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Impacts of climate variability and change on integrated crop-livestock farming systems in Machakos County, Kenya

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Abstract

Integrated crop-livestock production systems play an important role in meeting the rising demand for food and income for most developing countries, including Kenya. Production has become uncertain due to the rapidly changing climate, threatening food security. However, the potential impacts of climate variability and the change on the mixed crop-livestock systems have not been extensively studied. The study aimed to assess the impacts of climate variability and change on mixed crop-livestock farming in the arid and semi-arid county of Machakos. The study demonstrates that climate change and variability are already having significant adverse impacts on the mixed crop-livestock farming system in Machakos County. The most frequent climate variabilities and extreme events were unreliable rainfall (83.3%), drought (72.8%), rising temperatures (71.8%), and pests and diseases (65.3%). Several impacts of climate change were reported on both crops and livestock production. The major impacts experienced include low yields (88.8%), loss of income (82.3%), crop failure (81.1%), livestock deaths (69.0%), forage scarcity (65.2%), decline and drying of water sources (64.0%) and destruction of infrastructure (53.3%). The climate variability and change have adversely affected mixed crop-livestock farming in Machakos County and, ultimately, agricultural productivity and food security. The findings help site-specific intervention strategies to reduce the impacts of mixed agro-livestock farming on climate change.

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Introduction

Integrated crop-livestock systems form the bulk of smallholder production in nearly all ecological zones in developing countries and more so in the tropics, where they play a critical role in smallholder livelihoods and food security (Gurjar *et al.*, 2018; Herrero *et al.*, 2015). In Kenya, including Machakos County, agricultural production is mainly a mixed crop-livestock farming system practised by 76% of the rural population in Kenya (Amwata, 2020). Agriculture is critical to Kenya's economy and food security, contributing 21% of the country's Gross Domestic Product (GDP) and employing 70% of the labour force (KNBS, 2019). However, the sector is the most vulnerable to climate change and variability, given its exposure, sensitivity, and high dependence on rain-fed production (Amwata and Nyariki, 2021; Parry *et al.*, 2012).

Substantial evidence suggests unprecedented changes in the global mean and extreme climate events, and projections show a possible intensification of these variables in the coming decades due to anthropogenic activities (Intergovernmental Panel on Climate Change-IPCC, 2014; World Bank, 2021). According to IPCC (2018), the climate system will continue to warm, with temperatures projected to rise by 1.5°C above the pre-industrial levels by 2100. Locally, farmers are witnessing high temperatures, hotter days, more intense storms, persistent and widespread droughts, less rainfall, and or changes in the onset and length of growing seasons (IPCC, 2014; Lobell, 2011; Amwata *et al.*, 2018; Amwata and Nyariki, 2021).

It is generally projected that rainfall in Kenya will remain highly variable and uncertain; however, it is expected to decline in arid and semi-arid lands (ASALs) (Amwata, 2020; CCKP, 2020). ASALs will experience long and dry periods interposed with intense but shorter and unpredictable rainfall periods (Kisaka *et al.*, 2015; Speranza *et al.*, 2010). Temperatures are projected to continue rising by 1.7°C by the 2050s and by about 3.5°C at the end of the century (RoK, 2016), while extreme weather and climate events such as droughts and floods may increase in frequency, duration, and intensity (World Bank, 2021). Changes in climate variables directly affect agricultural production, food security and challenge the sustainability of the current mixed crop-livestock production systems, especially in the ASALs of Kenya (Amwata and Snelder, 2021; Aryal *et al.*, 2020; Matiu *et al.*, 2017; Omoyo *et al.*, 2015).

Despite the preceding evidence on climate change and its impacts on agriculture in Kenya, gaps remain in understanding the likely impacts of climate change on agriculture, especially mixed crop-livestock farming, and the resulting implications for adaptation planning. The focus has been on climate change's impacts on agriculture as a sector in general; therefore, the specific aspects related to integrated crop-livestock systems at the local level are missing (Thornton and Herrero, 2014). Previous research that assessed the impacts of climate variability and changes globally (Bernabucci, 2019; Harvey *et al.*, 2018; Gupta *et al.*, 2017; Lobell *et al.*, 2011; Kebubo-Mariara, 2009; Thornton *et al.*, 2007) and locally in Kenya (Kalele *et al.*, 2021; Mumo *et al.*, 2018; Kariuki *et al.*, 2018; Opiyo *et al.*, 2016; Omoyo, 2015). The studies have shown that climate change and variability has adversely impacted crops and livestock production. However, the studies have focused more on crops (Rivera-Ferre *et al.*, 2016) or crops and livestock separately (Amwata *et al.*, 2015; Amwata, 2020).

There has been very little focus on the influence of climate change and variability on the mixed crop-livestock production systems. This study examines smallholder farmers' perception of the understanding of climate change, including the impacts of extreme weather events on mixed crops and livestock production.

Materials and methods

The profile of the study area: topography and climate

The study was carried out in Machakos County (Fig. 1). The terrain in most of the County is relatively hilly, with hills rising between 1800-2100m above sea level (RoK, 2018).

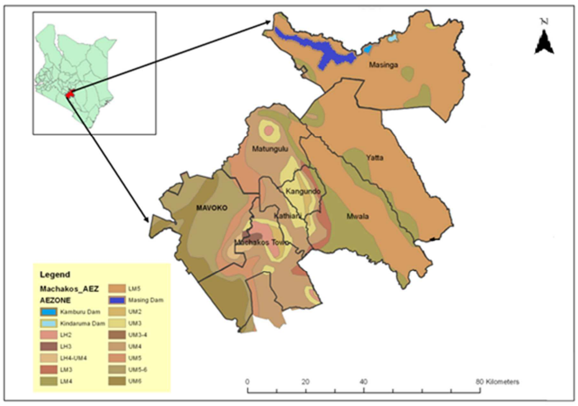

Fig. 1. Map of the study area (Source: Research generated from GIS)

The County is mainly arid and semi-arid and receives a bimodal rainfall with short rains from October to December and long rains from March to May. The rainfall ranges between 500mm and 1250mm and is highly influenced by altitude, with higher areas receiving an average of 1000mm while lowlands receive 500mm. Rainfall in the County is unevenly distributed and unreliable. Temperatures range from 18 to 29°C (Machakos County, 2015; MoALF, 2017). The County is categorized into five agro-ecological zones (AEZs) based on the potential crop production suitability (Jaetzold *et al.*, 2010): Upper midland (UM-2-3), U.M. 5-6, Midland (LM3), L.M. 4 and L.M. 5. The U.M. zones covering 2,730.2 km² have a higher potential for agriculture compared to lower midland zones covering 3,478 km² and are mainly occupied by agro-pastoralists and pastoralists. Mixed crop-livestock production systems are the main enterprises, with the major crops being maize, beans, cowpeas, pigeon peas, and sorghum. Indigenous chickens, goats, sheep, and Zebu cattle are the main livestock species kept.

Research design, data collection, and data analysis

The study employed a multi-stage sampling method that combined purposive and simple random sampling procedures to select households for the survey. In the first stage, Machakos County was purposively selected because of climate variability and change and the risks facing the agriculture sector and farmers in ASAL County. Household survey data were collected from six main agro-ecological zones in the county-Upper midland (UM-2-3), U.M. 4, U.M. 5-6, Midland (LM3), L.M. 4, and L.M. Next, locations in the County were listed and categorized according to the agro-ecological zones. This was followed by a random selection of six study locations, one from each agro-ecological zone. Then, using a list of all farming households obtained from the Kenya National Bureau of Statistics, households for the survey were selected from the six study locations through a systematic random sampling technique. The sample size for each location was calculated using Cochran's (1977) formula (see formula below). A total of 400 households in the county were interviewed. A random start was used to choose the first household to be interviewed.

$$n_0 = \frac{Z^2pq}{e^2} \longrightarrow \text{n}= \frac{n_0}{1+\frac{(n_0-1)}{N}}$$

Where

n_0 = the desired sample size when the population is greater than 10,000

Z= confidence level

P = proportion of the population to be included in the sample (as attributed in question)

q=1-p

e = the desired level of precision or accuracy (margin of error)

n = Sample size when the population is less than 10,000

N = the total population.

Data collection

The study applied a mixed-method approach in which the collection and analysis of data employed qualitative and quantitative techniques. Primary data was collected through interviews with key informants, group interviews with farmers, structured field observations, and household questionnaire surveys. Data collected included demographic and other socioeconomic characteristics, a list of biophysical and socioeconomic impacts of climate change, significant change patterns in the last 20 years, and local knowledge of farming methods and practices.

Secondary data included rainfall amounts, rainfall days, temperatures, land area, types of crop production, and yields. Crop and livestock production data for the last three decades was collected from the Ministry of Agriculture and the County Departments of Agriculture in Machakos County.

Descriptive statistics were used to assess the impacts of climate variability and change on agricultural production activities. Data from the questionnaire were coded, entered, and analyzed using a statistical package for social scientists (SPSS) and STATA software (version 9.0). Descriptive statistics of key variables were computed, analyzed, and presented through frequency distribution, percentages, and measures of central tendency. FGDs data entry, cleaning, and coding were done using emergent themes, and analysis was done using qualitative content analysis.

Results and discussion

Demographic characteristics of household survey respondents

The results show that females were the most dominant respondents at 54%, while 46% were males. Most (65%) of the respondents in the study area were male-headed, while the remaining 35% were female-headed. The results show that most respondents (44.8%) were in the 36-55 age bracket. This is slightly below the Kenyan farmers' average age, estimated at 60 years (GoK, 2019). Most respondents (46.8%) had primary education, followed by those with secondary education at 37.0%. 9.8% had tertiary education, and the remaining 3.0% had no formal education.

The results indicated that the average household size in the study area was 5.3 persons. This is relatively higher than the national household size of 3.9 (KNBS, 2019). Household size has an important implication on the adaptation to impacts of climate variability and change on agriculture in the study area. Family labour is recognized as a source of labour supply in smallholder food production in most parts of Africa, including Kenya. Therefore, farm households with a high level of family labour could counterbalance the impact of climate change on income by participating in off-farm activities (Amwata *et al.*, 2015). Off-farm activities are adaptive responses to climate change, particularly for those households with large family sizes (Karfakis *et al.*, 2012).

Farming patterns

Agricultural production was the primary source of income for most (97%) of the respondents, while 3% indicated they earned their livelihoods from off-farm activities. Most respondents (90.5%) said they practiced rain-fed farming, while only 9.5% said they practiced irrigation. The main crops commonly cultivated by farmers in the study area included maize, cultivated by about 87.8% of the respondents, green grams (82.5%), beans (76.5%), cowpeas (63.3%), and pigeon peas (33.5%). On the other hand, the types of livestock kept by farmers in the study area included cattle, goats, sheep, poultry, and donkeys. The survey showed that poultry was kept by 51% of the respondents, followed closely by goats at 46.0%, then cattle (44.3%), donkeys (40%), and sheep (39.3%) in descending order. The number of cattle owned in the study area ranged from a minimum of one (1) and a maximum of 30 cattle; a minimum of one (1) and a maximum of 31 goats; a minimum of one (1) and a maximum of 10 sheep; minimum of three (3) and a maximum of 100 chicken, and a minimum of one (1) and a maximum of 22 donkeys.

Focus group discussions and interviews revealed that crops are an essential source of livestock feed, alongside providing food income for households. According to FGDs, crop residues were collected and stored for livestock feeding during the dry seasons. The importance of crop residues, especially maize stover, as a strategic dry-season feed resource for livestock in the maize-based mixed crop-livestock system in sub-Saharan Africa, has been explained by Thornton *et al.* (2006), Nyariki (2004) and Amwata *et al.* (2015). Farmers reported that livestock contributes to crop productivity by providing draught power and farmyard manure in the study area, which increases soil fertility, improves soil structure, and enhances the water-holding capacity. This relates to a report by Pell *et al.* (2010) and Nyariki and Amwata (2019) on the benefits farmers derive from livestock and a finding by Herrero *et al.* (2010) on the contribution of livestock to increased crop productivity.

Farmers' perception of performance of agricultural production over the last 30 years

The household survey results indicate that 69% of farmers reported that crop production had declined in the last 30 years, 18% reported that production had remained the same, 8% reported a decline in production, while the remaining 5% had no idea of the changes that had occurred in the area (Fig. 2).

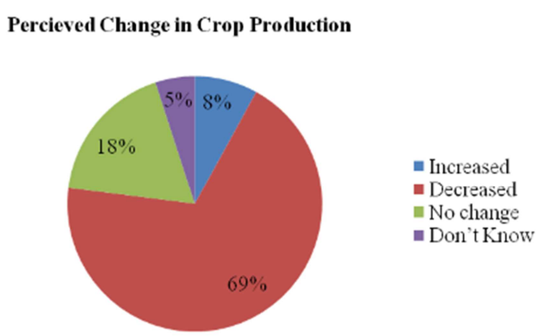

Fig. 2. Perceived changes in crop production

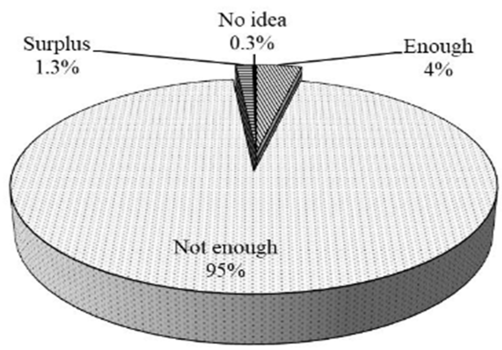

Fig. 3. Distribution of respondents based on views on the amount of crop harvest in the last ten years

Farmers described the performance of crops over the last 30 years during focus group discussions. Participants aged 35 years and below were excluded from this discussion. Table 1 shows the performance of selected crops over 30 years as perceived by smallholder farmers. Farmers observed that the average yield of maize declined by an average of 35% per acre per year over the last 30 years. However, a 26%, 19%, and 20% per acre per year decrease in the average yields of green grams, cowpeas, and pigeon peas, respectively, was recorded only over the last few years.

The study revealed that crop production in the County had declined in the last ten years. Most farmers (94.5%) reported not producing enough food for the household in the last ten years. Only 1.3% of sampled respondents reported having produced enough (Fig. 3). Similarly, secondary data from the Ministry of Agriculture and the County Department of Agriculture in Machakos County indicated low and declining crop productivity, notably maize, green grams, and beans. The county average yield for maize was 0.65 tons per hectare compared to 1.0 tons per hectare in the 70s and 80s. The yield for green grams was 0.45 tons per hectare compared to 0.70 tons per hectare in the 80s, while beans averaged 0.54 tons per hectare compared to 0.56 tons per hectare in the 80s. However, it was noted that sorghum yields had increased from 0.46 tons in the 80s to the current 0.67 tons per hectare. The decline in maize, beans, and green grams yields would be attributed to higher temperatures and low rainfall in the area, and a discussion with the County Director of Agriculture in Machakos County revealed that the increase in yields in sorghum resulted from the crop's promotion due to the market's availability through contractual engagements. The observed decline in yields is consistent with the findings by Omoyo *et al.* (2015), who observed that maize yields were declining by up to 15kgs per acre per year in Machakos, Makueni, and Kitui Counties. Similarly, Ayanlade *et al.* (2017) of Nigeria in which farmers noted that yields in maize, yams, and rice had declined compared to previous years.

Household survey results indicate that about 68% of respondents reported that livestock production had declined in the last 30 years, 15% reported that production had remained the same, 11% reported in production, while 6% reported they could not tell whether there had been any change (Fig. 4).

Table 1. Smallholder farmer's perception of the production of some selected crops in the last 30 years

Crop production per acre	5 years	10 years	20 years	30 years
	Perceived change	Perceived change	Perceived change	Perceived change
Maize	Decreasing	Decreasing	Decreasing	Decreased
Green grams	Decreasing	Decreasing	Increasing	Increasing
Cowpeas	Decreasing	Decreasing	No change	Increasing
pigeon peas	Decreasing	Decreasing	Increasing	Increasing

Table 2. Smallholder farmer's perception of livestock production in the last 30 years

Factor	5 years	10 years	20 years	30 years
	Perceived change	Perceived change	Perceived change	Perceived change
Livestock numbers	No change	Decreasing	Decreasing	Decreasing
Amount of milk	Decreasing	Increasing	Decreasing	Decreasing
Quantity of pasture	Decreasing	Deceasing	No change	No change
Diseases and pests	Increasing	Increasing	Decreasing	No change

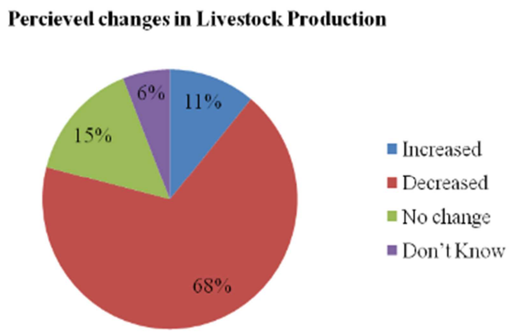

Fig. 4. Perceived changes in livestock production

As shown in Fig. 5, the highest proportion (68%) of respondents reported they had experienced a decline in livestock numbers, while 52.5% reported a decline in the amount of milk. A further 59.3% reported they had experienced a decline in the quantity of pasture. The observed decline in yields agrees with a previous study by Amwata and Nyariki (2021), who reported decreased pasture and livestock numbers in Kajiado County.

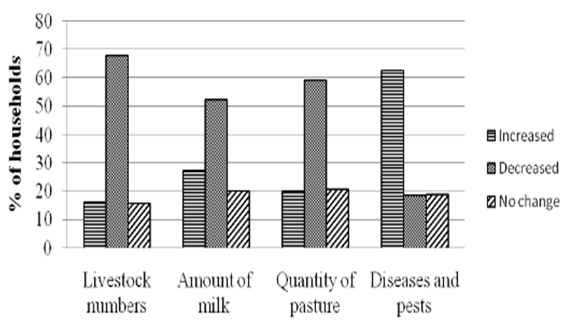

Fig. 5. Perceived changes in livestock production

Farmers described livestock production performance over the last 30 years during focus group discussions. Participants aged 35 years and below were excluded from this discussion.

Table 2 shows livestock production performance over the last 30 years as perceived by smallholder farmers. Results of the study indicate that there has been a gradual decline in livestock numbers from the 1990s to 2015. However, there has not been any noticeable change in the last five years. Average milk yields for smallholder farmers declined from 1990 to 2000, gradually increasing from 2000 to 2010 but declining in the last decade. Farmers attributed the change in livestock, milk, pasture, pests, and diseases to climate change and variability.

It was further reported that farmers kept different livestock with different grazing behaviours to take advantage of different ecological niches in the area and as insurance against the negative impacts of climate change and variability, especially drought. While cattle and sheep are predominantly grazers, goats are mainly browsers. According to farmers, goats were more adaptable and tolerant to drought. Similar findings have shown that farmers kept different livestock species to diversify risks (Njarui *et al.*, 2016; Pavanello, 2010; Amwata *et al.*, 2018). FGDs with farmers and key informant discussions confirmed the critical role livestock plays in controlling risks mainly associated with crop failures with a bearing on livelihood security in the study area, a view supported in a report by Thornton *et al.* (2007) and Nyariki and Amwata (2019). Consequently, farmers with little or no livestock were more likely to be exposed to climate change-related risks.

Climate change events affecting agricultural production in the study area

Fig. 6 shows the climate events and non-climate factors reported to affect agricultural productivity in Machakos County. Household interview results indicate that most respondents (83.3%) reported being impacted by highly unreliable rainfall, 72.8% by drought, 71.8% by high temperature, and 65.3% by pests and diseases. In addition, non-climate factors constraining crop production and livestock in the County were identified as inadequate capital (61.5%), the small sizes of the land (44.0%), inadequate knowledge of farming (40.3 %), lack/ or inadequate water for irrigation (34.8%), the inadequate market for produce (21.0%), land degradation (11.8) as well as lack of farm inputs (11.3%), use of poor seed/local varieties (11.0%), and post-harvest losses (13.0%).

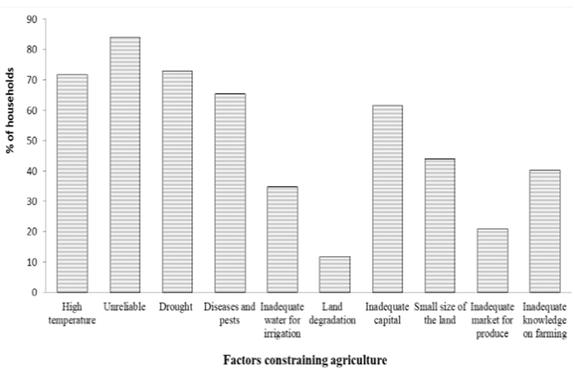

Fig. 6. Factors influencing declining agricultural productivity in machakos county

There was agreement across the FGDs and key informants that rains had become unreliable such that one was not sure what and when to plant, higher temperatures resulted in heat stress, increased frequency and intensity of droughts, high pest and disease incidences, and floods were all identified as impacting farming. The farmers linked changes in their farming, such as declining agricultural yields, to rising temperatures, increased rainfall variability, and drought. However, farmers in some FGDs reported that problems like low productivity might also result from the depletion of soil nutrients, in which farmers exploit crop nutrients without replenishments. Factors mentioned in FGDs included declining soil fertility due to farmers' poor crop and livestock management practices, low input use, and inadequate extension services. On the other hand, FGD revealed that crop yields were slightly better in areas where farmers use certified seeds, fertilizers and practice good agricultural husbandry.

The high numbers of farmers impacted by climate variables and events indicate the vulnerability of livelihoods to climate change and variability in the study area. Such vulnerability is because most households in the study area derive their livelihoods from rain-fed agriculture. According to Mohammed *et al.* (2018), the livelihoods of all rural communities that depend on primary resources such as agriculture are particularly vulnerable to climate change and variability.

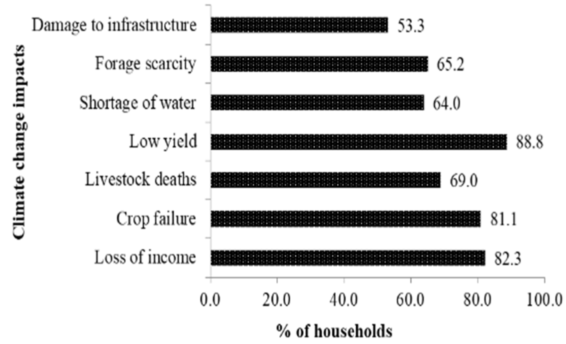

Fig. 7. Impacts of climate change and variability on household agricultural production in machakos county

Impacts of climate change on agricultural production

Results from the household survey and focus group discussions with farmers and key informants revealed that climate change and variability significantly impacted the mixed crop-livestock farming system in Machakos County. As shown in Fig. 7, the results from household surveys show that the majority of the respondents (88.8%) reported low yields as the impact experienced by farmers in the study area, closely followed by loss of income (82.3%), crop failure (81.1%), livestock deaths (69.0%), forage scarcity (65.2%), shortage of water (64.0%), and damage to infrastructure (53.3%) in descending order. The results were in agreement with other studies by Chand and Kumar (2018) in India, Gichangi and Gatheru (2018) in Kenya, and Mavuso *et al.* (2015) in Swaziland. Furthermore, the survey findings were corroborated during discussions in almost all FGDs.

FGD participants reported that:
"In the 1980s, rainfall used to be adequate for crops and livestock for cropping seasons; we would harvest enough food that would last until the next rainy season and sell some to get money to cater for our other family needs. Nowadays, rainfall is not enough, and we do not produce enough food. Sometimes, we abandon the farms for fear of incurring losses from crop failures.

Another participant recalled that:
"Livestock feed was never a problem, but now we have to buy, or otherwise, we sell the livestock, or they die out of starvation".

An FGD participant Noted:
"We used to fetch water from nearby rivers and springs, but nowadays we can only get water from very far. The river and springs have since dried up" (Muoka, Woman leader, October 22, 2021).

Low crop and livestock yields
The farmers explained that low crop and livestock yields are the most significant impacts of climate variability and change. Results from this study indicate that the average yield for maize, the most cultivated crop in the study area, was 8.0 bags per acre in years that recorded average to above average rainfall, which drops to 4.8 bags/acre in years that recorded below-average rainfall, thus a 40 % drop in maize yield or loss of income of Kes12,800 per acre. Milk production drops from an average of 10 litres per farmer per day in a typical year to an average of 6.5 litres per farmer in drought conditions, a 35% drop in milk yield and a loss of income of Kes 3500 per day. This finding is below the IPCC's projected decline of 50% in agricultural productivity by 2020 (IPCC, 2013). Similarly, a 35% drop in milk yield due to drought is below the figure of 80% reported by Kenya's government (GoK's, 2019). A study by Lilly *et al.* (2021) concludes that climate change and seasonal variability led to a reduction in Maize yield in Nyeri, Kenya.

Successive seasons of rainfall failure result in the depreciation of grazing pasture and impose severe nutritional stress on the animals, resulting in low productivity and even high livestock deaths. The decline in crop yields was associated with rising temperatures, excessive or insufficient water availability, drought, and losses to pests and diseases. According to El-Beltagy and Madkour (2012) and Thornton and Herrero (2014), the direct effects of climate change will be through changes in temperature and rainfall, especially in the ASALs where crops are near their maximum tolerance level; a temperature rise will result in yield decline, whereas agriculture productivity will be seriously compromised in regions with decreased rainfall.

Loss of income
Results from this study indicate that 97% of the respondents had agriculture as their primary source of income, while 24.6% exclusively depended on agriculture. Furthermore, in the ASALs, where farming is marginal, livestock plays a crucial role in the financial security of the farm household against frequent crop failures in addition to income generation through sales of animals, milk, or wool. Farmers explained that the weather event and changes in weather elements, such as poor rains, high temperatures, and droughts, had resulted in below-average harvests, low milk production, diminished fodder/pasture and browse, crop failure, and livestock deaths. Yields dropped from normal levels, and the livestock was malnourished. Farmers barely produce enough food for their families, let alone for sale. In addition to the direct loss of animals and milk, the marketability of the animals affected income flow. Consequently, the farmers have reported reduced incomes and about 77.5% of the respondents have reported losing more than half (50%) or Ksh 47,200 of their annual household income. The finding is consistent with Cleansens *et al.* (2012) study that

projects a 32% net loss in the mean of agricultural income due to the impacts of climate change and variability in a mixed crop-livestock system in Machakos County.

Crop failure

The temperature rise, changes in rainfall patterns, frequent and intensified weather events, and unavailability of water during the critical crop growing period may result in wilting, stunted growth, and crop failure. Farmers have experienced frequent crop failures over the last 20 years due to droughts and high climate variability, mainly erratic rainfall and rising temperatures. Farmers reported that crop failures in the study area occurred two times every five years from 2000, but it has since increased to three times every five years in the last ten years. In affirming frequent crop failures in the study, a participant in FDG noted that:

"Farming has become so risky these days, we can no longer be sure to harvest even after planting, and yet the family has to feed; after experiencing numerous crop failures over the years, some of us decided to start small businesses or look for work so that the family can feed even when the crops fail".

Loss of livestock

Livestock production is a significant economic activity for smallholder farmers in Machakos County. Farmers observed that frequent droughts had reduced fodder/pasture, triggered emergent new pests and diseases, and caused crop failures and livestock deaths. Crop failures further lead to loss of grain yield and little or no crop residues, significantly affecting the quantity of feed available for livestock. The diminished quantity and quality of pasture and other animal feed result in deplorable conditions for livestock in drought periods, leading to deaths mainly through starvation. Farmers reported that livestock numbers have declined over the years due to frequent droughts that rarely allow them time to recover from previous ones. Grazers, especially cattle, are most affected as compared to browsers. The study results show that each farmer has lost nearly 70% (estimated at Kshs105,000) of cattle value and about 68% (Kshs 27,600) of goats and sheep value to droughts in the last three decades.

This was confirmed in the FGDS by a participant who reported:

"Before droughts became very common in the 90s, we used to keep more than 20 cattle and 25 to 30 goats and sheep, but the numbers of animals have kept declining with each drought. Nowadays, we can hardly keep more than 5 (five) cattle and 6(six) to 10 goats and sheep". The finding agrees with GoK's (2019) report that an estimated 10-30% of livestock were lost dueto extreme weather-related deaths, especially drought in at least four droughts in the past ten years.

Forage scarcity

The combined effects of high temperatures and below-average rainfall have worsened pasture and browse conditions in the study area. Farmers explained that the primary feed source for livestock in the study area is the short-distance rangeland, maize stove, road sources, and cut-and-carry fodder, which have declined by about 40% over the last three decades. Changes in rainfall patterns and temperature ranges also impact feed availability, grazing ranges, and feed quality (Njarui *et al.*, 2016). Farmers reported that feed is rarely available throughout the year but face frequent feed shortages, especially during the dry season. Low and erratic rainfall, long dry season, and frequent droughts worsen feed scarcity. This finding is supported by a previous Silvestri *et al.* (2012) study. Temperature changes, rainfall variability, and drought affect grassland productivity and the composition of available livestock species (Thornton *et al.* (2009). Inference from focus group discussions pointed to a situation where some feed resources, such as African foxtail grass (*Cenchrus ciliaris*) and Maasai love grass (*Eragrotis superba*), available 20 years ago, are no longer available due to several factors, mainly low rainfall and recurrent and prolonged droughts, land degradation resulting from overgrazing and soil erosion and of hitherto grazing lands for cultivation. Compared to previous years (last 20 years), pastures have become inadequate partly due to farmers' poor management or negligence of pasture lands but mainly due to insufficient, erratic, and poorly distributed rainfall. This finding is supported by the IPCC (2007) report that states that various vegetation types and grasses, critical for livestock feed and understanding climate trends and predictions, disappear because of climate change.

Crop failures result in little or no crop residues, significantly affecting the quantity of feed available for livestock. Further, inference from focus group discussions points to a situation where farmers prioritize crops when allocating land for production activities, with very few farmers designating specific portions of land for livestock. The plots are rarely attended for those that do, leading to poor pasture conditions. Similar observations were made by (Njarui *et al.,* 2011).

Decline and drying of water sources

The unavailability of adequate water for crop and livestock production is one of the most important effects of climate change and variability. About 64% of the respondents mentioned a decline in water, leading to water shortages, as one of the experienced impacts of climate change and variability in the study area. Although the county's agriculture is mainly rainfed, water is required for irrigation and livestock. Farmers reported that water supplies from natural and man-made sources are fast diminishing, adversely affecting mainly water for irrigation in the irrigated areas. The water sources, especially rivers and water pans, easily dry up during drought.

Focus group discussions revealed that during the regular season, the average distance to the nearest water source was 1.0 km, increasing to 6.0 km in drought periods. Climate change and variability have significantly increased the average distance to the nearest water source, especially in rural areas in Machakos County (Machakos County, 2015). According to GoK (2019), water availability is projected to drop to ~230m^3 by 2025, partly due to the increasing incidences and severity of droughts in Kenya.

Damage to infrastructure

Farmers reported damages to irrigation canals, water piping systems, water storage tanks, water pans, and access roads from increased extreme weather events such as heavy rains, floods, and droughts, disrupting their farming activities. Farmers explained that damage to irrigation structures and water pans negatively impacts water availability for irrigation and livestock production. In addition to productivity losses, weather events result in crop damage and livestock death, while road damage impairs agricultural produce's transportation to markets, negatively affecting their livelihoods. The findings agree with a study by Njogu (2021), who reported that climate change-induced events, especially flooding, destroy infrastructure such as road networks, energy, and social facilities threatening the transportation of goods and services and access to reliable energy, which results in losses in incomes in Kenya.

Conclusion

The study assessed the impact of climate change and variability on mixed crop-livestock farming in Machakos County. The results of this study indicate that agricultural production was the primary source of income for most respondent's majority of whom practice rain-fed farming. The study concludes that indeed climate change has an effect on mixed crop-livestock farming in Machakos County. Farmers had observed declines in crop yields, livestock numbers, livestock products, and quantity of pasture. Among the climatic constraints perceived by the farmers, unreliable rainfall ranked highest, followed by drought, high temperature, and pests and diseases. The study has shown that decline in yields, low income from crop and livestock farming, crop failure, and livestock deaths were the most frequent climate variability, and change impacts the mixed crop-livestock farming in the County. The results also show mutualistic relationships between crops and livestock. For instance, while crop residues comprise the major source of animal feeds, in addition to natural pastures, livestock provides inputs for crop production in the form of traction and manure. Additionally, smallholder farmers' integration of crops and livestock helps diversify and spreads risks from threats such as climate change.

Based on the findings of this study, there is a need to identify adaptive measures accessible to smallholder farmers and suitable for their agro-ecological and socioeconomic contexts and other forms of support to facilitate adaptation. For example, investments in capacities will be required to optimize rain-fed crop and livestock production, management and conservation of locally available fodder for the dry season and drought periods, efficient use of available moisture, improved water use efficiency, and water harvesting and irrigation. In addition, adaptation-enhancing practices such as climate-smart agriculture should be encouraged to reduce the impacts of climate variability change.

Finally, the study recommends further research to identify locally appropriate adaptation strategies, especially in the integrated crop-livestock production system, as well as policy approaches for encouraging and implementing adoption.

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