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Pasture farming for climate change adaptation in a semi-arid dryland in Kenya: status, challenges and opportunities

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Abstract
Climate variability and change pose a major challenge to rain-fed agriculture in Africa. Extreme weather events are projected to continue affecting African drylands. Thus, it is essential to assess how rural farming communities in marginal environments are adapting to environmental changes. Specifically, there is need to assess local adaptations that can help enhance the resilience of socio-economic and environmental systems. This study identifies the current status, main challenges and opportunities of pasture farming for climate change adaptation among smallholder farmers in a semi-arid dryland in Kenya. It combines household and key informant interviews and participatory methods. Agropastoral farmers in the studied area are establishing native perennial pastures, where species selection is largely influenced by its forage value. Although agropastoral farmers have adopted pasture farming, they still face multiple challenges including climatic factors, lack of sufficient knowledge and information, limited access to markets, high cost and low availability of native grass seed, destruction of grazing herbivores and seed predation. Adopting strategies like low cost irrigation systems and agricultural technologies, cooperatives development and policy formulation to facilitate easy access of inputs and relevant markets has great potential to increase local resilience to environmental change and contribute to achieving wider development goals. Thus, policy makers should prioritize formulating climate adaptation policies and programmes that will promote diversification of livelihoods and support local climate adaptation strategies among farming communities in African drylands.

Article Highlights

- Forage value is a key factor in selecting grass species for pasture farming
- Agropastoral farmers have an in-depth knowledge of the native grasses
- Pasture farming a pathway to sustainable forage production

Keywords Adaptation · Forage · Livelihoods · Perennial grasses · Resilience · Farming communities

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1 Introduction

African drylands (i.e. arid, semi-arid, and dry subhumid areas) constitute approximately 11% of the global land surface, 27% of the global drylands, and 43% of the continent supporting rural livelihoods of an estimated 325 million people who rely on dryland resources and ecosystem services [1]. In Kenya, the arid and semi-arid lands (ASALs) cover over 80% of the country's land mass and host nearly 30 and 70% of the human and livestock populations, respectively [2]. These dry environments are characterized by very low and erratic bimodal rainfall pattern that is highly variable. Aridity Index (AI) defined as ratio between precipitation (P) and potential evapotranspiration (PET) is the most widely used statistical instrument for the analysis of global aridity. The arid and semi-arid drylands have AI's of 0.2–0.05 mm/mm and 0.5–0.2 mm/mm, respectively [3]. These typical African drylands are increasingly and frequently experiencing extreme changes in weather patterns notably temperature and rainfall. These changes have resulted in high variability of seasonal rainfall, extreme temperatures and recurrence of extreme climate events e.g. drought and floods [4]. Subsequently, agropastoralists and pastoralists communities in these harsh dry environments have become extremely vulnerable and their sources of livelihoods i.e. rainfed drylands agriculture and pastoralism, are threatened.

Crop-livestock dryland farming is the main agricultural production system in African drylands. Cereals e.g. pearl millet (*Pennisetum glaucum* (L.) R.Br.), finger millet (*Eleusine coracana* (L.) Gaertn.), sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.) and legumes e.g. cowpea (*Vigna unguiculata* (L.) Walp.), pigeon peas (*Cajanus cajan* L.) and mung bean (*Vigna radiata* L.) are some of the most important subsistence and cash food crops. Furthermore, livestock (mainly indigenous cattle, sheep, goats and camels) provide draft power for farming, meat and milk for households and income, that is often invested in crop production (e.g. purchase of farming inputs and technologies) [5]. Additional byproducts e.g. livestock manure and crop residues are vital soil amendments (organic fertilizer) and livestock feed, respectively. Nonetheless, naturally occurring perennial grasses e.g. African foxtail/Buffel grass (*Cenchrus ciliaris* L.), Maasai love grass (*Eragrostis superba* Peyr.), Bush rye grass (*Enteropogon macrostachyus* (Hochst. ex A. Rich.) Munro ex Benth.), Guinea grass (*Panicum maximum* Jacq.) and African horsetail grass (*Chloris roxburghiana* Schult.) are the main source of forage for free-ranging livestock. Forage tree species, e.g. *Melia volkensii and Leucaena leucocephala* are often incorporated in farms to provide an additional source of forage for livestock. Farmers often intercrop these trees with food crops such as maize, beans, and cowpeas. However, recurrent extreme climatic events mainly extremely low amount of rainfall and prolonged droughts, have contributed significantly to persistent crop failures (limited crop residues) and rapid disappearance and depletion of perennial forage grasses in dryland environments [6].

The insufficient supply of livestock forage (quantity and quality) is a leading contributor to low livestock productivity in crop-livestock production systems in African drylands [7]. In the arid and semi-arid drylands in Kenya, forage deficits especially during the lean dry seasons have increased considerably over the past decades exacerbated by frequent and prolonged droughts. Incidences of droughts and excesses of climate has increased drastically over the last 15 years severely affecting forage availability and livestock production. Historically in Kenya, droughts occurred on average every 7–10 years. However, after 1990, eight severe droughts occurred in 1991–1992, 1995–1996, 1999–2000, 2004–2005, 2008–2009, 2011, 2014, 2017 [8] and more recently 2020–2022. Specifically, the arid and semi-arid drylands in Kenya have endured three severe droughts in the last decade (2010–2011, 2016–2017 and 2020–2022). The most recent drought (2020–2022) has been the most severe and longest with widespread livelihood losses.

Thus, in these changing environments and climate extremes, agropastoralists are adopting and practicing different coping strategies and mechanisms to sustain their livelihoods and increase their resilience [9]. In reference to rural agropastoral farmers, resilience represents their capacity and ability to resist and adapt to the adverse effects induced by ecological and social changes [7]. Incorporating pasture farming in crop-livestock agricultural systems by establishing perennial grasses native to drylands is one of the strategies used by rural farmers in semi-arid drylands in Kenya. This strategy cushions them against vagaries of nature, mainly climatic shocks and ensure a continuous supply of livestock feed, especially during the lean dry seasons. In the arid and semi-arid drylands in Kenya perennial grass species notably *C. roxburghiana*, *E. superba*, *E. macrostachyus*, *C. ciliaris*, *Chloris gayana*, Bread grass (*Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf) and Sudan grass (*Sorghum sudanense* (Piper) Stapf) have been promoted for pasture production and fodder bulking through hay making in the region [10]. Pasture farming using native grasses is highly relevant in both environmental and social terms, with great ecological, landscape and cultural diversity exemplified by its productive, environmental and societal functions among the rural communities.

Recent studies investigating these grasses in the arid and semi-arid drylands in Kenya have largely focused on their agronomy and potential for ecological restoration and rehabilitation [10–12]. Little is known about the current status, challenges and emerging opportunities associated to pasture farming in crop-livestock production systems in the drylands. To fill this knowledge gap, the following research questions guided this study conducted in a typical semi-arid dryland in Kenya: (1) what informs the selection of the preferred grass species for pasture farming? (2) what are the key challenges of pasture farming in a semi-arid dryland? and (3) what are the opportunities to address the challenges and upscale pasture farming?

2 Materials and methods

2.1 Study area

This study was undertaken in Kitui County, southeastern Kenya. It is the sixth largest county in Kenya by land area, covering approximately 30,496.4 km^2 and is among the arid and semi-arid land (ASAL) counties that cover approximately 80% of the country's land mass and characterized by sporadic rainfall and cyclic droughts [13]. Kitui County experiences arid to semi-arid climate which is hot and dry with erratic and unreliable rainfall. The annual rainfall average ranges between 250 and 1050 mm with 40% reliability with high temperatures throughout the year ranging from 16 ºC to 34 ºC [14]. The rainfall pattern is bimodal, with the long rains (LR) in March–May and short rains (SR) in October-December. Intense LR have a rain peak in April while the less intense SR have a rain peak in November.

The Akamba sedentary agropastoralists are the main inhabitants in the study area. Their main economic activity is raising livestock and cultivating drought-tolerant cereals, pulses and incorporating several multipurpose tree species. Crop-livestock farming is the main agricultural production system characterized by a combination of one or more crops (e.g. millet, sorghum, pigeon peas, cowpeas and mung bean) and livestock (mix of largely free-ranging local livestock breeds e.g. small East African shorthorn zebu, Red Maasai sheep, small East African goat and exotic breeds under intensive/semi-intensive production). Competition for drought grazing areas mainly in Kitui East often result in conflict between the sedentary subsistence Akamba farmers neighbouring nomadic pastoralists (Somali and Orma communities). On the other hand, human-wildlife conflicts are particularly common in Thiunguni, bordering the South Kitui National Reserve wildlife conservation area characterized by thickets, grasslands and acacia savannah. However, these conflict prone areas were not included in this study. Common soil classes include Vertisols, Cambisols, Luvisols, Ferralsols, Arenosols, Gleysols and Acrisols often characterized by being low in organic matter content, nitrogen and phosphorus. On average, the soils have the following properties; pH (6.4), total organic C (9.7 g kg^{-1}), total N (1.2 g kg^{-1}), total available N (11.7 mg kg^{-1}), available P (73 mg kg^{-1}), K (1.1 cmol kg^{-1}), Na (0.4 cmol kg^{-1}), and CEC (10.1 cmol kg^{-1}) [14]. Native drought-tolerant perennial grasses e.g. *C. roxburghiana*, *E. superba*, *C. ciliaris*, *E. macrostachyus* are a key source of forage for livestock.

2.2 Sampling design data collection and analysis

The study combined purposeful and strategic sampling with stratified random sampling to determine interviewees. To obtain a representative sample of the population interviewees included; farmers, program managers working for various local and international NGO's, Kitui County officials in relevant ministries (i.e. water, agriculture and livestock), scientists from research institutions and institutions for higher learning (e.g. South Eastern Kenya University (SEKU) and Kenya Agricultural and Livestock Research Organization (KALRO)) and traders involved in the pasture value chain. In total 63 respondents were interviewed. Semi-structured questionnaires were used to gain insight on opinions and experiences of farmers on pasture farming.

Interviews were conducted in the official and national language in Kenya, S*wahili*. The questionnaire data collection tool was pre-tested in a non-sample community before the start of the study. In order to facilitate (1) flow of new ideas, (2) generate sufficient information during the interview and (3) quantification of phenomenon of interest and (4) ease of capture of the diverse issues being investigated, the questions were dichotomous, multichoice and open-ended.

Further, key informant interviews (model farmers and researchers) were administered to clarify and expound on technical issues that emerged during the face-to-face interviews. Triangulation of data was carried out to capture different phenomenon of the research subject to help build a clear understanding on relationships and linkages of different aspects of pasture farming.

Data collected from the interviews were subjected to descriptive analysis in Statistical Package for Social Scientists (SPSS). Furthermore, we conducted a cost benefit analysis (CBA) to compare annual income returns from selected food crops and pasture farming in the studied area. Figure 1. Illustrates the flow of the study methodology.

3 Results

3.1 Selection of the preferred grass species for pasture farming

In total, four grass species (*C. ciliaris, E. macrostachyus, E. superba* and *C. gayana*) were selected for pasture farming in the studied area. Specifically, more than half of the farmers interviewed (54%) favoured *E. superba. Chloris gayana* (22%)*, C. ciliaris* (15%) and *E. macrostachyus* (9%) were ranked second, third and fourth, respectively. Table 1 and Fig. 2 highlights the preferred grass species for pasture farming and their characteristics that informed their selection as identified by agropastoral farmers. The grass traits mentioned by the farmers ranged from ecological, morphological, socioeconomic, nutritional and cultural characteristics. Thus, this strongly signifies that the farmers possessed a deep wealth of indigenous knowledge and understanding of the grasses and their environment.

3.2 The key challenges of pasture farming in a semi-arid dryland

Most farmers (36%) cited climatic factors e.g. erratic and low amount of rainfall and frequent and prolonged droughts as the key challenge of pasture farming in the area. Thus, to harness water and facilitate the successful establishment of pastures, majority of the farmers (56%) employ different rainwater harvesting techniques namely; (1) creation of in-situ microcatchments using ox-driven ploughs, (2) construction of deep trenches, (3) terraces, (4) trench bunds and (5) diversion of water from roads into farms (spate irrigation) for pasture farming. The main reasons why farmers started combining road water harvesting with pasture farming were to (1) recharge and improve on soil moisture distribution and (2) enhance soil water availability to ensure survival and optimum biomass yields and seed production. Figure 3 highlights the key challenges of pasture farming highlighted by agropastoralists in semi-arid Kitui county, southeastern Kenya.

4 Discussion

4.1 Selection of the preferred grass species for pasture farming

Higher preference of *E. superba* and *C. gayana* var Boma among agropastoralists (Table 1) can largely be attributed to its contribution to livestock production. Pastoralist communities inhabiting the semi-arid drylands in northern Kenya i.e. Pokot and Il Chamus, have identified *E. superba* as an important forage species in their landscapes, largely due of its contribution to enhanced milk production, fattening livestock and sustain a good body condition score [15]. This observation by pastoralists conform well with findings evaluating the forage value of selected African grasses, where *E. superba* demonstrated greater potential as a forage species for ruminant animal production than *E. macrostachyus* and

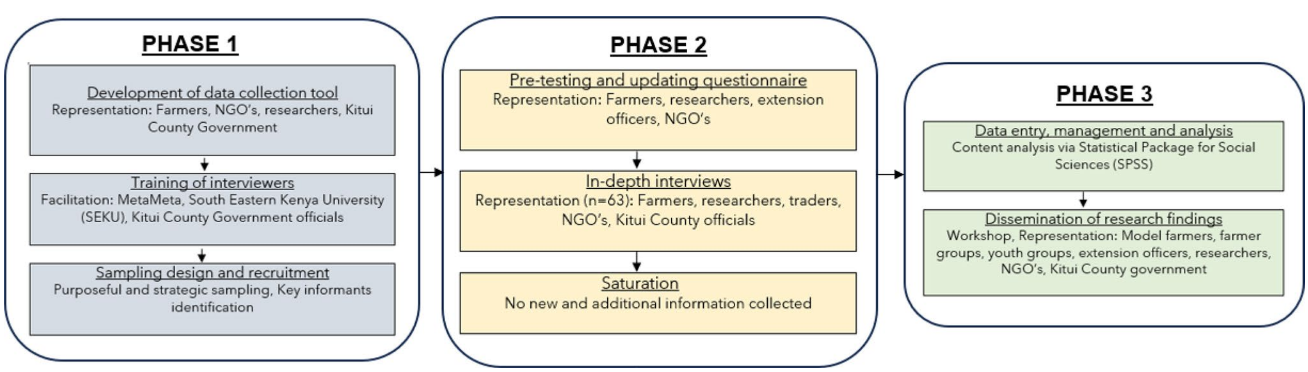

Fig. 1 Flowchart of the study methodology

Table 1 Preferred grass species for pasture farming and their characteristics as identified by agropastoral farmers in semi-arid Kitui County, Kenya

Species	Local name	Number of farmers (%)	Reasons for selecting the grass species
Cenchrus ciliaris (African foxtail grass)	*Ndata kivumbu*	15%	Drought tolerant; high forage yields; soil stabilization along trenches; good for hay making; establishes well and fast growth; ease of harvesting seeds
Enteropogon macrostachyus (Bush rye grass)	*Nguu*	9%	Good and quick germination; fast establishment; hardy species can grow in different soils and conditions; enhances a good vegetation cover to protect soil; good for rehabilitating denuded pastures patches
Eragrostis superba (Maasai love grass)	*Mbeetwa*	54%	Good establishment; wide funnel-shaped shoot architecture facilitates capture of rainwater thus minimal soil disturbance; high biomass yields; very palatable and preferred by grazing livestock; good for stabilizing terraces; suitable for fattening livestock for sale and increase milk production; bulk seeder; seeds easy to harvest
Chloris gayana (Boma Rhodes grass)	*Boma*	22%	High leafy biomass; easy to harvest and bale for storage; good nutritive value for grazing livestock; high seed production; very suitable as cover crop; good and quick establishment; soil and water conservation

Once the grasses have been established in farms, the farmers can benefit from multiple harvests (for up to 7 years)

Fig. 2 Grass species for pasture farming among agropastoral farmers in semi-arid Kitui County, Kenya. (**a**) *Cenchrus ciliaris* (African foxtail grass), (**b**) *Enteropogon macrostachyus* (Bush rye grass), (**c**) *Eragrostis superba* (Maasai love grass), (**d**) *Chloris gayana* var. Boma (Boma Rhodes grass)

C. ciliaris, largely due to it significantly higher crude protein (CP) yields [16]. Similarly, another study also observed higher CP content in *E. superba* (63.13 g kg^{-1} DM) and *C. gayana* var Boma (67.13 g kg^{-1} DM) compared to *C. ciliaris* (48.97 g kg^{-1} DM) and *E. macrostachyus* (44.23 g kg^{-1} DM) [17]. *Chloris gayana* var Boma has been promoted for adoption among farmers in semi-arid drylands in Kenya due to its high biomass yield and quality in order to supplement the livestock feed base [18]. Subsequently, our findings conform well to previous studies that have demonstrated that the choice of grass species for pasture farming and rehabilitating degraded agricultural landscapes in semi-arid drylands in Kenya is largely influenced by their forage value for livestock [10, 19].

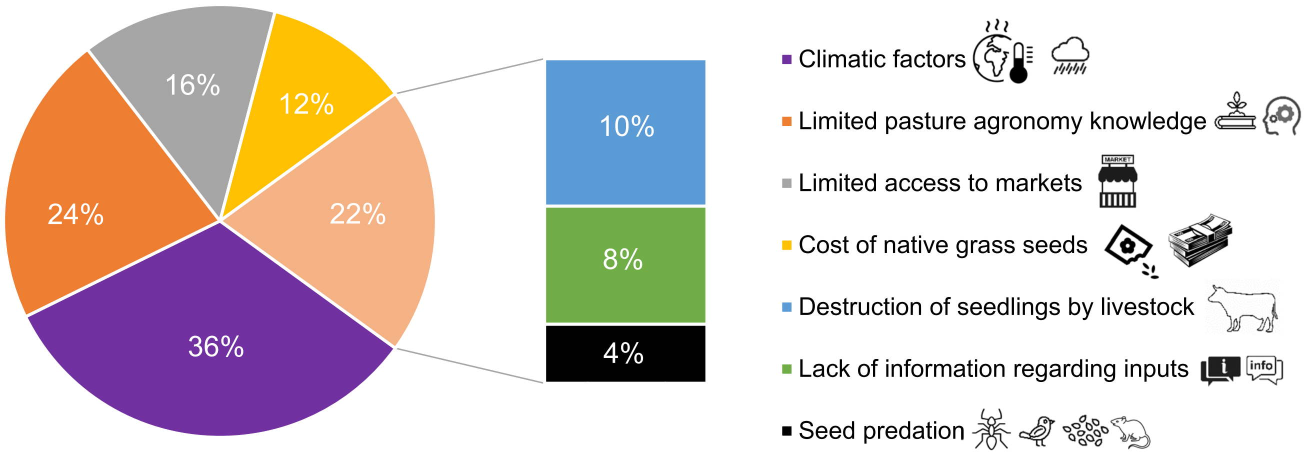

Fig. 3 Key challenges of pasture farming highlighted by agropastoralists in rural semi-arid Kitui county, southeastern Kenya

4.2 Challenges of pasture farming in a semi-arid dryland environment

Pasture establishment through native grass seeding is mainly constrained by climatic factors, notably erratic, low and variable precipitation and prolonged droughts characteristic of arid and semi-arid lands. This makes pasture farming in African dryland systems very challenging exemplified by extremely low success and establishment rate. Other similar studies have also found climatic factors (low and unreliable rainfall and droughts) as the greatest challenge for pasture production among agro (pastoralists) in Kenyan drylands [10, 20]. Extended water deficit conditions in-between rain events and prolonged droughts periods impedes seed germination and subsequent growth and development of the grass seedlings to maturity. Overcoming this challenge by employing innovative pasture agronomy strategies that can prolong soil moisture availability has great potential to enhance successful pasture production. This is because, once established, grasses native to African dryland, e.g. *C. ciliaris,* are capable to survive, grow, and reproduce viable seeds that can also replenish the soil seed bank [21].

Climate change and land degradation in rangelands has also led to the rapid depletion and disappearance of native forage resources preferred by grazing livestock. Subsequently, agropastoralists in the studied semi-arid drylands are now establishing native grass pastures to alleviate forage scarcity, especially during the long lean dry seasons. However, pasture farming is a relatively new agronomic practice and concept among (agro) pastoralists who have traditionally relied on rangeland forage resources as the main source of feed for their grazing livestock. Inadequate knowledge on suitable pasture agronomy practices is a great challenge for sustainable fodder production in marginal drylands systems [22]. Lack of sufficient expertise and management skills for forage cultivation, conservation and utilization continue to pose a great challenge to livestock production in pastoral areas [23]. Furthermore, availability of native grass seeds is very low. Lack of support mechanisms and information e.g. establishing informal seed systems of native grass species to fill the deficit in supply from the formal seed market, remains a great challenge to increase accessibility of native seed in the arid and semi-arid environments in Kenya. Other studies in African dryland systems have also identified low forage seed availability as a challenge to pasture and livestock production [23, 24].

In addition to low availability of native grass seeds in the formal and informal market, high costs often limit the ability of agropastoral farmers to purchase a sufficient amount of seeds needed to establish enough pasture to sustain their livestock herd. For example, in the southeastern drylands in Kenya, where this study was conducted, native grass seeds cost KES 1000–1800 (USD 7–13) per kilogram, which is much higher than in the northern rangelands KES 250–1000 (USD 2–7) per kilogram [20]. The differences in costs of native grass seeds in the drylands in Kenya can partly be attributed to the existing grass seed marketing channels and volume of seeds produced. Higher production of native grass seeds in the northern drylands has been attributed to the expansive provision of extension services (e.g. information dissemination and training in pasture farming) by local and international NGOs and government institutions (e.g. Kenya Agricultural and Livestock Research Organisation (KALRO)). Bulk seed production of native grasses from northern Kenyan rangelands can play a significant role in supplying sufficient grass seeds in other rangelands occurring in similar ecological ranges. This will subsequently lower the cost of purchasing the seed and enhance adoption of pasture farming among smallholder farmers. Furthermore, increased access of affordable seed will entice business-minded farmers to scale up and gradually ensure higher volume of seeds production and improve marketing channels. This suggests that empowering agropastoralists with adequate training can significantly enable them to appropriately plan and practice pasture farming and make informed and timely decisions, to enhance successful pasture production [25]. However, for this to be successful, multistakeholder participation of relevant stakeholders (farmers, youth and farmer groups, research institutes, NGOs, seed producers and community based organisations, local government authorities), will ensure that the needs of the local farmer take centre stage.

However, grass seedlings are often prone to destruction and trampling by stray grazing livestock leading to pasture establishment failures and economic losses. This is because, due to insufficient financial resources, livestock keepers in the area use easily available materials e.g. bushes of thorny *Acacia* species to fence the established pastures. This is a practice also commonly used by pastoralists to fence pasture reserve enclosures [22, 26]. However, over time, these fences are frequently and easily destroyed by livestock, especially when the branches start disintegrating and thorny mesh becomes weak as the termites start consuming and reducing the branches. In addition to destroying the thorny branches fences, termites and other granivores (rodents, squirrels, birds especially *Quelea quelea*) common in dryland ecosystems affect pasture establishment through seed predation [27]. High proportion of seeds are usually removed or transported by granivores [28]. Grass seeds require sufficient moisture to support germination and subsequent seedling establishment. Thus, to enhance successful establishment, pasture farmers practice traditional dry planting, prior to the rainy season, to ensure planted grass seeds take advantage of the first rainfall event. However, the period just before the onset of the rainy season also coincides with scarcity of food resources for the granivores. Consequently, the predators consume the planted grass seeds covered with a thin layer of soil due to their small size. Moreover, because grass seeds are smaller in size, they experience higher removal rates and can be transported over long distances by the granivores [29]. Subsequently, seed predation by granivores contributes to patchy seed germination and poor grass establishment. This often forces the pasture farmers to sow additional seeds, making the process time consuming and expensive.

4.3 Opportunities to address the challenges and upscale pasture farming

In sub-Saharan Africa, less than 2% of arable land in the region is under irrigation [30]. Thus, rain-fed agriculture plays a significant role in sustaining rural livelihoods. However, arid and semi-arid drylands are adversely affected by climate change, characterized by low amount of rainfall and droughts, thus negatively impacting the hydrological cycle, water resources, provision of ecosystem services and agricultural production, including pasture farming. Subsequently, in order to sustain rural livelihoods in the study area, there is a need to enhance water use efficiency by optimizing pasture production per drop of rain [11]. Water harvesting and soil conservation technologies enhance and prolong soil moisture availability and promote infiltration in dryland agricultural landscapes. In the studied area, farmers that have adopted low cost rainwater harvesting and small scale irrigation (e.g. diverting runoff from 'green roads' and flood irrigation https://roadsforwater.org/) and soil conservation technologies witnessed increased pasture production. These marginal water sources normally lost through erosion, could be used more efficiently. Thus, in the context of pasture farming in semi-arid regions, soil and water conservation technologies e.g. rainwater harvesting, provide an opportunity to stabilize agricultural landscapes and enhance production per drop of rain, making them more resilient to climate change [31].

Furthermore, increasing pasture farming productivity (notably labour productivity) can play a significant role in alleviating poverty and spur economic growth among the small-holder farmers. Most of the pasture farmers in the studied area utilize simple tools e.g. hand-held hoes, which is often tedious and labor intensive. Adopting agricultural technology e.g. simple and low cost mechanization (use of ox-driven ploughs, affordable hand-pushed multipurpose tractor) can significantly augment labour, enhance output per person instead of output per unit of land. Land and climatic constraints notwithstanding, increased use of simple mechanization can lead to direct increases in pasture production in drylands. However, to facilitate widespread adoption among the farmers, there is need to pay close attention to the location-specific conditions and tailor technologies to satisfy farmers interests [32]. This will enhance adoption and make agricultural technologies effective, relevant and less costly.

Agricultural cooperatives and farmer groups play an important role in increasing small-holder farms' productivity and farmers' incomes [33]. This can be attributed to their role in enabling rural smallholder farmers access markets, credit facilities, farm inputs, information and get higher prices for their agricultural produce. Thus, forming and/or joining agricultural cooperatives will enable small-holder pasture farmers in the study area cope with market imperfections by providing access to larger national and international high-quality markets, inputs, higher prices and more reliable contracts. Moreover, opportunities to export (e.g. native grass seeds) in liaison with other stakeholders e.g. KALRO, FAO, can entice the farmers to engage in quality improvement via product differentiation [34]. Ultimately, the services offered by cooperatives will provide the pasture farmers with a stronger market position and the pooling of investments resulting in cost sharing.

Policies are established in specific economic, political, and social contexts. Input support from national and county government for pasture farming (yields and productivity) e.g. through fertilizer and equipment subsidies, and provision of improved and high quality native grass seeds has great potential to enhance pasture production. Previous studies have shown that providing improved subsidized seed and agricultural inputs e.g. fertilizer led to a significant increase in farmers' income [35, 36]. Price incentives have shown to increase agricultural production and livelihood diversification in African drylands [37]. Price support policies for hay and seed production in the pasture farming enterprise in the study areas e.g. community-based grass seed and hay bulking, has potential to increase forage production and subsequently sustain livestock production and diversify sources of livelihood among the smallholder farmers. Ultimately, such price incentives are likely to encourage more farmers to practice pasture farming and increase farm acreage under native pasture grasses. Technical support that captures a broad scope of policy tools e.g. agricultural extension services and structural development investment (e.g. designing and constructing 'green roads' for rainwater harvesting) can address challenges associated with lack of information and knowledge related to pasture farming and agronomy. Regular visits, quality of extension services, living labs for field demonstrations and well trained extensions officers can augment the positive impact of this policy on native pasture production. Combining input (access to subsidized inputs (e.g., seeds, fertiliser)) with technical (extension services and structural development) support has been found to be an effective approach in Africa [38].

Pasture establishment from seed is regarded as the most suitable and preferred approach among small-holder farmers in African drylands [11]. Thus, enhancing efficiency and successful establishment from seed will play a pivotal role in promoting uptake of native pasture farming and commercialization of the agricultural enterprise. Seed enhancement technologies (SETs, e.g. seed coating and extruded pelleting), defined as post-harvest seed treatments targeting germination, emergence and establishment challenges [39], may offer multiple opportunities and benefits to native pasture establishment. In addition to enhancing seed germination, emergence and establishment, covering grass seeds with synthetic layers of powders and binders (seed coating) and incorporating seeds within a soil–slurry matrix molded or extruded into different forms (extruded pelleting) promotes stress tolerance (e.g. drought) and protects sown seeds from granivores and herbicides [40]. Combining different SET under field conditions is an innovative strategy that can be used to overcome multiple barriers to plant recruitment and establishment [41] and subsequently enhance native pasture production in dryland environments. Additionally, using sustainable and environmentally friendly approaches to control granivores, e.g. Ecologically-Based Rodent Management (EBRM), is a realistic alternative to synthetic rodenticides for rodent management in agricultural landscapes of sub-Saharan Africa [42].

5 Conclusions

This study has focused on the status, challenges and opportunities of pasture farming for climate change adaptation in a typical African dryland. Specifically, it has drawn on practitioners experience, knowledge and adaptive evidence from an agropastoral farming community in a semi-arid dryland environment in Kenya. In particular, our findings indicated that agropastoralists have extensive knowledge of the native grasses occurring in their environment, especially their morpho-ecological characteristics and nutritive value for livestock production. This wealth of indigenous and traditional ecological knowledge has contributed significantly to the choice of grass species for pasture farming. However, environmental and structural challenges mainly related to climatic factors, technical knowledge related to pasture agronomy, market and policy dynamics continue to pose a threat to the successful adoption and upscaling of pasture farming especially in African arid and semi-arid environments. These challenges limit livelihood diversification options and weaken climate resilience and adaptative capacity of rural farming communities in these drylands systems. Thus, to facilitate adoption and upscaling of pasture farming in African drylands, indigenous and traditional ecological knowledge should be integrated in climate adaptation policies and programmes aimed at promoting diversification of livelihoods and mitigating the impacts of climate change and variability.

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Author Contribution K. M., F. S., L.B. and B.M. conceived the ideas and designed methodology; E. K., N. K., G.M., T. K., K.A. and B. M. collected the data; K. M., L. B. and N. K. analyzed the data; K. M., B.M. and L.B. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Data availability All data generated or analysed during this study are included in this published article and are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The protocol of this study was approved by the National Commission for Science, Technology and Innovation (NACOSTI), Kenya (No 2950/0614/2017). The authors obtained informed consent from all participants in the study to use their data in scientific publication. Only adults (> 18 years old) were involved in this study. The respondents were reassured that their participation is voluntary and that they were free to withdraw at any time. Additionally, all data and information was collected anonymously and handled confidentially. The study design assured adequate protection of study participants.

Competing Interests The authors declare no competing interests.

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