase in temperature and decrease in rainfall amount, changes in cropping calendar, rainfall frequency, drought occurrence, and flooding frequency.

4.3. Farmers' strategies to adapt to drought and prolonged dry spells

In the quest to overcome the effects of drought and prolonged dry spells, farmers employed several adaptation strategies in their farming activities (Fig. 3). The most common climate adaptation strategies that farmers adopted included terraces (89%), early maturity varieties (82%), and intercropping (79%), while the least common strategies included water-harvesting strategies (29%), trenches (35%), and staggering of planting dates (46%) across all study sites (data not shown). In Mbeere South Sub-County, planting early maturing crop varieties, use of cover crops, and terracing were the farmers' most preferred climate adaptation strategies. Unlike Meru-South and Maara Sub-County, the farmers preferred water harvesting structures, planting of agroforestry trees, and digging trenches/infiltration ditches in Mbeere South Sub-County. Although Meru-South and Maara Sub-Counties are adjacent, there was a difference in the adaptation strategies employed by farmers. In Meru South Sub-County, terracing was the most utilized strategy, followed by cover crops and planting early maturing crops while reducing plant population, water harvesting and digging trenches/infiltration ditches were the least utilized. In Maara Sub-County,

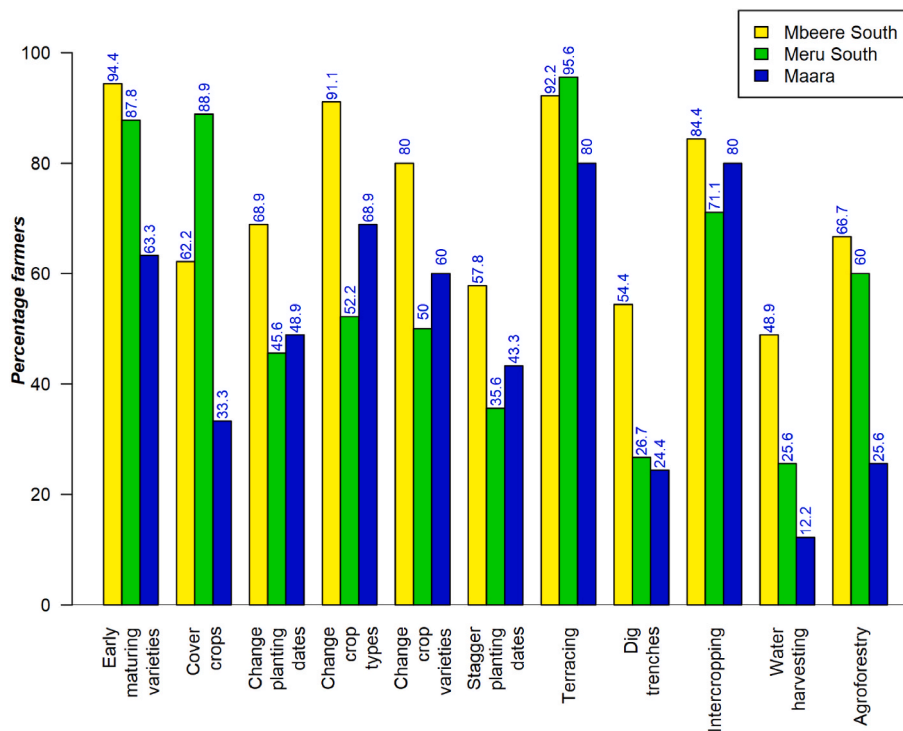


Fig. 3. Utilization of the different climate adaptation strategies in Mbeere South, Meru-South and Maara Sub-Countries. All strategies were significantly linked with the site ($X^2 = 0.000$).

intercropping and terracing were the most popular, followed by changing crop type, while water harvesting was the least common adaptation strategy (Fig. 3).

The popularity of terracing in these two sites is probably due to the prevailing altitude, slope, and terrain. Maara and Meru-South Sub-Countries have relatively steep slopes compared to Mbeere South. Hence, terracing has the dual benefits of being both a soil conservation strategy and water harvesting structure. It was the most utilized strategy probably because of its effectiveness in maximizing rainfall infiltration and soil profile recharge, which, to a certain extent, may contribute to dry spell mitigation. Construction of on-farm (in-situ) water harvesting structures for supplemental irrigation and digging trenches were the least utilized in Maara and Meru South Sub-Countries. This is because the technology is both labor-intensive and resource-intensive and that the initial investment for its construction is high. In Mbeere South Sub-County, the implementation of different strategies seemed to be guided more by their efficiency to retain as much rainwater/runoff as possible into the dry spell duration to reduce the risk of crop failure in the semi-arid farming system. This is reflected by the popularity of terraces and digging trenches compared to the other sites (Fig. 3). Besides the labor-intensive water conservation strategies in Mbeere South Sub-County, there was also a tendency for diversification through implementing strategies like agroforestry, planting of cover crops, and intercropping. This is probably due to the low annual rainfall and the prevailing agro-climatic conditions that predispose crops to higher risks than the high potential agricultural sites.

Planting dates were primarily dependent on the rainfall onset, while changing crop type and variety were mostly remedial actions that farmers employed when the rains were late. As an approach of planting dates, staggered planting is a strategy where farmers plant their crops in smaller plots over time. In doing so, they can spread their risks, especially under the circumstances when false rainfall commences. Indeed, the perfect timing of planting dates is one of the critical factors which strongly affect crop production in rainfed (Ati et al., 2002) farming systems. This is especially true in many parts of sub-humid and semi-arid Africa, where the rainy season starts with some light showers followed

by dry spells, which can cause poor crop emergence or desiccate a young crop (Makarau, 1995). Timely farm preparation and planting enable complete crop response to the rainfall at the beginning of the rainy season may constitute the difference between harvesting a crop and a complete crop failure.

Reduction of plant population in Maara and Meru South Sub-Countries was common, especially during the long rains season. During this season, the farmers increased the space between the rows to accommodate more beans because the chances of beans growing to maturity were higher than maize. Most farmers in the three study areas reported changing their maize varieties towards early maturing genotypes in the recent past. This is in line with the observed early rainfall cessation attributed to patterns of climate variability.

Cover crops were not very popular in all the sites because of the competing interests in utilizing the fields, especially inter-seasonal for livestock feeding. Also, the depletion of soil moisture through transpiration was considered negative except for those cover crops that could be used for human consumption. Successful trials have been carried out on cover crops farming in more water-scarce environments (Fowler & Rockström, 2001). Farmers try to incorporate leguminous intercrops whenever possible (Kaumbutho et al., 2009). While promoting soil and water conservation, terracing results in the deposition of fine sediments rich in nutrients around the excavations and bunds that improve nutrient concentration and result in improved productivity (Makurira et al., 2009).

The finding indicated that small-scale farming households adopted various climate variability coping strategies. Moreover, the adoption level of specific practices ranged from low to high. The findings were consistent with previous studies in the SSA, which revealed that adoption of individual technologies varies extensively, with some practices recording low adoption rates while others were high (Mango et al., 2017). Additionally, the findings indicated that small-scale farming households adopted a bundle of technologies. The findings suggested that smallholders adopt multiple technologies to harness their complementary benefits. Our results were in line with Ndiritu et al. (2014), Mairura et al. (2021), and Musafiri et al. (2022b), who revealed that

small-scale farmers practiced joint adoption of climate-smart practices.

4.4. Farm-level predictors for climate adaptation strategies

The binary regression model results indicated that male-managed farms were positively and significantly associated with changing planting dates, crop varieties, and crop types than female-managed farms. At the same time, younger farmers recorded a higher propensity to use in-situ water-harvesting structures than older farmers (Table 5).

The findings from the regression model indicated that male-managed farms were more likely to adopt crop adjustment strategies, including changing planting dates, than female-managed farms. This finding contrasted with Alhassan et al. (2019), who concluded that female farmers had a higher probability of changing their planting dates due to their high vulnerability to climate change. The possible reason for male-managed fields being likely to adjust planting dates, crop varieties, and crop types in the study area was due to the decision-making role of male farmers, which influenced crop adjustment strategies in the context of climate variability. Asrat and Simane (2018) explained that female-headed households were limited by labor because they were involved in farming and household activities in rural Ethiopia.

The younger farmers in the study were more likely to adopt water-harvesting strategies than older farmers due to the labor-intensive nature of the technology. The significant negative regression was in agreement with Alhassan et al. (2019) and Marie et al. (2020), who found that younger farmers in arid regions of Ghana and Ethiopia were more likely to adopt labor-intensive soil conservation strategies compared to their older counterparts due to their capability to provide labor. Marie et al. (2020) also found that gender was important for the use of improved crop varieties in Ethiopia, similar to the study findings. The findings indicate that apart from decision-making, male-headed farms were more likely to access crop technologies and climate change knowledge in Central Kenya than female households, explaining their significant propensity to adopt the strategies. The findings agreed with Macharia et al. (2014), who found that old farmers were risk-averse and slower in adopting agricultural innovations.

Higher educational attainments were positively and significantly associated with changing crop types, staggering planting dates, intercropping, and reducing plant populations, compared with farmers who had not attained secondary level education, while increasing farm TLU was positively and significantly linked with the adoption of water-harvesting structures. The regression for education showed that farmers with more education (above high-school qualification) were more likely to employ knowledge-based strategies to modify their cropping practices, including changing crop types, staggering planting dates, intercropping, and reducing plant populations than farmers who had attained lower educational qualifications. Mulwa et al. (2017) found that educated households were more likely to adopt drought-tolerant and disease-tolerant crop varieties than farmers who had attained lower education levels in Malawi. This finding was also supported by Alhassan et al. (2019), who found that higher education levels were associated with changing crop varieties in an arid region of Ghana. Education and farmer experience were likely to influence changing crop varieties. This is likely to influence changing crop varieties and several crop adjustment strategies, including changing planting dates, as was supported by Alhassan et al. (2019). Formal learning can make farmers knowledgeable, both general and explicit knowledge, regarding different crop varieties, which can affect climate adaptation strategies (Gbetibouo, 2009).

The TLU positively and significantly influenced the adoption of water harvesting technologies. The findings suggested that small-scale farming households with higher TLU were more likely to adopt water harvesting technologies. The farmers with higher TLU were expected to adopt in-situ water-harvesting strategies compared to those with lower TLU due to fodder production for livestock and to benefit from the

Table 5
Binary regression models of factors influencing climate variability adoption strategies.

Farm household parameters	Climate adaptation strategies											Nagelkerke R ² Percentage correct (Yes)
	Early maturing varieties	Cover crop	Changing planting dates	Changing crop type	Changing crop variety	Staggering planting date	Terracing	Trenches	Intercropping	Water-harvesting	Agroforestry	
Gender	1.141	-0.101	0.976*	1.673**	1.035*	0.512	-0.787	0.154	0.222	-0.015	-0.359	0.611
Age	-0.004	0.030	-0.017	-0.029	-0.029	0.009	0.029	0.010	-0.013	-0.046*	-0.015	-0.011
Farm	0.194	-0.074	-0.122	-0.163	-0.033	-0.067	0.190	0.066	0.106	0.197	-0.031	0.157
Education	0.497	-0.253	0.367	0.974*	-0.217	0.820*	-0.708	0.329	0.978*	0.634	-0.186	0.716*
TLUha ⁻¹	-0.035	0.006	-0.016	-0.029	-0.003	0.005	-0.004	0.040	0.072	0.080*	0.027	0.025
Has title	1.412**	0.456	-0.489	-0.916	-0.049	-0.649	0.929	-0.302	-0.679	0.495	0.661	0.587
Food insecurity	1.171*	1.132**	1.104	0.005	-0.392	-0.474	1.009	-0.116	0.175	-0.178	0.202	0.564
Cultivates fodder	-1.165	0.421	1.026*	-0.637	0.851	0.105	1.190	-0.172	0.773	-0.059	-0.182	0.560
Hired labour	-0.108	0.317***	0.034	-0.102	-0.007	0.054	0.363**	0.136	-0.127	0.253**	0.146*	-0.061
Credit	0.693	0.292	-0.722	-0.048	-0.865*	-1.292**	-0.328	-0.159	-0.068	-0.715	-0.786	-0.140
Group	0.911	-0.039	0.229	0.422	0.119	0.372	-0.857	-0.208	0.397	0.708	-0.167	0.527
Extension/NGO	0.346**	0.416***	0.170*	0.220*	0.067	0.027	0.193	0.137*	0.016	0.257**	0.197**	0.048
Climate change	-0.296	1.644***	0.713*	-0.564	0.133	1.282***	-0.626	0.968**	0.487	1.927***	0.764*	0.676
Poor soils	0.043	0.076	0.499*	0.103	0.601*	0.662**	0.535	0.390*	-0.060	0.619**	0.625**	0.355
Good soils	-0.165	0.053	0.273	0.727**	0.526*	0.311	0.020	0.022	-0.021	0.408**	-0.121	0.307*
Crop failure	0.292	-0.044	0.543	0.773	0.419	0.741*	1.382*	-0.061	0.835*	0.635	0.120	0.885**
Constant	-3.569	-4.116*	-0.938	21.184	0.279	-0.371	-2.216	-3.048	19.397	-3.011	0.642	-3.675*
				36.4	22.9	37	35.8	22	19.9	43.3	26.9	27.1
	36.5	40	25.6	79.4	68.3	74.2	92.3	72.4	76.4	81.4	70.6	69.2

complementary interactions of soil-water conservation, livestock production, and fodder production. In semi-arid areas of Botswana, higher TLU and more secure land tenure increased the likelihood of adopting climate adaptation strategies (Mugari et al., 2020). The findings were consistent with Musafiri et al. (2022b), who found that TLU positively influenced the adoption of climate-smart agricultural practices.

Farmers with secure land tenure were more likely to adopt early-maturing crop varieties than their counterparts without, while farmers who experienced food insecurity had a higher propensity to adopt early maturing varieties and cover crops. Farmers who cultivated fodder crops had a higher propensity to adjust planting dates than those who did not. Regarding hired labor, farmers who hired external labor for their farm operations recorded a higher propensity to adopt cover crops, terracing, water-harvesting strategies, and agroforestry practices. Land tenure was reported by Mugari et al. (2020) to influence the adoption of crop adjustment strategies, a finding which was expected. Farmers who had experienced food insecurity were more likely to adopt early maturing crop types and use cover crops. Early-maturing varieties reduce the risk of crop failure, while cover crops contribute to soil and water conservation. Farmers who used hired labor recorded a higher propensity to adopt cover crops, terraces, water-harvesting technologies, and agroforestry, labor-intensive climate adaptation technologies.

Farmers who received more training from extension services and NGOs (number of strategies trained) recorded a higher likelihood of adopting early maturing varieties, cover crops, changing planting dates, changing crop types, digging trenches, water-harvesting, and agroforestry practices. Regarding training, farmers who accessed more technologies recorded a higher propensity to adopt knowledge-intensive and resource-intensive climate adaptation strategies. This was expected because of the significantly influenced technologies, including early maturing varieties, cover crops, changing of planting dates, use of terraces, in-situ water harvesting, and agroforestry. The training was a significant factor that influenced crop adjustment practices and sustainable land management practices in Kenya (Aryal et al., 2021). Aryal et al. (2021) showed that trained farmers were more likely to adopt crop adjustment practices because they were more aware of adequate practices to cope with climate risks, including the use of early maturing varieties and changing planting dates. The training was also beneficial for farmers adopting climate adaptation strategies in case of resource and labor-intensive technologies, including in-situ water-harvesting, terraces, and agroforestry practices, which can be varied and complex. Bryan et al. (2013) found that adopting soil-water conservation and changing planting dates was influenced by training from agricultural extension, including researchers and shared interest groups, which included NGO training sources in this survey.

Regarding environmental factors, farmers who had larger proportions of their farms with poor soils were more likely to adopt changing planting dates, crop varieties, staggering planting dates, digging of trenches, in-situ water harvesting, and agroforestry. This finding was expected because farms that reported higher portions of poor soil niches were likely characterized by low soil organic matter contents and poor soil texture, contributing to low soil moisture contents and water-holding capacities (Bot & Benites, 2005). Thus, the farmers adjusted planting dates on these soils due to the higher risk for crop failure partly as a result of their low water and nutrient holding capacities. Farmers also adapted crop varieties to poor soil niches by planting drought-resistant crops or staggering planting dates on these sites. Terraces and in-situ water harvesting strategies were adopted to preserve water and soil nutrients. Asrat and Simane (2018) showed that farmers were more likely to adopt climate coping strategies in on-farm niches that were more susceptible to climate change risks, including steep slopes and poor soil fertility in farm sector units. Poor farm niches were negatively and significantly related to adaptation in more arid lowlands, where farmers may abandon a given plot when the soil fertility reduces beyond certain thresholds (Asrat & Simane, 2018). This is comparable to high potential agricultural zones due to larger per

capita land areas in semi-arid areas such as Mbeere South Sub-County. The finding was in line with Otieno et al. (2021), who found that smallholders farmers who perceived their land had poor soil fertility were more likely to adopt integrated soil fertility practices.

Farmers who experienced climate change during the decade that preceded the survey were more likely to adopt cover crops, changing planting dates, staggering planting dates, terraces, water-harvesting, and agroforestry than farmers who did not experience climatic changes. Climate change triggers small-scale farmers to experience climate change-related shocks, including reduced productivity (Amadu et al., 2020; Mairura et al., 2021). Cognizant of the vagaries of climate change, the smallholders adopt climate variability coping strategies. Our findings were similar to Tesfahunegn et al. (2016), who showed that climate change perceptions significantly influence adaptation.

Farms that recorded higher crop failure instances were also more likely to adopt staggering planting dates, terracing, intercropping, and reductions in plant populations than farms that observed lower instances of crop failure during the preceding five years. The findings suggested that the propensity to adopt climate variability coping strategies increased with the increase in crop failure incidences. Similar to our findings, Marie et al. (2020) found that small-scale farmers who experienced crop failure adopt climate variability coping practices to curb the shocks.

4.5. Challenges in implementing various climate coping strategies

This section reports the main challenges for coping with climate variability that was encountered by the farmers in Fig. 4.

The constraints that farmers encountered and limited them from implementing these strategies included; shortage of labor, financial constraints, lack of access to inputs, and lack of information on climate change and adaptation. In Maara Sub-County, lack of information on climate change was identified by 49% of the respondents as the most limiting constraint, followed by 36% citing financial constraints, while no access to inputs was the least common, with 2% citing (Fig. 4). Shortage of labor was the most common constraint identified by 44% of the respondents in Mbeere South Sub-County, and financial shortage and lack of information on climate change and adaptation were ranked second and third by 28% and 23% of the respondents, respectively (Fig. 4). In Meru South Sub-County, the trend followed that of Maara Sub-County with variations in the number of respondents. Lack of information on climate change and adaptation was the most common constraint in the two sites, followed by financial constraints, labor shortage, and lastly, no access to inputs.

The opportunity to identify alternatives, secure diverse sources, and experience ensuing benefits partly depends on people's objective adaptive capacity. Kuruppu (2009) defines this as "the set of resources available for adaptation and the ability or capacity of that system to use these resources effectively in the pursuit of adaptation" (. The farmers in the Central Highlands of Kenya were able to identify the most dominant day-to-day challenges as they carried out their farming activities.

Lack of information on climate change and adaptation strategies was the most limiting in both Maara and Meru-South Sub-Counties, probably because of the region's socioeconomic conditions and farm characteristics. As shown in Table 1, these regions generally have a small farm size which affects the scales of production of all other agricultural activities. For instance, the TLU was higher in Maara and Meru South than Mbeere South Sub-County. The small farm sizes and high population densities call for agricultural production intensification, requiring new climate adaptation strategies. Also, the farmers in the high-potential regions were more educated than those of Mbeere South. Hence, they were more likely to make a deliberate effort to source information and do their own needs assessment concerning their prevailing climate adaptation situations. Labour shortage was the most prominent challenge in Mbeere South, probably due to bigger farm sizes ($p = 0.05$), low population densities, and prevailing agro-climatic conditions that call for more

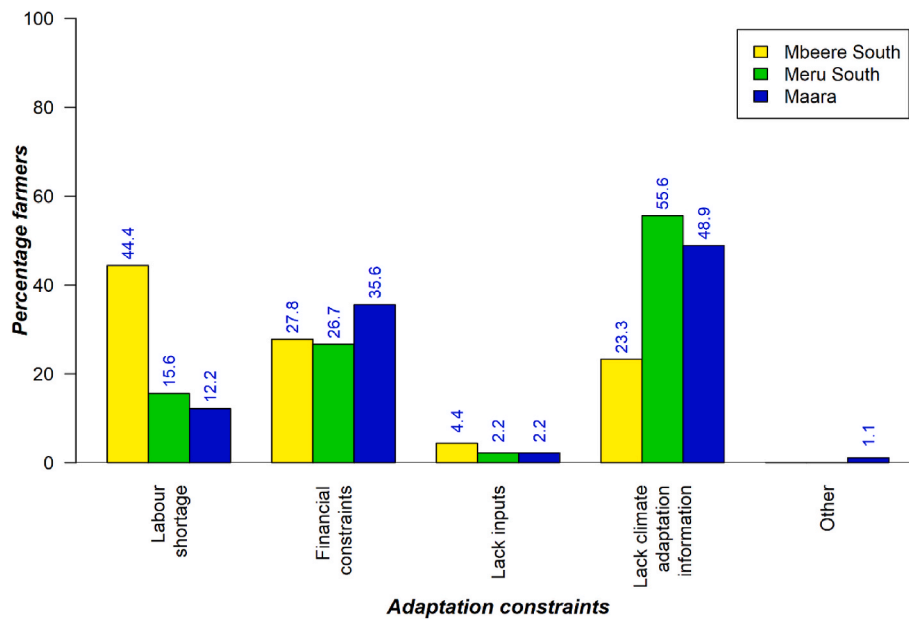


Fig. 4. The most important constraint to implementing the coping strategies against rainfall variability in Mbeere South, Meru-South, and Maara Sub-Countries.

labor-intensive strategies (such as infiltration ditches and terraces). As observed in the rainfall variability component and coping strategies, it was clear that Mbeere South was most affected by the climatic variability that has had adverse effects on rainfall patterns and amounts.

Furthermore, education levels were low and are reflected by the inverse relationship with lack of information as a challenge to adopting various coping strategies (Table 1 and Fig. 3). Although access to inputs was not a major constraint, financial constraints were prominent with almost equal measure in all the study areas (Fig. 4). The relationship between these constraints and the farm socioeconomic characteristics might suggest that vulnerability cannot be attributed to climatic factors alone but to a multiplicity of contextual conditions (Eriksen & Silva, 2009). These household contextual conditions include; gender, household types, types of livelihood activities, and education levels (Tschakert, 2007). Also, social factors such as institutional capacity and governance, social capital and access to transport infrastructure are important in determining farmer responses to climate stress (Reid & Vogel, 2006). The findings indicated that the small-scale farming households were confronted with multiple challenges in adopting agricultural technologies. The findings agreed with Musafiri et al. (2022a), who found that small-scale farmers in Western Kenya dealt with unpredictable weather patterns, financial constraints, and limited agricultural training. The results agree with several studies that report financial constraints and high implementation costs as main hurdles of small-scale farmers' adopting resource-intensive and labor-intensive climate variability coping practices.

5. Conclusions

Based on the results of this study, there were lessons learned on how the farmers adapted to climatic variability. As shown by the various adaptation strategies adopted by the farmers, the farmers could adjust their livelihood strategies to the variations in climate, both short and long-term. Farmers can make sound decisions on what to plant, field management, such as when to plant and agronomic practices, and the general tendency to diversify production systems. Such strategies as intercropping, planting of cover crops, and construction of water harvesting structures were employed in all the study areas.

The study findings have indicated that farmers in ASALs, including Mbeere South, faced more risks due to climate variability due to the nature of climatic variation in this agro-ecozone that differed from high

potential zones. The farmers in low-potential zones were also least capable of coping with climatic variability than their counterparts in higher potential zones. In low potential zones, farmers were characterized with lower endowments in natural capital, financial capital, human capital, social capital, and institutional capital compared to farmers in high potential zones. Farmers in low potential zones were characterized by lower socioeconomic endowments, including education levels, less secure land tenure systems, poor training access, and poor extension and credit facilities necessary for resilience and successful climatic adaptation strategies. There was evidence that climatic changes, including more erratic rainfall patterns and temperature regimes, had affected farm management decisions and cropping patterns more significantly in semi-arid zones than high potential zones in central Kenya. In the drier zones, farmers tended to prioritize implementation of water conservation, unlike in Meru South and Maara, where the focus was on those agronomic strategies that provided dual purpose and complimentary benefits, including soil and water conservation. The tendency of the farmers to diversify through the utilization of cover crops, intercropping, and agroforestry is a clear indication of the versatility of the farmers in the drier areas in minimizing climate variability-related risks.

In agreement with our hypothesis, farm and farm, environmental and institutional factors influenced the adoption of climate variability coping strategies. Farm socioeconomic characteristics were important factors that influenced farmer adaptation, including gender and age differentials, education and training, labor availability, household food security status, and preceding occurrences of crop failure. Within the backdrop of everyday life, the results illustrate the struggles the small-scale farmers in the central highlands of Kenya undergo in their attempts to enhance their agricultural production despite the adverse effects of rainfall variability in order to transform their endeavors into quality livelihood outcomes. The highlighted challenges would need to be considered in future efforts to promote field management adaptation strategies. There is a need to develop holistic approaches that incorporate scientific findings from the researchers and the local households-based strategies that can enhance risk assessment and management, coping and adaption strategies, and decision-making by multiple stakeholders.

CRedit authorship contribution statement

Felix K. Ngetich: Conceptualization, Investigation, Methodology,

Formal analysis, Data curation, Writing – original draft. **Franklin S. Mairura**: Formal analysis, Visualization. **Collins M. Musafiri**: Writing – review & editing. **Milka N. Kiboi**: Writing – review & editing, Validation. **Chris A. Shisanya**: Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors wish to thank the Belgian Directorate-General for Development Cooperation (DGDC) through the Flemish Interuniversity Council–University Development Cooperation (VLIR-UOS) for providing financial support (Project nr. ZEIN2008PR349). We appreciate the participation of our collaborators and farmers.

References

- van Aalst, M. K., Terry Cannon, T., & Burton, I. (2008). Community level adaptation to climate change: The potential role of participatory community risk assessment. *Global Environmental Change*, 18, 165–179.
- Adger, W. N., Arnell, N., & Tompkins, E. (2005). Successful adaptation to climate change across scales. *Global Environmental Change*, 15(2), 77–86.
- Alhassan, H., Kwakwa, P. A., & Adzawla, W. (2019). Farmers choice of adaptation strategies to climate change and variability in arid region of Ghana. *Review of Agricultural and Applied Economics*, 22(1), 32–40.
- Amadu, F. O., McNamara, P. E., & Miller, D. C. (2020). Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi. *World Development*, 126, Article 104692.
- Aryal, J. P., Sapkota, T. B., Rahut, D. B., Marenya, P., & Stirling, C. M. (2021). Climate risks and adaptation strategies of farmers in East Africa and South Asia. *Scientific Reports*, 11, Article 10489.
- Aseyhegn, K., Temple, L., Sanchez, B., & Iglesias, A. (2017). Perception of climate change and farm level adaptation choices in central Kenya. *Cahiers Agricultures*, 26, Article 25003. <https://doi.org/10.1051/cagri/2017007>
- Asrat, P., & Simane, B. (2018). Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecological Processes*, 7, 7. <https://doi.org/10.1186/s13717-018-0118-8>
- Ati, O. F., Stigter, C. J., & Oladipo, E. O. (2002). A comparison of methods to determine the onset of the growing season in northern Nigeria. *Agricultural and Forest Meteorology*, 117, 23–37.
- Barron, J., Rockström, J., Gichuki, F., & Hatibu, N. (2003). Dry spell analysis and maize yields for two semi-arid locations in East Africa. *Agricultural and Forest Meteorology*, 117(1-2), 23–37.
- Berrang-ford, L., Ford, J. D., & Paterson, J. (2010). Are we adapting to climate change? *Global Environmental Change*, 2, 25–33.
- Bot, A., & Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food production*. Rome: Food And Agriculture Organization of The United Nations.
- Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., & Herrero, M. (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, 114, 26–35. <https://doi.org/10.1016/j.jenvman.2012.10.036>
- Camberlin, P., Janicot, S., & Pocard, I. (2001). Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. *International Journal of Climatology*, 21, 973–1005.
- Cooper, P., Dimes, J., Rao, K., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems & Environment*, 126, 24–35.
- Core Team, R. (2020). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. URL <https://www.R-project.org/>.
- Dessai, S., Hulme, M., Lempert, R. J., & Pielke, R., Jr. (2009). Climate prediction: A limit to adaptation? In W. N. Adger, I. Lorenzoni, & I. K. L. O'Brien (Eds.), *Adapting to climate change: Thresholds, values, governance* (pp. 49–57). Cambridge, UK: Cambridge University Press.
- Eriksen, S., & Silva, J. A. (2009). The vulnerability context of a savanna area in Mozambique: Household drought coping strategies and responses to economic change. *Environmental Science & Policy*, 12, 33–52.
- FAO. (1978). *Report on the agro-ecological zones project. Methodology and results for Africa*. (= world soil resources Rep., 248/1). Rome.
- Fowler, R., & Rockström, J. (2001). Conservation tillage for sustainable agriculture. An agrarian revolution gathers momentum in Africa. *Soil and Tillage Research*, 61, 93–108.
- Gbetibouo, G. A. (2009). *Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo basin*. South Africa (No. 15–8). Washington, DC.
- Gichangi, E. M., Gatheru, M., Njiru, E. N., Mungube, E. O., Wambua, J. M., & Wamungu, J. W. (2015). Assessment of climate variability and change in semi-arid eastern Kenya. *Climatic Change*, 130, 287–297. <https://doi.org/10.1007/s10584-015-1341-2>
- Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L., & Rockström, J. (2010). Greening the global water system. *Journal of Hydrology*, 384, 177–186.
- Released IBM Corp. (2020). *IBM SPSS statistics for windows (version 27.0)*. Armonk, NY: IBM Corp.
- IPCC. (2007). *IPCC 4th assessment report - climate change 2007. Working group II on "impacts, adaptation and vulnerability"*. <http://www.ipcc-wg2.org>.
- IPCC. (2014). Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In *Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]* (pp. 117–130). Geneva, Switzerland: IPCC.
- IPCC. (2014a). *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*.
- Jaetzold, R., Schmidt, H., Hornet, Z. B., & Shisanya, C. A. (2007). In *Farm management handbook of Kenya. Natural conditions and farm information* (2nd ed., Vol. 11). Nairobi, Kenya: Ministry of Agriculture/GTZ. C. Eastern Province.
- Kabubo-Mariara, J., & Karanja, F. K. (2007). The economic impact of climate change on Kenyan crop agriculture: A Ricardian approach. *Global and Planetary Change*, 57, 319–330.
- Kalele, D. N., Ogara, W. O., Oludhe, C., & Onono, J. (2021). Climate change impacts and relevance of smallholder farmers' response in arid and semi-arid lands in Kenya. *Scientific African*, 12, Article e00814. <https://doi.org/10.1016/j.sciaf.2021.e00814>
- Kaumbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., & Mawenya, L. (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. *Soil and Tillage Research*, 103, 23–32.
- Kenya Soil Survey. (1982). *Exploratory soil map and agro-climatic zones map of Kenya*. scale 1:1 000 000, Rep. E 1, Nairobi.
- Kisaka, M. O., Mucheru-Muna, M., Ngetich, F. K., Mugwe, J. N., Mugendi, D. N., & Mairura, F. S. (2015). Rainfall variability, drought characterization and efficacy of rainfall data reconstruction: Case of Eastern, Kenya. *Advances in Meteorology*, Article 380404. <https://doi.org/10.1155/2015/380404>
- KNBS (Kenya National Bureau of Statistics). (2019). *Kenya population and housing census* (Vol. 1). Nairobi, Kenya: Population by County and Sub-County.
- Kuruppu, N. (2009). Adapting water resources to climate change in Kiribati: The importance of cultural values and meanings. *Conservation Ecology*, 12, 799–809.
- Macharia, J., Mugwe, J., Mucheru-Muna, M., & Mugendi, D. (2014). Socioeconomic factors influencing levels of knowledge in soil fertility management in the central highlands of Kenya. *Journal of Agricultural Science and Technology B*, 4(9), 701–711.
- Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., Okeyo, J. M., Mugendi, D. N., Okwuosa, E. A., & Ngetich, F. K. (2021). Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya. *Weather and Climate Extremes*, 34, Article 100374.
- Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., Okeyo, J. M., Okwuosa, E. A., & Ngetich, F. K. (2022). Farm factors influencing soil fertility management patterns in Upper Eastern Kenya. *Environmental Challenges*, 6, Article 100409.
- Makarau, A. (1995). *Intra-seasonal oscillatory modes of the Southern Africa summer circulation*. Town, South Africa: Ph.D thesis. University of Cape.
- Makurira, H., Savenije, H. H. G., Uhlenbrook, S., Rockström, J., & Senzanje, A. (2009). Investigating the water balance of on-farm techniques for improved crop productivity in rainfed systems: A case study of Makanya catchment, Tanzania. *Physics and Chemistry of the Earth*, 34, 93–98.
- Mango, N., Makate, C., Tamene, L., Mponela, P., & Ndengu, G. (2017). Awareness and adoption of land, soil and water conservation practices in the Chinyanja Triangle, Southern Africa. *International Soil and Water Conservation Research*, 5(2), 122–129.
- Marie, M., Yirga, F., Haile, M., & Tqubao, F. (2020). Farmers' choices and factors affecting adoption of climate change adaptation strategies: Evidence from northwestern Ethiopia. *Heliyon*, 6(4), Article e03867.
- Martey, E., & Kuwornu, J. K. (2021). Perceptions of climate variability and soil fertility management choices among smallholder farmers in northern Ghana. *Ecological Economics*, 180, Article 106870.
- Mavhura, E., Manatsa, D., & Matiashe, M. (2017). Adapting smallholder farming to climate change and variability: Household strategies and challenges in Chipinge district, Zimbabwe. *Climate Change*, 3(12), 903–991.
- Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M., Kitoh, A., Knutti, R., Murphy, J. M., Noda, A., Raper, R. L., Watterson, I. G., & Zhao, Z. C. (2007). Global climate projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.), *Climate change: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Mortimer, M., & Manvel, C. (2006). *Climate change: Enhancing adaptive capacity. Natural resources systems program briefing note*. www.nrsp.org.uk.
- Mugari, E., Masundire, H., & Bolaane, M. (2020). Adapting to climate change in semi-arid rural areas: A case of the Limpopo Basin part of Botswana. *Sustainability*, 12, 8292. <https://doi.org/10.3390/su12208292>
- Mugi-Ngenga, E. W., Kiboi, M. N., Mucheru-Muna, M. W., Mugwe, J. N., Mairura, F. S., Mugendi, D. N., & Ngetich, F. K. (2021). Indigenous and conventional climate-knowledge for enhanced farmers' adaptation to climate variability in the semi-arid agro-ecologies of Kenya. *Environmental Challenges*, 5, Article 100355.

- Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merckx, R., Chianu, J., & Vanlauwe, B. (2009). Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. *Experimental Agriculture*, 45, 61–75. <https://doi.org/10.1017/S0014479708007072>
- Mulwa, C., Marenya, P., Rahut, D. B., & Kassie, M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management*, 16, 208–221.
- Musafiri, C. M., Kiboi, M., Macharia, J., Ng'etich, O. K., Kosgei, D. K., Mulianga, B., Okoti, M., & Ngetich, F. K. (2022a). Smallholders' adaptation to climate change in Western Kenya: Considering socioeconomic, institutional and biophysical determinants. *Environmental Challenges*, 7, Article 100489.
- Musafiri, C. M., Kiboi, M., Macharia, J., Ng'etich, O. K., Kosgei, D. K., Mulianga, B., Okoti, M., & Ngetich, F. K. (2022b). Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: Do socioeconomic, institutional, and biophysical factors matter? *Heliyon*, 8(1), Article e08677.
- Musafiri, C. M., Macharia, J. M., Ng'etich, O. K., Kiboi, M. N., Okeyo, J., Shisanya, C. A., Okwuosa, E. A., Mugendi, D. N., & Ngetich, F. K. (2020). Farming systems' typologies analysis to inform agricultural greenhouse gas emissions potential from smallholder rain-fed farms in Kenya. *Scientific African*, 8, Article e00458.
- Mutua-Mutuku, M., Ngululu, S. N., Akuja, T., Lutta, M., & Bernard, P. (2017). Factors that influence adoption of Integrated Soil Fertility and Water Management practices by smallholder farmers in the semi-arid areas of Eastern Kenya. *Tropical and Subtropical Agroecosystems*, 20, 141–153.
- Mwaura, G. G., Kiboi, M. N., Mugwe, J. N., Nicolay, G., Bett, E. K., Muriuki, A., Musafiri, C. M., & Ngetich, F. K. (2021). Economic evaluation and socioeconomic drivers influencing farmers' perceptions on benefits of using organic inputs technologies in Upper Eastern Kenya. *Environmental Challenges*, 5, Article 100282.
- Ndeke, A. M., Mugwe, J. N., Mogaka, H., Nyabuga, G., Kiboi, M., Ngetich, F. K., Mucheru-Muna, M., Sijali, I., & Mugendi, D. (2021). Gender-specific determinants of Zai technology use intensity for improved soil water management in the drylands of Upper Eastern Kenya. *Heliyon*, 7(6), Article e07217.
- Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117–127.
- NEPAD. (2004). *Implementing the comprehensive Africa agriculture development program and restoring food security in Africa*. New Partnership for Africa's Development.
- Njuki, J., Poole, J., Johnson, N., Baltenweck, I., Pali, P., Lokman, Z., & Mburu, S. (2011). *Gender, livestock and livelihood indicators*. Nairobi: ILRI.
- O'Donoghue, C., & Heanue, K. (2018). The impact of formal agricultural education on farm level innovation and management practices. *The Journal of Technology Transfer*, 43, 844–863. <https://doi.org/10.1007/s10961-016-9529-9>
- Omoyo, N. N., Wakhungu, J., & Oteng'i, S. (2015). Effects of climate variability on maize yield in the arid and semi arid lands of lower eastern Kenya. *Agriculture & Food Security*, 4(8). <https://doi.org/10.1186/s40066-015-0028-2>
- Otieno, E. O., Kiboi, M. N., Gian, N., Muriuki, A., Musafiri, C. M., & Ngetich, F. K. (2021). Uptake of integrated soil fertility management technologies in heterogeneous smallholder farms in sub-humid tropics. *Environmental Challenges*, 5, Article 100394.
- Ovuka, M., & Lindqvist, S. (2000). *Rainfall variability in Murang'a District, Kenya: Meteorological data and farmers' perception*, 82A pp. 107–119. Geografiska Annaler Series a-Physical Geography.
- Oyetunde-Uzman, Z., Olagunju, K. O., & Ogunpaimo, O. R. (2021). Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria. *International Soil and Water Conservation Research*, 9(2), 241–248.
- Rapholo, M. T., & Makia, L. D. (2020). Are smallholder farmers' perceptions of climate variability supported by climatological evidence? Case study of a semi-arid region in South Africa. *International Journal of Climate Change Strategies and Management*, 12 (5), 571–585. <https://doi.org/10.1108/IJCCSM-01-2020-0007>
- Reid, P., & Vogel, C. (2006). Living and responding to multiple stressors in South Africa—glimpses from KwaZulu-Natal. *Global Environmental Change*, 16, 195–206.
- Republic of Kenya. (2012). *National policy for the sustainable development of northern Kenya and other arid lands*. Nairobi, Republic of Kenya.
- Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., & Damgaard-Larsen, S. (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. *Soil and Tillage Research*, 103, 23–32.
- Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., Janssen, M. A., McAllister, R. R. J., Müller, B., Orach, K., Schwarz, N., & Wijermans, N. (2017). A framework for mapping and comparing behavioural theories in models of social-ecological systems. *Ecological Economy*, 131, 21–35.
- Shisanya, C. A. (1996). *Chances and risks of maize and bean growing in the semi-arid areas of SE-Kenya during expected Deficient, Normal and above Normal rainfall of the short rainy seasons*. Materialien zur Ostafrika-Forschung. Heft 14, Trier.
- Simbanegavi, W., & Arndt, C. (2014). Climate change and economic development in Africa: An overview. *Journal of African Economies*, 23(2), ii4–ii16. <https://doi.org/10.1093/jae/eju010>
- Smit, B., Burton, I., Klein, R., & Wandel, J. (2001). An anatomy of adaptation to climate change and variability. *Climatic Change*, 45, 233–251.
- Sombroek, W. G., Braun, H. M. H., & Van Der Pouw, B. J. A. (1982). *Exploratory soil map and agro climatic soil survey. Report E1*. Nairobi: Kenya Soil Survey.
- Stige, C., Stave, J., Chan, K., Giannelli, L., Petteorelli, N., Glantz, M., Herren, H., & Stenseth, N. (2006). The effect of climate variation on agro-pastoral production in Africa. *Proceedings of the National Academy of Sciences*, 103, 3049–3053.
- Stringer, L. C., Dyer, J. C., Reed, M. S., Dougill, A. J., Twyman, C., & Mkwambisi, D. (2009). Adaptations to climate change, drought and desertification: Local insights to enhance policy in southern Africa. *Development*, 12, 748–765.
- T Njoka, J., Yanda, P., Maganga, F., Liwenga, E., Kateka, A., Henku, A., Mabhuve, E., Malik, N., & Bavo, C. (2016). *Kenya: Country situation assessment -working paper. Center for sustainable dryland ecosystems and societies/pathways to resilience in semi-arid economies*. Nairobi.
- Tarchiani, V., Rossi, F., Camacho, J., Stefanski, R., Mian, K. A., Pokperlaar, D. S., Coulibaly, H., & Adamou, A. S. (2017). Smallholder farmers facing climate change in West Africa: Decision-making between innovation and tradition. *Journal of Innovation Economics Management*, (3), 151–176.
- Tesfahunegn, G. B., Mekonen, K., & Tekle, A. (2016). Farmers' perception on causes, indicators and determinants of climate change in northern Ethiopia: Implication for developing adaptation strategies. *Applied Geography*, 73, 1–12.
- Thornton, P. K., Jones, P. G., Alagarswamy, G., Andresen, J., & Herrero, M. (2010). Adapting to climate change: Agricultural system and household impacts in East Africa. *Agricultural Systems*, 103, 73–82.
- Tschakert, P. (2007). Views from the vulnerable: Understanding climatic and other stressors in the Sahel. *Global Environmental Change*, 17, 381–396.
- Twomlow, S., Mugabe, F. T., Mwale, M., Delve, R., Nanja, D., Carberry, P., & Howden, M. (2008). Building adaptive capacity to cope with increasing vulnerability due to climatic change in Africa – a new approach. *Physics and Chemistry of the Earth*, 33, 780–787.
- (U.S. Geological Survey), USAID (U.S. Agency for International Development USGS). (2010). *A climate trend analysis of Kenya: August 2010. FEWS NET informing climate change adaptation series*. Washington DC: USAID.
- Waldman, K. B., Todd, P. M., Omar, S., Blekking, J. P., Giroux, S. A., Attari, S. Z., Baylis, K., & Evans, T. P. (2020). Agricultural decision making and climate uncertainty in developing countries. *Environmental Research Letters*, 15(11), Article 113004.
- Wonacott, T. H., & Wonacott, R. J. (1977). *Introductory statistics* (3rd ed.). New York, USA: John Wiley and Sons.