Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya

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HIGHLIGHTS

- Awareness and access are key factors in determining utilization of climate-smart agricultural practices and technologies.
- Objective was to identify climate-smart agriculture constraints among farmers in Taita Taveta County of South-East Kenya.
- The study applied Climate-Smart Agriculture Rapid Appraisal.
- Climate-smart agriculture require more localized solutions in policies, extension services and development interventions.
- This study increases understanding of constraints affecting adoption of new farm and land management practices.

GRAPHICAL ABSTRACT
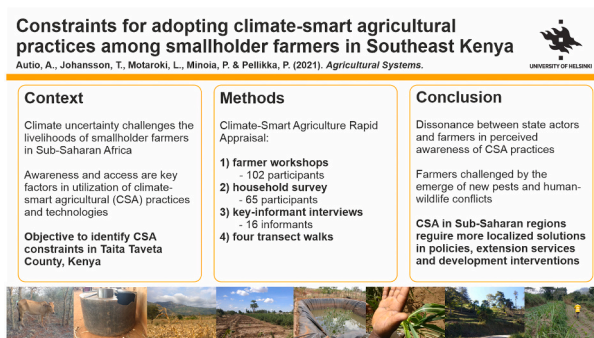
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ABSTRACT

CONTEXT: Climate uncertainty challenges the livelihoods of smallholder farmers in sub-Saharan Africa. Awareness of climate-smart agricultural (CSA) practices and access to climate-smart technologies are key factors in determining the utilization of farm and land management practices that may simultaneously decrease greenhouse gas emissions, increase the adaptive capacity of farmers, and improve food security.

OBJECTIVE: Understanding how biophysical and socio-economic constraints affect the adoption of CSA practices and technologies plays an essential role in policy and intervention planning. Our objective was to identify these constraints among smallholder farmers in Taita Taveta County of Southeast Kenya across varying agro-ecological zones.

METHODS: We conducted a Climate-Smart Agriculture Rapid Appraisal that consisted of four mostly gender-disaggregated smallholder farmer workshops (102 participants), a household survey (65 participants), key-informant interviews (16 informants), and four transect walks.

RESULTS AND CONCLUSIONS: Our results indicate a dissonance in the perceived awareness of CSA practices and utilization of CSA technologies between state actors and farmers. State actors emphasize lack of awareness as a barrier to adoption, while farmers express knowledgeability regarding environmental change and climate-smart practices but are confined by limitations and restrictions posed by e.g. market mechanisms, land tenure issues,

and lack of resources. These restrictions include e.g. uncertainty in product prices, lack of land ownership, scarcity of arable land, and simply lack of capital or willingness to invest. Farmers are further challenged by the emergence of new pests and human–wildlife conflicts. Our research findings are based on the contextual settings of Taita Taveta County, but the results indicate that adopting CSA practices and utilizing technologies, especially in sub-Saharan regions that are heavily based on subsistence agriculture with heterogenous agro-ecological zones, require localized and gender-responsive solutions in policy formation and planning of both agricultural extension services and development interventions that take into account the agency of the farmers.

SIGNIFICANCE: This study contributes to existing climate change adaptation research by increasing our understanding of how physical and socio-economic constraints can affect the adoption of new farm and land management practices, and how CSA-based intervention strategies could be restructured by local stakeholders to be more inclusive.

1. Introduction

The biophysical and socio-economic effects of anthropogenic climate change show large spatial variation globally (Wiebe et al., 2015), while responses to changes in global food security discourse emphasize homogeneous technical responses in regional and national policies. Rigorous scientific and political debate is ongoing concerning farmers' capability to adapt to changing climatic conditions and possibilities to mitigate climate change without threatening their livelihoods. Climate-smart agriculture (CSA) is a key concept in the present discourse of climate change mitigation and adaptation (FAO, 2017; IPCC, 2019; Klytchnikova et al., 2015). It can be defined as an agricultural activity that: 1) mitigates greenhouse gas emissions, 2) increases the adaptive capacity of farmers, and 3) sustainably intensifies agriculture for better livelihoods (Lipper et al., 2014).

The main critique of CSA concerns its technically oriented nature, as it fails to consider for example labour advances, consumption patterns, and land tenure questions (Taylor, 2018). Climate-smart agriculture also suffers from conceptual misunderstandings in the scientific community and resistance from civil society (Saj et al., 2017). Despite being in a restructuring stage, the concept has been proven to fulfil its three-win scenario worldwide, with positive impacts on the environment, agriculture, and socio-economic development (FAO, 2014; Neate, 2013). Recent studies have shown that common CSA technologies, such as no tillage, integrated soil fertility management, alternate wetting and drying, and nitrogen use efficiency, may bring benefits on a global scale (De Pinto et al., 2020). In addition, CSA technologies can substantially reduce women's labour burdens in agriculture (Khatri-Chhetri et al., 2019). Thornton et al. (2018) emphasized that CSA prioritization must also consider spatial and temporal scales to address producer and consumer needs. These findings increase the incentive to test their applicability in case studies.

As Andrieu et al. (2019) suggest, co-designing climate-smart farming systems is a complex process in which knowledge, technologies, and institutional environments interact, and a participatory and systems approach is therefore needed to generate local scientific knowledge that can identify appropriate solutions. In addition, Lan et al. (2018) have shown great variation in farm profitability with CSA practices across scales, meaning that similar practices can generate different profitability outcomes depending on the context. Understanding the constraints and local knowledge on CSA practices assists in formulating extension services, agricultural policies, and relevant interventions in the geographical context (Aryal et al., 2018). Empirical evidence from Western Kenya shows that locally driven adaptation incentives also provide implementation cost benefits (Chaudhury et al., 2016). Despite the importance of local knowledge in identifying appropriate climate-smart solutions, we found that the knowledge interactions on farm and land management practices between farmers and state actors are not clearly defined in the current CSA literature.

Our study investigates the spatial differences in climate change constraints of smallholder farmers in Taita Taveta County (TTC) of Southeast Kenya. The county's agriculture is drastically affected by climate change while also being a major source of greenhouse gas emissions exacerbating climate change and land-cover change due to agricultural expansion (Ge and Friedrich, 2020; Pellikka et al., 2018; Wachiye et al., 2020). This study uses the Climate-Smart Agriculture Rapid Appraisal (CSA-RA) -tool in TTC. The tool enables evaluating the state of agriculture to recognize challenges faced by smallholder farmers and to identify locally suitable practices that can be promoted in policy-making and development interventions (Mwongera et al., 2017). The tool is gender disaggregated, incorporating the fact that agricultural practices are also shaped by the cultural norms of societies, including gender-based roles in agriculture. Furthermore, by including gender when examining CSA adoption constraints, our aims are also to recognize women as active agents in adapting to change and contribute to filling the evident gap of research into the many gender dimensions of climate change, especially from a localized perspective (MacGregor, 2010; Ravera et al., 2016). On a broader level, we aimed to identify the primary constraints of smallholder farmers and CSA across TTC, to gain a view of possible areas requiring interventions on both policy and implementation levels.

Climate-Smart Agriculture Rapid Appraisal has previously been tested at a regional level in Tanzania and Uganda (Mwongera et al., 2015). In Kenya, a multicriteria decision support framework to target CSA intervention needs has been tested at the national level, although focusing on quantifiable data concerning vulnerability (Brandt et al., 2017). An earlier study in the Ndome and Ghazi areas of TTC has identified secured access to land as a significant disincentive for structural conservation measures for land improvement (Waswa et al., 2002). Previous research has also shown that cultivation of the most prominent agricultural land has occurred already a decade ago, and agriculture is expanding into areas with lower precipitation, stressing the need to adopt better soil conservation practices (Maeda et al., 2011; Maeda et al., 2010; Pellikka et al., 2018; Pellikka et al., 2013). Participatory methods for examining climate change impacts on traditional farming communities of the Taita Hills in TTC have previously been utilized by Capitani (2019). Our study broadens the analysis to cover both highlands and lowlands, which are dependent on ecosystem services such as water provisioning provided by the highland catchment areas. Earlier research on water governance in the area by Hohenthal et al. (2018) identified significant challenges in collaboration and dialogue-building between local people and state actors within power relations. Thus, there appears to be weak confidence in local resource management and knowledge in TTC.

Our research questions to investigate the CSA constraints are:

1) Which climate change -related challenges do farmers and state representatives identify for agriculture across TTC?

2) What factors restrain the adoption of climate-smart practices and use of climate-smart technologies across TTC?

3) Does spatial heterogeneity in agro-ecological conditions on a regional level necessitate locally appropriate responses to climate change adaptation?

Our hypotheses are that existing heterogeneity in the constraints to regional-level climate change adaptation prevents uniform upscaling of CSA practices and all-encompassing policies for small-scale agriculture in TTC (Abegunde et al., 2019), and that this heterogeneity is realized as

a perceived knowledge gap in adapting CSA technologies. Heterogeneity in the constraints to climate change adaptation and suitable responses to it not only manifest spatio-temporally but also among the stakeholder groups depending on their socio-economic profiles, thus having both potential winners and losers (Notenbaert et al., 2017). Farmers lacking surplus land resources or investment capital have limited access to many of the climate change adaptation techniques, and possible intervention could come at the expense of disadvantaged farmers if this is not taken into consideration (Clay and King, 2019). Besides resource-related issues, farmer access to training, farm inputs, climate information technologies, markets, and credit have been identified as key challenges in adopting CSA technologies, particularly for women farmers (World Bank Group et al., 2015). Determining how these constraints differ by socio-economic profiles and gender is crucial to understanding the adaptive capacities of agricultural systems.

2. Study area

Taita Taveta County (TTC) in the Coast Region of Kenya (Fig. 1) consists of Mwatate, Taveta, Voi, and Wundanyi sub-counties. Sixty-three per cent of TTC is covered by the Tsavo West and Tsavo East National Parks that border Taveta in the east and surround Mwatate, Voi, and Wundanyi. The Taita Hills that rise to over 1500 m.a.s.l., peaking at 2208 m, characterize the landscape, while the lower slopes of Mount Kilimanjaro characterize the landscape in Taveta. The county has a population of 340,671 (Kenya National Bureau of Statistics, 2019a). A large proportion of the land is communally owned, with approximately 35% of the population having title deeds for land and 55% with no formal land ownership documentation (County Government of Taita Taveta, 2018). Agriculture is the main source of livelihood, contributing to approximately 95% of household incomes and over 80% of employment (MoALF, 2016:1). In 2015–2016, the food poverty estimate for TTC was 39% which means that 139,000 people were unable to meet daily dietary recommendations (Kenya National Bureau of Statistics, 2018: 46). This exceeds the national average of 32%.

TTC has a bimodal rainfall pattern, with long rains occurring between March and May, and short rains between October and December (Ogallo et al., 2019). The County has nine agro-ecological zones (see Fig. 2 for Taita Hills) where microclimatic and soil conditions vary greatly, depending strongly on the altitude (Jaetzold et al., 2012). The average farm size is 0.4 ha in the highlands, 1.3 ha in the midlands, and 4.8 ha in the lowlands (County Government of Taita Taveta, 2018). Commercialized irrigated farming is practised in Taveta, while farming in Taita is mainly rain-fed domestic production. Agricultural products, such as tomatoes (*Lycopersicon esculentum*) and onions (*Allium cepa*), are also imported from Tanzania, while local cash crop production is exported e.g. to Mombasa.

This study was carried out in the wards of Kishushe, Maktau, Ngerenyi, and Chala, which represent different agro-ecological settings (see Table 1) that tend to also result in different adaptation strategies (Amare and Simane, 2017). Kishushe, Maktau, and Chala in the lowlands have low rainfall, while Ngerenyi in the highlands experiences more abundant rainfall. Kishushe and Maktau are characterized by predominantly subsistence agriculture with crops, such as maize (*Zea mays*), common beans (*Phaseolus vulgaris L.*), cowpeas (*Vigna unguiculata*), green grams (*Vigna radiata*), pigeon peas (*Cajanus cajan*), and sorghum (*Sorghum bicolor*), grown for domestic consumption. Ngerenyi and Chala have a stronger focus on commercial farming with the cultivation of e.g. bananas (*Musa spp.*), macadamia nuts (*Macadamia tetraphylla*), tomatoes, onions, and kales (*Brassica spp.*), in addition to subsistence crops.

3. Materials and methods

Climate-Smart Agriculture Rapid Appraisal is a research tool developed to evaluate agricultural conditions in adapting to climate change, mitigating greenhouse gases, and providing sustainable livelihoods (Mwongera et al., 2017). It combines both participatory rural appraisal (PRA) and rapid rural appraisal (RRA) methods to form a holistic view of CSA practices and technologies. Practices are understood broadly as ways of doing things, for example, precision farming, tillage, and fertilization. Technologies are new farm products, services, or applications introduced into new or existing practices, and include e.g. new drought-tolerant varieties; a hardy breed of cattle; or a new slow-release fertilizer. The RRA methods include farmer and key informant interviews to gather basic socio-economic information. The PRA methods engage community members into participatory exercises. In this study, data were gathered through household surveys, farmer workshops, key informant interviews, and transect walks. The CSA-RA tools and their
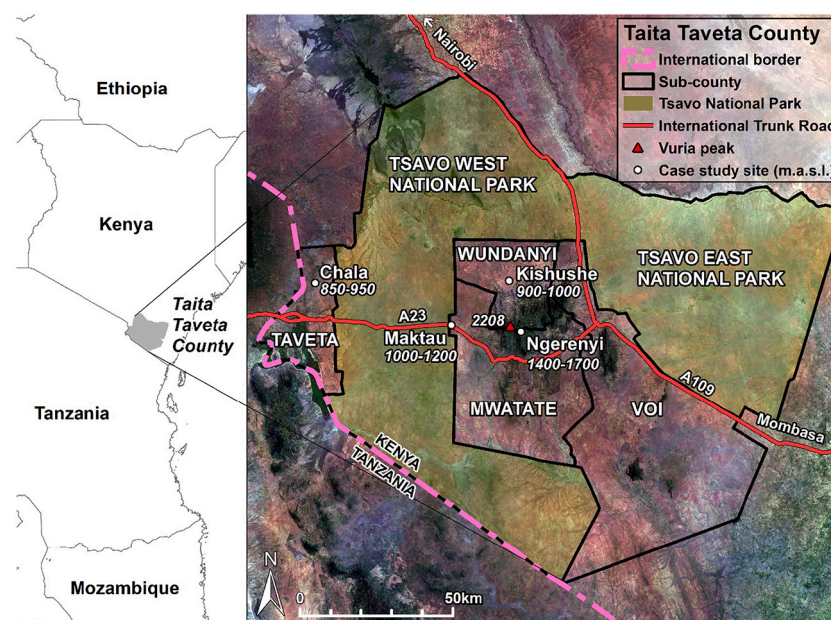

Fig. 1. Taita Taveta County and the case study sites. Sources: Landsat 8 median composite for 2019 processed using Google Earth Engine and map data © OpenStreetMap contributors (2019).
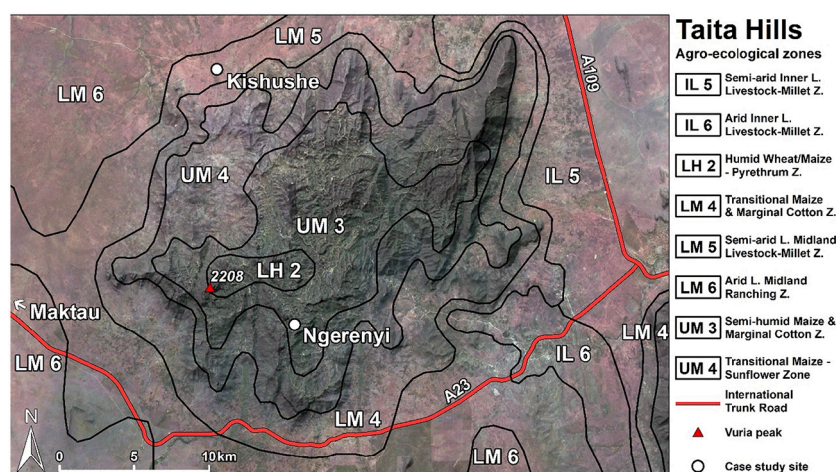
Fig. 2. The agro-ecological zones in Taita Hills. Sources: Landsat 8 median composite for 2019 processed using Google Earth Engine, ALOS Global Digital Surface Model "ALOS World 3D - 30m" (Japan Aerospace Exploration Agency, 2015), agro-ecological zones based on Jaetzold et al. (1983, 2012), and map data © OpenStreetMap contributors (2019).

Table 1
Agro-ecological conditions in the case study sites (Jaetzold et al., 2012; Kenya National Bureau of Statistics, 2019b).

Location	Popu-lation	Land area (km²)	Annual rainfall (mm)	Altitude range (m.a.s.l.)	Agro-ecological zones	1. cropping season (long rains)	2. cropping season (short rains)
Kishushe	5756	248	300–700	900–1000	North: Arid lower midland ranching zone (LM 6)	Rainfed agriculture not possible without run-off catching*	
					South: Semi-arid lower midland livestock–millet zone (LM 5)	Very short (40–54 days)	Very uncertain
Maktau	8448	301	300–500	1000–1200	North: Semi-arid lower midland livestock–millet zone (LM 5)	Very short (40–54 days)	Very uncertain
					South: Inner lowland ranching zone (IL 6)	Rainfed agriculture not possible without run-off catching*	
Kidaya/ Ngerenyi	3836	7	>1200	1400–1700	East: Semi-humid maize and marginal cotton zone (UM 3)	Medium to short (115–134 days)	Short to medium 105–114 days)
					West: Transitional maize–sunflower zone (UM 4)	Short (85–104 days)	Short or very short (75–84 days)
Chala	9016	144	500–700	850–950	Transitional maize and marginal cotton zone (LM 4)	short to very short (75–84 days)	Very short to short (55–74 days)

* Growing period of more than 45 days possible with run-off catching techniques.

validity for the local community were discussed and modified together with local stakeholders before the actual fieldwork. This included adjusting the questions asked based on prior knowledge of local conditions, such as contemplating whether a clan-based land tenure system still played a role in agricultural activities or how to discuss the interconnectedness of the lowlands and highlands. Preliminary fieldwork was conducted in July–August 2018 and the actual CSA-RA in February–March 2019.

3.1. Workshop exercises

Altogether 102 farmers participated in four two-day workshops held at each location: 31 in Kishushe, 24 in Maktau, 27 in Ngerenyi, and 20 in Chala. Gender and age balances were emphasized in the participant mobilization, with preconditions of farming activities, local residence, and not belonging to the same household. Of the participants, 50 were women and 47 were men, while five did not identify their gender. Participants came from 36 villages in the four sites, and the villages were distributed roughly within each site's agro-ecological zone. The average age of participants identifying their age ($n = 72$) was 45 years; the youngest was 20 years and the oldest 75 years. The gender-disaggregated workshop exercises included cropping calendars, organization mapping, climate calendars, historical calendars, and the use/ awareness of CSA technologies in CSA ranking. Mixed-gender exercises

included crop listing, participatory resource mapping, and final ranking of the CSA practices. In participatory resource mapping, participants drafted a map of their locality including settlements, roads, rivers, boundaries, and the locations of various services. By drafting climate calendars, the farmers identified rainfall patterns and typical weather events and conditions at different times of the year. Within the historical calendar exercise, farmers rated the quality and quantity of conditions regarding climatic, resource, and agricultural activities at various temporal scales. The last exercise was a pairwise ranking of CSA practices, in which the awareness and use of various practices were examined according to gender.

Informed consent was acquired from all participants, and gender-disaggregated workshop activities were facilitated for women groups by women facilitators and for men groups by men facilitators. Facilitators were prepared for situations with more dominant participants and how to de-escalate these situations. All two-day workshop sessions ended with a wrap-up, during which the results were presented and the exercises discussed together with the participants.

Key comments made by farmers in the workshops were transcribed and quantified, and organization and local resource maps alongside tables, such as rainfall distribution patterns, filled by the workshop groups, were digitized. The transcribed data were analysed and compared with simple queries to the etic coded key informant data to form coherent thematical entities that express the farmers' personal

views on climate change challenges and adaptation methods in the county. Furthermore, the analyses compared trends across the study sites to recognize spatial variability in agriculture and responses to climate change.

3.2. Transect walks, household surveys, and key informant interviews

Transect walks were carried out to better understand the environmental conditions and challenges faced by the farmers and to verify the data collected from the workshops, household survey, and key informant interviews (Fig. 3). The transect walks and household surveys took place within a 5-km radius from the workshop locations. The walks were 2–4 km long, stopping approximately every 100 m to record a Global Positioning System (GPS) coordinate point, and to photograph and examine the environmental and socio-economic conditions. All transects were conducted together with a local expert who could identify farming practices, built structures, soil types, flora and fauna in the area.

Household surveys were conducted in the workshop localities. Participants were randomly sampled using geospatial building data traced from satellite imagery. Altogether 65 interviews were conducted in the household surveys: 12 in Kishushe, 21 in Maktau, 21 in Ngerenyi, and 11 in Chala. The household survey data comprised farming activities and the land tenure system. We used the quantified household survey data to build an economic gross margin analysis of the agricultural activities in the four case study sites taking into consideration the production costs for each product (e.g. input costs and hired labour) and their selling price and quantities. The survey data collected were compared with the workshop data to find similarities and irregularities in the responses regarding environmental challenges and social constraints to CSA practices and technologies. In addition, awareness and use of various CSA technologies and practices were quantified and compared.

Key informants were chosen to represent local agricultural stakeholders in the administrative and civil society sectors. Sixteen key informants were interviewed during 10 interview sessions. These included individuals from e.g. non-governmental organizations (NGOs) that worked with farmers, and government and county officers from the departments of the environment, livestock, agriculture, drought management, gender, social development, and co-operatives. The recorded audio data were transcribed and then analysed with ATLAS.ti 9 -qualitative analysis software to find regularities, co-occurrence, and inter-linkages between hierarchical codes ($N = 166$). The coding framework contained categories and subcategories based on predefined and emerging codes. Predefined codes were categorised into thematical semi-structured interview questions, respondent background codes, location codes, crop variety and livestock codes, CSA practices and technologies, land tenure related codes, and other descriptive and meta codes. Emerging codes included relevant topics that were frequently mentioned in the interviews such as fall armyworm. Combined codes were used in queries to record patterns in the responses.

4. Results

4.1. Perceived changes in the climate and environment

The household interviews showed that 92% of respondents had observed a change in weather conditions during the past 20-year period, with increased variability, temperatures, and either reduced or unreliable rainfall across the sites. The perceived trends of increasing temperature and shifting rainfall patterns are in line with the temperature and rainfall distribution analyses of historical climate data collected from local weather stations in the county but slightly contradict the actual precipitation quantity, which appears to have only a minor decreasing trend and high spatial variability in the county (MoALF, 2016; Ogallo et al., 2019). The largest challenges regarding climate variability were identified as water scarcity, prolonged droughts, and unpredictable or reduced rainfall. Of the survey respondents, 60% had

experienced either low or non-existent yields due to these challenges. Only 20% of respondent households had been self-sufficient in terms of food they would normally produce throughout the previous year (two seasons), and 57% of respondents identified no significant income activities outside of farming.

Forty-five per cent of respondents identified pests as their most significant natural disaster challenge, with fall armyworm (*Spodoptera frugiperda*) infestations being the most cited. Other key challenges were human–wildlife conflicts, mentioned by 31% and mostly caused by elephants (*Loxodonta africana*) and monkeys (such as *Cercopithecus mitis, Chlorocebus pygerythrus*), and strong winds causing erosion and structural breakages, mentioned by 14%. These challenges were also noted in the transect walks (see Fig. 3). Key informant interviews noted human–wildlife conflicts to be rampant due to the human population increase, which has forced farmers to encroach closer to conservation areas and sanctuaries. Floods and droughts were also identified as key challenges.

Due to these challenges, farmers have had to source water from outside their localities and buy food they would normally produce, which has required seeking alternative sources of income such as casual labour, beekeeping and increasing livestock numbers. Farm-level responses to the above-mentioned challenges included finding water sources for irrigation, planting smaller areas to prevent risks, changing seed varieties and livestock breeds to more drought-tolerant ones, and increasing pesticide use. Especially in Maktau, water shortage was perceived as moderate and constant, which has forced farmers to cultivate more drought-tolerant crops and to shift pastures more frequently. In Chala, water shortages have led to farmers implementing shallow wells to irrigate their crops. A reduction in soil fertility was experienced elsewhere, except Maktau, forcing farmers to apply fertilizers. Minimum or zero tillage has increased in Kishushe due to soil quality depletion. However, newly adopted soil conservation and crop rotation practices were noted to have improved soil quality in Ngerenyi. Soil erosion was considered an issue in the highlands, causing landslides and eroding roads, which has restricted market accessibility.

4.2. Impacts of extreme weather conditions

The climate calendars indicated that women and children are disproportionately affected during perceived extremely dry years, as they typically travel long distances to fetch water. Crops that are not normally under irrigation require watering. When irrigation by any means is impossible, farmers must reduce the land size under cultivation and change their farming practices or abandon them. Nevertheless, crops may end up drying in the fields, creating severe food shortages. Human and livestock diseases and pests increase alongside human–wildlife conflicts. Livestock deaths occur, and animals are badly affected by dust. Cattle are sold at throwaway prices to buy food. While food is bought from outside the locality, communities must also depend on government support for food relief and charcoal burning for income increases. Heavy winds also occur during some years, ripping off roofs, destroying storage facilities, and felling trees.

During wet years, the harvest may be bountiful, but significant yield losses are stated to occur, as either crops cannot be collected or cereals become impossible to dry. Crops can be attacked by pests, such the fall armyworm, and challenges in post-harvesting create a risk for aflatoxin poisoning. Blight disease can affect tomatoes. Farmers therefore tend to use crude methods, such as excessive pesticide, herbicide, and fungicide application, to control crop pests and plant diseases, especially when confronted with unfamiliar ones. Although livestock benefits from abundant pastures, cattle may contract diseases sensitive to moisture, such as hoof diseases. Nevertheless, fruit trees produce well during extremely wet years, and large production may be gained from livestock. Floods and gully erosion may wash away houses, break structures, and destroy farms in the lowlands, and, according to women, repairing and cleaning the damages and finding firewood increases their workload

Fig. 3. Gully erosion in Kishushe (upper left), a water tank destroyed by an elephant in Maktau (upper right), a fall armyworm infestation in Ngerenyi (lower left), and sand turbulence in Chala (lower right). Antti Autio, March 2019.

significantly. In the following season, planting crops becomes more arduous due to overgrown weeds.

4.3. Shifting agricultural practices and technology transfer

Regarding the second research question on CSA constraints, government officials in Mwatate and Wundanyi sub-counties emphasized that lack of knowledge is the main reason for the low utilization level of several CSA technologies such as intercropping, green manure, cover crops, and composting. By contrast, Taveta was said to be technologically more advanced, and challenges there were more related to a lack of capital and resources. An NGO representative noted that while farmers are aware of many CSA technologies, they are confused with which of them to invest in, as e.g. conservation agriculture equipment are costly.

The extension services provided by the county were perceived as inadequate by some workshop participants in Maktau, even though the respondents in all four locations had identified receiving extension services. Government agencies and parastatals, along with informal, local, national, and international NGOs, have implemented agricultural development interventions in the county. For example, World Vision, Plan International, and Action Aid have worked with farmers on issues such as water conservation techniques and women empowerement. The Kenya Climate Smart Agriculture Project conducted research and farmer workshops simultaneously with our fieldwork in the area.

According to county officials, the past decades have seen a dramatic shift from manual land preparation to machinery use, e.g. communally rented tractors. Land in the highlands suitable for agricultural expansion has been exhausted and farmers are cultivating very small parcels of land, but cultivated land is increasing in the lowlands, as also evidenced by Pellikka et al. (2018). This has led to the abandonment of fallowing and to increased fertilizer use in the highlands. Land scarcity in the hills has also encouraged zero-grazing of livestock, and stricter control has been implemented to prevent grazing in national parks and conservation areas. Taveta has experienced a shift from cultivating maize to high-value horticultural crops, such as chillies and bananas, while horticulture has decreased in the hills.

4.4. Gendered roles in agriculture

The gendered roles in agricultural practices appear to depend on the perceived physicality of the task that derive from cultural assumptions concerning gender differences (Little, 2002), but even more so on whether the produce is meant for home consumption or sale. Table 2 describes the perceived five most important crops and their gendered associations. Produce that requires sourcing from the markets or creates sales revenue is typically associated with men, while produce for home consumption is associated with women. This was expressed more clearly in the key informant interviews. A practice changing from subsistence to commercial or vice versa may also have implications for the agricultural roles of families.

The key informant interviews further disclosed that decision-making power in the household over agricultural issues, such as the type of crops to be grown, livestock to be reared, and where to sell the products and at what price, was dominated by the men. The following quotes are by county-level, government-level, and parastatal officers working directly with women farmers on issues such as gender, agriculture, and development.[2] A key informant (#1, a woman) expressed the following concerning intrahousehold decision-making:

'*The few times I've gone to the field and posed this question, the women will say they have to consult their husbands before they engage in anything. So, decisions are made, based on the agreement that they have with the husband. – – I think the issue[,] of course[,] is when you want to engage in*

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[2] To increase readability, we have slightly changed the punctuation and omitted or added individual words in the quotes with respect to the original phrases, but without changing the original meaning of the sentences.

Table 2

Lists of the five most highly ranked crops and livestock, and their gendered association in the crop-listing exercise of the workshops. F = women, M = men, C = consumption, S = sale, D = dairy, and B = beast of burden.

Kishushe[a]							Ngerenyi							
Rank	Crop	Gender	Use	Livestock	Gender	Use	Rank	Crop	Gender	Use	Livestock	Gender	Use
1	Maize *(Zea mays)*	M	C	Goats	M	n.d.	1	Maize *(Z. mays)*	F	C	Cows	M	S + D
2	Green grams *(Vigna radiata)*	F	C + S	Cows	M	n.d.	2	Beans *(Phaseolus vulgaris L.)*	F	C	Chicken	F	C + S
3	Sorghum *(Sorghum bicolor)*	F	C + S	Sheep	M	n.d.	3	Kales *(Brassica spp.)*	M	C + S	Sheep	M	S
4	Cowpeas *(Vigna unguiculata)*	F	C	Donkeys	M	n.d.	4	Macadamia *(Macadamia spp.)*	M	S	Rabbits	M	C + S
5	Pigeon peas *(Cajanus cajan)*	F	C	Chicken	F	n.d.	5	Bananas *(Musa spp.)*	F	C + S	Pigs	M	S
Maktau							Chala						
Rank	Crop	Gender	Use	Livestock	Gender	Use	Rank	Crop	Gender	Use	Livestock	Gender	Use
1	Maize *(Z. mays)*	F	C + S	Chicken	F	C + S	1	Maize *(Z. mays)*	F	C + S	Goats	M	S
2	Beans *(P. vulgaris L.)*	F	S	Goats	F	C + S	2	Beans *(P. vulgaris L.)*	F	C + S	Cows	M	S + D
3	Cowpeas *(V. unguiculata)*	F	C + S	Donkeys	M	B	3	Tomatoes *(Lycopersicon esculentum)*	M	S	Sheep	M	S
4	Green grams *(V. radiata)*	F	C + S	Cows	M	C + S	4	Onions *(Allium cepa)*	M	S	Poultry	F	C + S
5	Cassava *(Manihot esculenta)*	F	C + S	Bees	M	S	5	Bananas *(Musa spp.)*	M	S	Rabbits	F	C + S

[a] Livestock use data on Kishushe is missing due to field work practicalities in the farmer workshop

any agricultural activity[,] [a] woman has to first consult the husband if she can go ahead and do the agriculture activity. – – I think the biggest problem the woman faces is 1) the right to own land, 2) she faces a lot of difficulties even in making personal choices when it comes to what do I want for myself, because she is tied to her family and to the society.'

Another respondent (#2, a woman) stated:

'The main decision maker is the man. There could be a few houses where you have consultations, but I [. . .] believe that in most households the man makes the decision on [. . .] what is to be farmed, the size of the farm to be used, the type of inputs to be used. Because you see in most of the houses, it's the man who has the money.'

However, non-farm employment outside the community is common for men in TTC, and practical agricultural decisions are often made by women in the two-headed households. Agricultural information provided by extension services was identified to reach both men and women equally in the county. Furthermore, women were said to participate more in communal meetings regarding agriculture. Additionally, in the organizational mapping exercises in all four locations, women identified more agriculture-related organizations, social groups, and especially women-targeted small-loan providers than the men did.

Despite women playing a major role in agricultural production, the key informant interviews revealed that women rarely hold titles to their plots due to the traditional land tenure system that favours men in inheriting, selling, and bequeathing land, regardless of whether households are single- or two-headed households. This complicates investing in new technologies, as loans from major financial institutions typically necessitate land titles for approving credit. A key informant (#1, a woman) stated the following regarding the land tenure system:

'Men own land. And you find [in] our traditions and our cultures with the patriarchal society, it was very [pause], women just don't own land. If a woman will own land, [she] will own land for example [. . .] in places like Taveta because, I'm going to give an example. I'm a Taita myself. So, I can't own land [. . .] where my dad is staying because they're given to the boy child. So, if you want to own land, for example me, I have to buy land from somewhere else. So, I'll either own land in Mwatate or I'll own land in Taveta or Voi, because they're their lands, you see. – – But for the tradition[al] woman who stays at home, even the cash that she has started saving if she's going to buy a land, you know she has to make the decision with the husband. But of course who is more probable to take the title deeds? It's the man.'

Another key informant (#2, woman) stated the following on acquiring loans:

'They [women] are not major decision makers on how the land will be used. They don't make that decision. They cannot even use the title deed to access credit. They cannot use the title deed as security to get loans if the title deed is in the name of the husband, they can't.'

A third key informant (#3, man) expressed the following statement on the challenges that women face in agriculture:

'One of them [challenges] is on the side of labour, they [women] normally put [in] a lot of labour, but when it comes to returns, much of these returns is taken by men.'

4.5. Socio-economic constraints in agriculture

The key informant interviews identified marketing structures to be challenging for farmers, as prices fluctuate unexpectedly. Farmers have been discouraged from forming strong co-operatives to gain agglomeration benefits because of competition by large-scale farmers selling their products, brokers exploiting the farmers, and poor management that has been claimed to have occurred in previous years, for example in coffee and aloe production. Value addition was noted to be minimal and mainly focused in Chala, with its horticultural products and fruits. Food distribution centres operated by e.g. brokers and co-operatives were also considered ineffective. The key hindering factors for value addition include lack of technical know-how, lack of a suitable market, and insufficient capital to invest in the required infrastructure. Officials stated that despite general improvements of the road networks in Taveta and Taita Hills, the poor feeder road network hindered transporting products to the markets.

Attracting youth to agriculture was identified as a main challenge, as farmers are ageing and the land tenure system does not support intergenerational transitions well. In the lowlands, some farmers are squatting on communal land, whereas title deeds may be registered to earlier generations in the hills. Acquiring title deeds was described to be expensive outside government-led land adjudications.

The economic analysis shows positive net returns from crop production in Kishushe and Chala and negative returns in Maktau and Ngerenyi (Table 3). Livestock production was excluded from the analysis based on the high diversity of livestock production systems and

Table 3

Gross margin analysis in Euros (EUR), based on the household survey in 2019 in Kishushe ($n = 12$), Maktau ($n = 21$), Ngereyni ($n = 21$), and Chala ($n = 11$). Crop income was calculated for all crops grown and 1 EUR was equivalent to an average of 113.64 Kenyan Shillings in 2019.

	Kishushe	Maktau	Ngerenyi	Chala
Crop income	242	19	86	953
Input costs	32	14	51	246
Labour costs	99	142	132	189
Cost of renting land	0	0	2	66
Total variable cost	130	155	185	501
Gross margin	112	−137	−99	452

short-term viewing cycle of one year. This underestimates the variable production costs. The higher crop returns in Chala are likely attributed to more commercialized farming techniques, land availability, and farmer focus on high-value horticultural crops, such as bananas, compared with subsistence crops. Renting land from irrigation schemes is reflected in the variable costs in Chala. In Ngerenyi, the lower crop income may be attributed to limited land holdings. Farm inputs were mentioned to be readily available from agrovets, but prices were considered high, and seed quality was also identified as a problem.

4.6. CSA applicability

The pairwise ranking of CSA farm management practices showed similarities between the sites, while each site prioritized differently their most important practice. The use of zaï pits was ranked as the most important practice in the dry agro-ecological zone of Kishushe, while Maktau, suffering from a constant water shortage, emphasized the importance of rainwater harvesting. Farmyard manure application was prioritized in Ngerenyi, where soils were eroded. The more commercial agriculture in Chala focused on irrigation (Table 4).

The lack of awareness stated in the key informant interviews contradicts our findings from the household survey and the workshop data. A further examination of the household interviews regarding awareness and use of CSA technologies related to the third research question on spatial heterogeneity reveals that farmers are aware of most available technologies, but their utilization typically follows the agro-ecological division between the lowlands and highlands (Fig. 4). Major knowledge gaps may be seen in the awareness of zero tillage, green manure, and organic agriculture. Notably, agroforestry and mulching are practised more commonly in Kishushe than in Maktau, despite both representing relatively similar agro-ecological zones. Maktau, on the other hand, is the only site where organic agriculture is practised more commonly.

The household data concerning technological awareness and where agricultural information is acquired from (44% of women and 60% of men mentioned extension services) suggest, alongside the statements made in the key informant interviews, that women and men have relatively equal access to agricultural information regarding CSA technologies. However, men are more aware of practices such as composting, green manure use, mulching, and zero tillage (Fig. 5). Fallowing, farmyard manure, intercropping, and organic agriculture were practised more frequently in households where women farmers were interviewed.

The constraints of adopting CSA technologies expressed in the pairwise ranking indicate that the challenges differ greatly depending on the

agro-ecological zone (Table 5). Moreover, the ranking exercise demonstrates that farmers are aware of the common CSA technologies and they have opinions of their applicability in their local context. Lack of knowledge or awareness of CSA technologies was most common in Maktau, where workshop participants also indicated inadequate extension services. In general, the main hindering factors across the scale of CSA technologies are characterized by a lack of resources such as water, land, labour, time, money, knowledge, or training. Other constraints are mainly related to human–wildlife conflicts, pests, and diseases. Societal pressure affecting the adoption of terracing, farmyard manure, and contour ploughing may exist, as these technologies have been heavily promoted by the government and even by the colonial administration before the independency of Kenya (Thurston, 1987). According to key informants, farmers have also been encouraged by the Ministry of Agriculture, Livestock and Fisheries of Kenya to engage in agroforestry and intercropping and to avoid over-grazing.

Agricultural water management methods in the lowlands are emphasized by rainwater harvesting, whereas they focus more on water retention, irrigation, and erosion avoidance in the highlands. Irrigation is commonly used in Chala, while it was severely hampered by water scarcity in other locations. Irrigation-related conflicts between farmers are also common in Chala and in the highlands. Zaï pits have been introduced to the lowland people, but a lack of continued awareness creation and training has led to less people utilizing them after the first stage of adoption. Land tenure restrictions limit practice and technology adoption, such as fallowing and crop rotation, in the Taita Hills.

Several CSA practices and technologies, namely composting, mulching, building ridges or bunds, and terracing, are also considered laborious. Composting and green manure use are restricted by plant material scarcity. According to participants, agroforestry practices are hindered by wildlife attacks and a general lack of knowledge. Practising organic agriculture was disrupted by pest attacks and soil infertility in the highlands, forcing farmers to use chemicals. Inorganic fertilizers are readily available, and they are being widely used in the highlands and in Chala, where workshop participants had also indicated a decline in soil fertility. In contrast, soil is considered fertile in Kishushe and Maktau, which eliminates the need for fertilizers. Green manure and zero tillage had the lowest awareness levels and were considered risky practices amid uncertain climatic conditions.

5. Discussion

We examined the constraints faced by smallholder farmers in TTC that prevent them from effectively adapting to climate change and improving their livelihoods amid changing environmental conditions. The results provide similar evidence as the conclusions obtained with CSA-RAs conducted in Tanzania and Uganda by Mwongera et al. (2017): great heterogeneity exists in agricultural conditions on a regional level, guiding the adoption of CSA technologies. Further, in line with the research by Belay et al. (2017) in Ethiopia and Elum et al. (2017) in South Africa, the majority of farmers in TTC have acknowledged changes in the local climate and are reacting autonomously to these changes. The model by Boitt et al. (2014) revealed that climate change will likely shift agro-ecological zones in the Taita Hills, forcing farmers to change cultivation patterns, and indeed, farmers in Taita Taveta are both knowledgeable and utilize the most common climate-smart farm and crop management practices. They use improved seed and livestock

Table 4

The five most preferred CSA farm management practices ranked by workshop participants.

| Site	1.	2.	3.	4.	5.
Kishushe	zaï pits	terracing	farmyard manure	crop rotation	intercropping
Maktau	rainwater harvesting	early planting	terracing	intercropping	crop rotation
Ngerenyi	farmyard manure	terracing	crop rotation	agroforestry	ridges
Chala	irrigation	crop rotation	rainwater harvesting	terracing	zero tillage

Awareness and use of selected CSA technologies by location
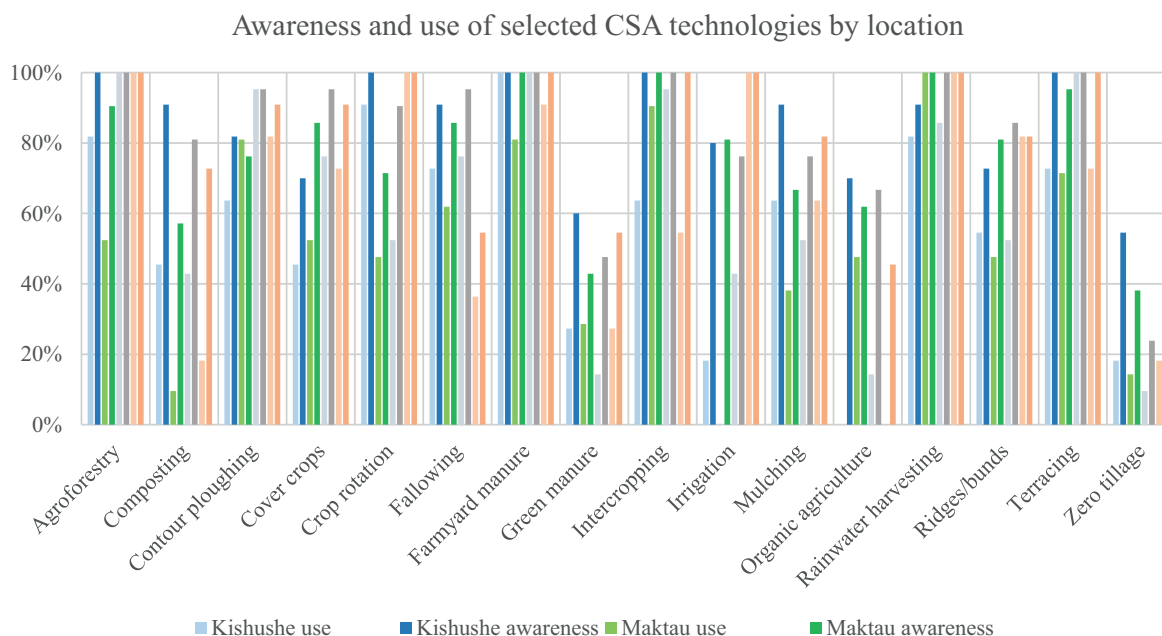
Fig. 4. Proportion (%) of use and awareness of selected CSA practices by location, according to household surveys.

Awareness and use of selected CSA technologies by respondents' gender
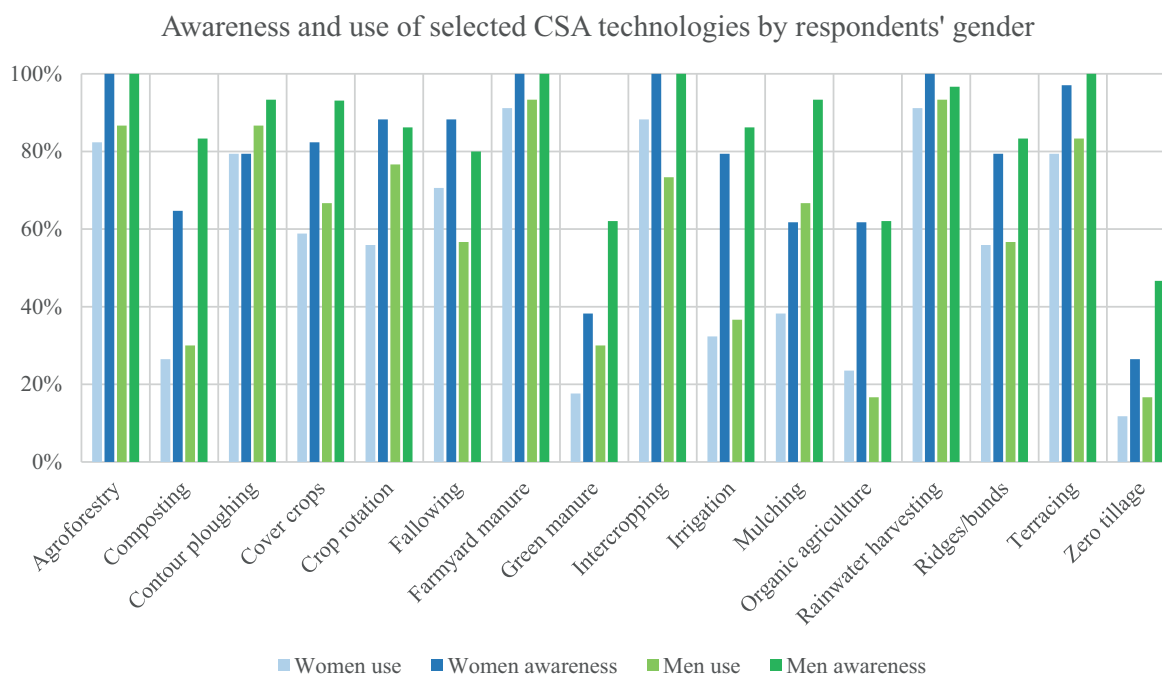

Fig. 5. Proportion (%) of use and awareness of selected CSA practices by respondent gender, according to household surveys.

varieties and constantly seek new information from agricultural extension officers, NGOs, and other farmers. Farmers have changed their ways of agricultural production to better meet market requirements.

Key informant interviews in Taita emphasized that low adoption rates of CSA technologies are due to farmers' lack of knowledge. In contrast, during both the workshops and household surveys, the farmers themselves acknowledged strong awareness of these technologies across the agro-ecological zones. The adoption gap for CSA technologies and

practices in TTC can be seen in the difference between awareness and adoption rates. Despite farmers being aware of many CSA practices and technologies, a smaller proportion implement these technologies. Moreover, the farmers in TTC perceived inequality in the extension services provided based on geographical location but not according to gender. Kpadonou et al. (2017) and Holden et al. (2018) have noted that a positive correlation exists between agricultural training and the adoption of agricultural technology. Therefore, as expressed by Eshetu

Table 5
Factors affecting the adoption of different CSA practices in four locations in TTC according to workshop participants.

	Semi-arid/Arid lower midland zone	Semi-arid lower midland and Inner lowland zone	Semi-humid maize and transitional maize–sunflower zone	Transitional maize and marginal cotton zone
CSA practice	Kishushe	Maktau	Ngerenyi	Chala
Agroforestry (trees grown among crops or pasture)	No answer	- hindered by human–wildlife conflicts - lack of awareness	- limited by attacks from monkeys - lack of knowledge, although educated on the practice	- land scarcity - lack of water to raise the seedlings
Composting (fertilizer composed of organic waste material)	- laborious and other alternatives exist	- lack of water and materials to compost	- laborious and time-consuming	- time-consuming and requires skill - remains fed to livestock
Contour ploughing (ploughing along contours)	- mainly flat land	+ conserves soil and water - preyed upon by livestock and wildlife	+ practised by all - moles and other pests	No answer
Cover crops (plants that cover the soil)	- an abandoned practice	+ majority of farmers plant them	- unavailability of seeds - used more in the past	No answer
Crop rotation (growing various crops in the same area in sequence to growth seasons)	+ popular + controls pests and diseases + people alternatively use intercropping	- difficult to use because of land shortage + increases yields + reduces pest attacks + practised to make use of rains together with early harvesting - termites may destroy seed or seeds spoil if rains are late	+ pest and disease control	+ benefits for fertility and restoration + control of pests and diseases
Early planting (planting before onset of rainy season)	No answer		No answer	- too much water needed
Fallowing (cultivated land not seeded for one or more growing seasons)	+ saves energy - land size limitations - overtaken by crop rotation	- land size limitations	- land size limitations - wildlife conflicts - used in the past	+ lack of funds can lead to fallowing - expensive to transport - may increase pests - takes longer for crops to grow and may scorch the plant
Farmyard manure (fertilizer composed of manure)	+ easy to use and not labour-intensive + does not scorch the crops	- lack of knowledge	+ practised by all	
Green manure (crop parts left to wither in fields)	- risky to use with uncertainty of next harvest	- dry area, only during planting season + practised by all + diversifies farming	- lack of awareness	- waste or loss of crop
Intercropping (growing a crop between other crops)	+ controls pests + prevents diseases	+ increases harvest because of land shortage + helps with nitrogen fixation	- vegetable farmers avoid intercropping because of competition between crops - lack of water, time, and equipment - farms built on slopes	- timing is a challenge - a fear of competition for light and nutrients - lack of mechanization
Irrigation (supply of water to crops)	- lack of water - eaten by livestock and termites (*Macrotermes*) - blown away by wind - lack of knowledge - disrupted by fall armyworm attacks forcing farmers to use chemicals	- lack of water - depends on the type of crops grown - eaten by livestock and termites - less vegetation cover to make	- conflicts between farmers - termites eat the mulch - not enough plant material - mulch left for livestock as fodder and used in terraces	- water conflicts, especially outside irrigation schemes - mulch used to feed the cattle - laborious
Mulching (covering soil between plants with a layer of material)				
Organic agriculture (minimum use of inputs)		No answer	- no longer used due to lack of soil fertility and increased pests	- lack of knowledge
Rainwater harvesting (rain collection and storage)	No answer	+ practised by all to fight water shortages and reduce erosion - costly	- lack of money to buy tanks and install gutters	+ common practice
Ridges (crops planted into ridges)	+ helps in holding runoff water - laborious and time-consuming + increases yields + combats soil erosion and assists in growing napier grass	- laborious to build + used for soil and water conservation	+ ridges help in water conservation + increases production	No answer
Terracing (graduated terrace farms on a slope)	- rocky area difficult to construct - lack or training + prevents soil erosion and works as alternative for terracing.	- broken by livestock - laborious to build	+ practised by all farmers	+ increases soil and water conservation
Zaï pits (pits in the soil to harvest water pre-season)	- nearly an abandoned practise	- lack of awareness	No answer	- no follow-up on zaï pit education - yielded scant produce
Zero tillage (soil not tilled before planting)	No answer	- lack of knowledge	- lack of knowledge - farmers prefer tilling for the land to get aeration in the soil	+ requires little time and costs

et al. (2020), while farmers practise various adaptation strategies, these actions may not be sufficient without government extension services combining both adaptive information and technological support. Nevertheless, our results are also in line with research conducted in Busia County of Kenya by Wekesa et al. (2018), which indicates that even CSA practices that require low capital investments may have low adoption rates, possibly due to non-monetary resource constraints.

This study further shows that unfavourable market conditions and limited value addition, especially outside Taveta, are also constraints to farming in the area. This is in accord with Kirui et al. (2017), who noted that many farmers in rural Kenya are constrained by poor marketing facilities characterized by high transportation costs, poor storage, and high wastage. The results of our gross margin analysis of crops further indicate that agriculture in Maktau and Ngerenyi must be sustained

more by keeping livestock and other forms of income, such as casual labour, as the gross margins are negative. This could mean that there are less resources to invest in agriculture and to respond quickly to extreme weather events and pest infestations. The high prevalence of pests, such as fall armyworm, in the data is likely linked to the first major fall armyworm outbreak in Kenya, which occurred in 2017, causing annual losses of over 3 billion KSh (ca. 2,640,000€) to maize farmers (De Groote et al., 2020). This may also explain the increased adoption of pesticides and changes in crop varieties. The rationale behind the shifts in land and farm management practices is thus highly complex when interlinked with such phenomena as climate change.

Further, women's marginalization in TTC from decision-making processes, as described in the household roles, lack of property rights, and limited access to credit and other production inputs, hinder them from investing in CSA technologies and practices to achieve their optimal production potential. This hindrance may, for example, be reflected in agroforestry and cover cropping that require monetary inputs, in building ridges and terraces that increase on-farm labour and crop rotation, and in fallowing and intercropping that require the acquisition of larger land parcels. According to FAO and CARE (2019), the agricultural sustainability can best be enhanced by ensuring that men and women have equal access to productive resources, CSA, and labour-saving technologies, services, and institutions within their localities. Tsige et al. (2020) also suggest that while CSA presents opportunities for economic development and food security, technological success has been continuously hindered by gender constraints. This emphasizes the need for institutions working on climate change to partner with local women's organizations to adequately tap the potential of women as adapters of CSA technologies and practices. Tapping into this potential is important, especially when considering women's central role in agriculture and their high social capital within the organizational network. Gender transformative actions are also needed within the policy and legal framework to ensure better access to resources when promoting CSA practices and technologies.

Despite advances, TTC significantly lags behind the rest of Kenya when it comes to food security (Kenya National Bureau of Statistics, 2018). Nearly all respondents described growing irregularity in weather conditions and having faced challenges due to climate change. Their adaptation capacity seems to be hindered by a myriad of sources besides farm and crop management practices such as access to land and resources, land ownership issues, human–wildlife conflicts, pest infestations, and unpredictable market mechanisms. Dhanya and Ramachandran (2016) have also recognized that in South India, farmer perceptions are consistent with observed changing weather patterns, except for rainfall quantity and distribution, and that farmers are able to clearly express their specific adaptation needs. However, farmers have relatively low resources to invest in CSA innovations, and adopting multiple technologies may impose a considerable burden on an individual farmer (Makate et al., 2019). Moreover, CSA technologies have proven to be labour-, knowledge- and capital-intensive, and often adopting these technologies is highly dependent on land tenure-related issues (Kpadonou et al., 2017). The socio-economic perspectives in our results are in line with Hohenthal et al. (2017) in recognizing the complexity of local resource management and empowering the farmers from the narrative in which their lack of knowledge of farm and land management practices is the main constraint on technology adoption. This may further contribute to imagining alternative intervention strategies that are based on dialogue-building between state actors and farmers (Hohenthal et al., 2018).

5.1. Study limitations

Participatory methods, such as CSA-RA, can provide insight to local complexities that shape the agricultural production and livelihoods of a community or a district-level administrative unit. The benefit of these methods is that they provide a fair amount of flexibility. Nevertheless, generalizability and representativeness tend to suffer from typically smaller sample sizes and the subjectivity of perceived applicability and impacts of CSA practices. Sampling may exclude the most marginalized farmers, and research settings with focus groups, such as farmer workshops, may produce biased data if unequal power structures in knowledge production are not taken into consideration. The descriptiveness of the data allows for bringing forth the voices of farmers and other local stakeholders but simultaneously makes detecting significant drivers of agricultural knowledge and technology uptake more difficult and unsure.

6. Conclusion

The diversity of agro-ecological zones and socio-economic settings in TTC creates a complex food production system that is significantly affected by climate change. Farmers have acknowledged a shift towards uncertainty in weather patterns and are attempting to find ways to secure their livelihoods amid these processes. Upscaling CSA technologies is challenging due to heterogeneity in both biophysical and socio-economic conditions, but there is evidence that locally appropriate responses to climate change are utilized in agriculture. Moreover, development interventions have been conducted in the case study area, and farmers have found many of these interventions useful. Nevertheless, the civil society sector may not produce adequate solutions for climate change adaptation among the farmers, and government extension services should provide technical support suitable for the differing agro-ecological zones in the region.

Dissonance also occurs in the perceived awareness and utilization of CSA technologies between state actors and farmers, which requires dialogue-building across diverse agricultural settings to find the most effective focus for extension services and interventions. Our results also highlight the need to invest in rural public education to provide farmers with training in CSA practices and technologies after the local focus has been identified through dialogue. Further research is needed to examine the limitations that gender and the current land tenure system in TTC, with its land-use conflicts, create for the climate change adaptation efforts of smallholder farmers. The findings of our research are based on the contextual settings of TTC, but the results indicate that the adoption of CSA practices and utilization of technologies especially in sub-Saharan regions that are heavily based on subsistence agriculture with heterogenous agro-ecological zones, require localized solutions in policy formation and planning of both agricultural extension services and development interventions that consider the agency of the farmers.

Declaration of Competing Interest

None.

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References

Abegunde, V.O., Sibanda, M., Obi, A., 2019. The dynamics of climate change adaptation in sub-saharan africa: a review of climate-smart agriculture among small-scale farmers. Clim. 7, 132. https://doi.org/10.3390/cli7110132.

Amare, A., Simane, B., 2017. Determinants of smallholder farmers' decision to adopt adaptation options to climate change and variability in the Muger Sub basin of the Upper Blue Nile basin of Ethiopia. Agric. food Secur. 6, 1–20. https://doi.org/10.1186/s40066-017-0144-2.

Andrieu, N., Howland, F., Acosta-Alba, I., Le Coq, J.-F., Osorio-Garcia, A.M., Martinez-Baron, D., Gamba-Trimiño, C., Loboguerrero, A.M., Chia, E., 2019. Co-designing climate-smart farming systems with local stakeholders: a methodological framework for achieving large-scale change. Front. Sustain. Food Syst. 3 https://doi.org/10.3389/fsufs.2019.00037.

Aryal, J.P., Rahut, D.B., Maharjan, S., Erenstein, O., 2018. Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic Plains of India. Nat. Resour. Forum 42, 141–158. https://doi.org/10.1111/1477-8947.12152.

Belay, A., Recha, J.W., Woldeamanuel, T., Morton, J.F., 2017. Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. Agric. food Secur. 6 https://doi.org/10.1186/s40066-017-0100-1.

Boitt, M., Mundia, C.N., Pellikka, P., 2014. Modelling the impacts of climate change on agro-ecological zones–a case study of Taita Hills, Kenya. Univers. J. Geosci 2, 172–179. https://doi.org/10.13189/ujg.2014.020602.

Brandt, P., Kvakić, M., Butterbach-Bahl, K., Rufino, M.C., 2017. How to target climate-smart agriculture? Concept and application of the consensus-driven decision support framework "targetCSA.". Agric. Syst. 151, 234–245. https://doi.org/10.1016/j.agsy.2015.12.011.

Capitani, C., 2019. Views from two mountains : exploring climate change impacts on traditional farming communities of Eastern Africa highlands through participatory scenarios. Sustain. Sci. 14, 191–203. https://doi.org/10.1007/s11625-018-0622-x.

Chaudhury, A.S., Helfgott, A., Thornton, T.F., Sova, C., 2016. Participatory adaptation planning and costing Applications in agricultural adaptation in western Kenya. Mitig. Adapt. Strateg. Glob. Chang. 21, 301–322. https://doi.org/10.1007/s11027-014-9600-5.

Clay, N., King, B., 2019. Smallholders' uneven capacities to adapt to climate change amid Africa's 'green revolution': Case study of Rwanda's crop intensification program. World Dev. 116, 1–14. https://doi.org/10.1016/j.worlddev.2018.11.022.

County Government of Taita Taveta, 2018. County Government of Taita Taveta - Integrated Development Plan 2018–2022.

De Groote, H., Kimenju, S.C., Munyua, B., Palmas, S., Kassie, M., Bruce, A., 2020. Spread and impact of fall armyworm (Spodoptera frugiperda J.E Smith) in maize production areas of Kenya. Agric. Ecosyst. Environ. 292, 106804. https://doi.org/10.1016/j.agee.2019.106804.

De Pinto, A., Cenacchi, N., Kwon, H.-Y., Koo, J., Dunston, S., 2020. Climate smart agriculture and global food-crop production. PLoS One 15, e0231764. https://doi.org/10.1371/journal.pone.0231764.

Dhanya, P., Ramachandran, A., 2016. Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi arid region of south India. J. Integr. Environ. Sci. 13, 1–18. https://doi.org/10.1080/1943815X.2015.1062031.

Elum, Z.A., Modise, D.M., Marr, A., 2017. Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. Clim. Risk Manag. 16, 246–257. https://doi.org/10.1016/j.crm.2016.11.001.

Eshetu, G., Johansson, T., Garedew, W., Yisahak, T., 2020. Determinants of smallholder farmers' adaptation options to climate change in a coffee-based farming system of Southwest Ethiopia. Clim. Dev. 1–8 https://doi.org/10.1080/17565529.2020.1772706.

FAO, 2014. Success Stories on Climate-Smart Agriculture.

FAO (Ed.), 2017. Climate-Smart Agriculture Sourcebook Summary, 2nd ed. FAO, Rome.

FAO and Care, 2019. Good practices for integrating gender equality and women's empowerment in climate-smart agriculture programmes. FAO and Care, Atlanta, 108 pp. Licence: CC BY-NC-SA 3.0 IGO.

Ge, M., Friedrich, J., 2020. 4 Charts Explain Greenhouse Gas Emissions by Countries and Sectors [WWW Document]. World Resour. Inst. URL https://www.wri.org/blog/2020/02/greenhouse-gas-emissions-by-country-sector (accessed 12.13.20).

Hohenthal, J., Minoia, P., Pellikka, P.K.E., 2017. Mapping meaning : critical cartographies for participatory water management in Taita Hills, Kenya. Prof. Geogr. 69, 383–395. https://doi.org/10.1080/00330124.2016.1237294.

Hohenthal, J., Räsänen, M., Minoia, P., 2018. Political ecology of asymmetric ecological knowledges: diverging views on the eucalyptus-water nexus in the Taita Hills, Kenya. J. Polit. Ecol. 25, 1–19. https://doi.org/10.2458/v25i1.22005.

Holden, S.T., Fisher, M., Katengeza, S.P., Thierfelder, C., 2018. Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. Land Use Policy 76, 113–123. https://doi.org/10.1016/j.landusepol.2018.04.048.

IPCC, 2019. Climate Change and Land: an IPCC special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes In Terrestrial Ecosystems.

Jaetzold, R., Schmidt, H., Hornetz, B., Shisanya, C., 2012. Coast Province: Taita-Taveta County, in: Farm Management Handbook of Kenya VOL.II. Ministry of Agriculture, Nairobi, p. 46.

Kenya National Bureau of Statistics, 2018. Basic Report on Well-being in Kenya (Nairobi).

Kenya National Bureau of Statistics, 2019a. 2019 Kenya Population and Housing Cencus: Volume 1 (Nairobi).

Kenya National Bureau of Statistics, 2019b. 2019 Kenya Population and Housing Cencus: Volume 2 (Nairobi).

Khatri-Chhetri, A., Regmi, P.P., Chanana, N., Aggarwal, P.K., 2019. Potential of climate-smart agriculture in reducing women farmers' drudgery in high climatic risk areas. Clim. Chang. 158, 29–42. https://doi.org/10.1007/s10584-018-2350-8.

Kirui, V., Kisang, A., Kiptum, E., 2017. Investigating farmer's participation in value–added activities in rural Kenya: case of kapkamak-kabonon irrigation project in arror ward, Elgeyo Marakwet County. J. Small Bus. Entrep. Dev 5, 59–66. https://doi.org/10.15640/jsbed.v5n2a6.

Klytchnikova, I.I., Sadler, M.P., Townsend, R., Edmeades, S., Choudhary, V., Hussain, S., Kray, H.A., Fernandes, E., Moses, E.D., Cantrell, J.T., 2015. Future of Food: Shaping a Climate-Smart Global Food System. The World Bank.

Kpadonou, R.A.B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., Kiema, A., 2017. Advancing climate-smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. Land Use Policy 61, 196–207. https://doi.org/10.1016/j.landusepol.2016.10.050.

Lan, L., Sain, G., Czaplicki, S., Guerten, N., Shikuku, K.M., Grosjean, G., Läderach, P., 2018. Farm-level and community aggregate economic impacts of adopting climate smart agricultural practices in three mega environments. PLoS One 13, e0207700. https://doi.org/10.1371/journal.pone.0207700.

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., Sen, P.T., Sessa, R., Shula, R., Tibu, A., Torquebiau, E.F., 2014. Climate-smart agriculture for food security. Nat. Clim. Chang. 4, 1068–1072. https://doi.org/10.1038/nclimate2437.

Little, J., 2002. Rural geography: rural gender identity and the performance of masculinity and femininity in the countryside. Prog. Hum. Geogr. 26, 665–670. https://doi.org/10.1191/0309132502ph394pr.

MacGregor, S., 2010. 'Gender and climate change': from impacts to discourses. J. Indian Ocean Reg. 6, 223–238. https://doi.org/10.1080/19480881.2010.536669.

Maeda, E.E., Pellikka, P.K.E., Siljander, M., Clark, B.J.F., 2010. Potential impacts of agricultural expansion and climate change on soil erosion in the Eastern Arc Mountains of Kenya. Geomorphology (Amst). 123, 279–289. https://doi.org/10.1016/j.geomorph.2010.07.019.

Maeda, E.E., Pellikka, P.K.E., Clark, B.J.F., Siljander, M., 2011. Prospective changes in irrigation water requirements caused by agricultural expansion and climate changes in the eastern arc mountains of Kenya. J. Environ. Manag. 92, 982–993. https://doi.org/10.1016/j.jenvman.2010.11.005.

Makate, C., Makate, M., Mango, N., Siziba, S., 2019. Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. J. Environ. Manage. 231, 858–868. https://doi.org/10.1016/j.jenvman.2018.10.069.

MoALF, 2016. Climate Risk Profile for Taita Taveta: Kenya County Climate Risk Profile Series (Nairobi).

Mwongera, C., Shikuku, K.M., Winowiecki, L.A., Twyman, J., Läderach, P., Ampaire, E.L., van Asten, P., Twomlow, S., 2015. Climate-Smart Agriculture Rapid Appraisal (CSA-RA): A Prioritization Tool for Outscaling CSA - Step-by-Step guideliNes.

Mwongera, C., Shikuku, K.M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., Twomlow, S., Winowiecki, L.A., 2017. Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. Agric. Syst. 151, 192–203. https://doi.org/10.1016/j.agsy.2016.05.009.

Neate, P., 2013. Climate-smart agriculture success stories from farming communities around the world. In: CGIAR Research Program on Climate Change. Agriculture and Food Security (CCAFS) and the Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen.

Notenbaert, A., Pfeifer, C., Silvestri, S., Herrero, M., 2017. Targeting, out-scaling and prioritising climate-smart interventions in agricultural systems: Lessons from applying a generic framework to the livestock sector in sub-Saharan Africa. Agric. Syst. 151, 153–162. https://doi.org/10.1016/j.agsy.2016.05.017.

Ogallo, L., Omay, P., Kabaka, G., Lutta, I., 2019. Report on Historical Climate Baseline Statistics for Taita Taveta, Kenya Vol 1. IGAD Climate Prediction and Application Centre.

Pellikka, P.K.E., Clark, B.J.F., Gosa, A.G., Himberg, N., Hurskainen, P., Maeda, E., Mwang'ombe, J., Omoro, L.M.A., Siljander, M., 2013. Chapter 13 - agricultural expansion and its consequences in the Taita Hills, Kenya. In: Paron, P., Olago, D.O., Omuto, C.T.B.T.-D. (Eds.), Kenya: A Natural Outlook. Elsevier, pp. 165–179. https://doi.org/10.1016/B978-0-444-59559-1.00013-X.

Pellikka, P., Heikinheimo, V., Hietanen, J., Schäfer, E., Siljander, M., Heiskanen, J., 2018. Impact of land cover change on aboveground carbon stocks in Afromontane landscape in Kenya. Appl. Geogr. 94, 178–189. https://doi.org/10.1016/j.apgeog.2018.03.017.

Ravera, F., Iniesta-Arandia, I., Martín-López, B., Pascual, U., Bose, P., 2016. Gender perspectives in resilience, vulnerability and adaptation to global environmental change. Ambio 45, 235–247. https://doi.org/10.1007/s13280-016-0842-1.

Saj, S., Torquebiau, E., Hainzelin, E., Pages, J., Maraux, F., 2017. The way forward: An agroecological perspective for Climate-Smart Agriculture. Agric. Ecosyst. Environ. 250, 20–24. https://doi.org/10.1016/j.agee.2017.09.003.

Taylor, M., 2018. Climate-smart agriculture: what is it good for? J. Peasant Stud. 45, 89–107. https://doi.org/10.1080/03066150.2017.1312355.

Thornton, P.K., Whitbread, A., Baedeker, T., Cairns, J., Claessens, L., Baethgen, W., Bunn, C., Friedmann, M., Giller, K.E., Herrero, M., Howden, M., Kilcline, K.,

Nangia, V., Ramirez-Villegas, J., Kumar, S., West, P.C., Keating, B., 2018. A framework for priority-setting in climate smart agriculture research. Agric. Syst. 167, 161–175. https://doi.org/10.1016/j.agsy.2018.09.009.

Thurston, A., 1987. Smallholder Agriculture in Colonial Kenya. African Studies Centre.

Tsige, M., Synnevåg, G., Aune, J.B., 2020. Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers. Sci. African 7, e00250. https://doi.org/10.1016/j.sciaf.2019.e00250.

Wachiye, S., Merbold, L., Vesala, T., Rinne, J., Räsänen, M., Leitner, S., Pellikka, P., 2020. Soil greenhouse gas emissions under different land-use types in savanna ecosystems of Kenya. Biogeosciences 17, 2149–2167. https://doi.org/10.5194/bg-17-2149-2020.

Waswa, F., Eggers, H., Kutsch, T., 2002. Beyond land titling for sustainable management of agricultural land: Lessons from Ndome and Ghazi in Taita-Taveta, Kenya. J. Agric. Rural. Dev. Trop. Subtrop. 103, 107–115.

Wekesa, B.M., Ayuya, O.I., Lagat, J.K., 2018. Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. Agric. Food Secur. 7, 1–14. https://doi.org/10.1186/s40066-018-0230-0.

Wiebe, K., Lotze-Campen, H., Sands, R., Tabeau, A., van der Mensbrugghe, D., Biewald, A., Bodirsky, B., Islam, S., Kavallari, A., Mason-D'Croz, D., 2015. Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. Environ. Res. Lett. 10, 85010.

World Bank Group, FAO, IFAD, 2015. Gender in Climate-Smart Agriculture: Module 18 for the Gender in Agriculture Sourcebook. Washington DC.