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Climate vulnerability of agroecological and conventional smallholders in Mvomero district, Tanzania: using mixed-methods to uncover local experiences and motivations of farming for the future

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Changing rainfall patterns make farmers increasingly vulnerable to crop failure, income loss and food insecurity. Agroecology is proposed to reduce climate vulnerabilities of farmers, as such practices and social movement aim to create more resilient farm and food systems. It is however fairly unknown if, and to what extent, agroecological farmers are better able to cope with climate induced exposures as compared to conventional smallholders. We conducted 194 surveys with agroecological and conventional smallholders to explore the three components of climate vulnerability: exposure, sensitivity and adaptive capacity. We combined this with field observations and interviews, and an analysis of long-term rainfall data. We also followed up the initial survey analysis with additional focus group discussions. Just as climate change occurs incrementally over time, we highlight modest, yet important differences between conventional and agroecological farmers. We find that agroecological farmers are less vulnerable to short-term dry spells, due to a combination of farming practices that improve soil water retention, like mulching and the use of cover crops. However, the use of botanicals might induce new vulnerabilities, as their processing requires additional labor, and sometimes expenditures, and may not protect the crops from pests and diseases. We also find limitations to agroecology in terms of scale, as most farmers are unable to use botanicals on all their farmland. Yet, agroecological farmers process and apply botanicals for health benefits both in production and consumption of foods, and they can occasionally sell their organic farm products for a higher price than conventional famers. With this study, we emphasize that farmers' reasons to practice agroecology is not just to boost productivity and become more climate resilient, but rather for improving the long-term health of producers, consumers, soils and the environment.

KEYWORDS

climate vulnerability, agroecology, botanicals, participatory methods, small-scale farming, mixed methods

1 Introduction

Extreme weather events are increasingly attributed to climate change, with losses and damages all over the World (Boyd et al., 2021; IPCC, 2021; Trisos et al., 2022). Agriculture is one of the most vulnerable sectors to climate change, since temperature and the timing and quantity of water are key variables for crop growth and productivity (Altieri et al., 2015; Williams et al., 2018). Even though climatological factors are central for understanding the impacts of climate change, the vulnerability of different people in different places need to be analyzed together with other socioeconomic conditions (Grothmann et al., 2017). Smallholder farmers who mainly depend on rainfall are particularly vulnerable to climate change, and challenges are intensified by factors like poverty, limited production capacity, poor land tenure arrangements, and unstable commodity prices (Williams et al., 2018). Climate vulnerability is a concept that can be used to describe people's sensitivity and adaptive capacity to meet exposures related to agricultural conditions aggravated by climate change, while also considering the socioeconomic context of farmers (IPCC, 2007; Gebre and Rahut, 2021). Farmers' perceptions of drought are also an important indicator for climate vulnerability, as meteorological definitions of drought can overlook how farmers experience droughts and intense rainfall events due to complex and reinforcing biogeophysical and socioeconomic interactions (Gabrielsson et al., 2012).

The agricultural productivity in Africa is severely affected by climate variability, in turn elevating food insecurity of rural households (Mohmmed et al., 2018; Gebre and Rahut, 2021). The latest IPCC AR6 report emphasize (with high confidence) that climate-related extremes have affected the productivity of all agricultural sectors, with negative consequences for food security and livelihoods (Bezner Kerr et al., 2022). Farmers who engage with monocropping might be particularly vulnerable to climate extremes, as a low diversity might lead to complete losses from pests, diseases and droughts (Levia et al., 2020). Vice versa, farmers with more diversified production systems might be better able to tackle climate extremes, since some crops might be able to cope and outlive certain shocks (Altieri et al., 2015). In East Africa, maize productivity has already started to decline due to extreme heat and soil moisture loss (Ramírez Villegas and Thornton, 2015).

Agroecology might have the potential to reduce both biophysical and socioeconomic vulnerabilities to climate hazards on the farm-scale, but its wider promotion and use is constrained in the larger-scale contexts of political, institutional, and market support (Holt-Giménez et al., 2021). However, agroecology is receiving increasing attention, both by agrarian researchers and development institutions (Holt-Giménez et al., 2021). One reason for the lack of political will to promote agroecological intensification lies in the lack of quantitative assessments that compare agroecological farm systems and similar inorganic farm systems. However, there is a growing number of studies that compare organic or agroecological and conventional farm systems in the Global South (Heckelman et al., 2018, 2022; Bezner Kerr et al., 2021; Hilbeck et al., 2023, 2024), and yield gap assessments comparing conventional and agroecological systems is an active area of research (HLPE, 2019). For example, Hilbeck et al. (2023) found no differences in cassava yields between farmers who combine a range of agroecological practices (e.g., compost application, mulching, intercropping, and biological pest control), and those who do not. But, Hilbeck et al. (2024) found that mulching plays a central role for reducing vulnerabilities to droughts. However, yield is not the only factor to describe vulnerability, as vulnerability is comprised of a diverse set of livelihood assets and capabilities (Serrat and Serrat, 2017). There have been relatively few studies that focus on agroecological smallholders' climate vulnerability in the East African region (Williams et al., 2018), and to what extent agroecological smallholders are (less) vulnerable to climate extremes in comparison to conventional smallholders. Most climate vulnerability assessments focus on the regional level, and few assess individual vulnerabilities connected to conventional and agroecological smallholder practices (Williams et al., 2018). Therefore, vulnerability assessments often fail to include local experiences, perspectives and knowledges.

The aim of this study is to understand and compare climate vulnerabilities of smallholders who have been trained in, and practice, agroecology, and those who have not been trained. We focus on their climate vulnerability in relation to changing rainfall patterns during the maize growing season in Mvomero District, Tanzania, where an extensive number of farmers have been trained in, and practice agroecology. Exposure is explored in terms of both rainfall measurements and mappings, as well as local perceptions of changes in rainfall to understand when maize is most vulnerable to precipitation extremes. Sensitivity is explored in terms of changes in yields, and how the two farmer types differ in productivity and yield stability. Farmers' adaptive capacity is understood through different livelihood assets, coping strategies, and capacities to buffer against external shocks (e.g., droughts and flash floods). We develop a case-specific heuristic for climate vulnerability that describes key differences between agroecological and conventional farmers, and discuss these key findings in relation to our empirical data and other studies.

2 Contextual background

In Tanzania, the agricultural sector is at the core of the country's GDP (26.9%) and a major source of food, employment, material, and foreign exchange (NSCA, 2021). Tanzania is currently experiencing a dramatic movement of labor out of agriculture, where households engaged in agricultural activities have fallen from 82 to 66% between 2008 and 2020 (Wineman et al., 2020), but in absolute numbers the rural population is increasing (NBS, 2021). Most smallholder farms are rain-fed, and rainfall is therefore one of the constraining variables for food production. As this variable is external, farmers must find ways to cope with, and adapt to, changes in rainfall in order to stabilize food production. Understanding the dynamics of rainfall is therefore fundamental in order to assess how it induce changes in socio-environmental systems.

2.1 Setting the scene

Established in 2002, Mvomero District is one of seven districts of Morogoro region in Tanzania, located at latitude 06°26′S and 07°40′S and longitude 37°32′E at 300–2300 m above sea level (Mvomero District Council, 2015). The climate varies from semi-tropical and warm-tropical, to cool high-altitude tropical. The rainfall pattern is bimodal, meaning that there are two rainy seasons. The 'short rain' season in October to December defined by intense showers, and the 'long rain' season from March to May defined by long-lasting rains.

The mean annual rainfall ranges across the district, from 500 to 600 mm in the west, to 800–1,000 mm in the east. Rivers and wells are occasional sources of water for agriculture during dry periods, but are not always available (Mkonda, 2014).

Mvomero district consists of 30 wards and 130 villages, with a total population of 312,109 people in the last national census (2012), and an annual population growth rate estimated to 1.86% (Mvomero District Council, 2015). The district has a large rural population, 88.6% of the households in comparison to the 70% national figure, where smallholder farmers represent the majority (98%) (NBS, 2016; Mvomero District Council, 2017). According to the Mvomero District Council (2017), 75% of the district's total area is arable land, of which less than half is utilized for farming. Another figure shows that 73.3% of the arable land in Mvomero district is under cultivation (NBS, 2022). These contradictory figures might point to that the region is experiencing farmland expansion, which is a trend in Tanzania as a whole (NBS, 2021). The district's economy mainly depends on agriculture, and crop production is the main economic activity (Mkonda, 2014). Maize is grown in both highland and lowland areas, and is relatively drought tolerant in comparison to other crops (e.g., rice). Decreases in maize yields particularly threatens food security, since it is the main staple food (Mkonda, 2014). Also sorghum, paddy, banana, horticulture and leguminous products are common food crops, while cash crops are sugarcane, cocoa, sesame, sunflower, paddy, coffee and spices (Mvomero District Council, 2015).

2.2 Agricultural development trends

There are competing ideas about agricultural development by the Tanzanian government and local NGOs. Since the 1990s, the dominant discourse of the government has been to intensify, modernize and commercialize agriculture through initiatives like "Kilimo Kwanza" (Agriculture first), the "Southern Agricultural Growth Corridor of Tanzania" (SAGCOT) and the "Agricultural Sector Development Program" I and II. All these initiatives build on promoting private-public investments in agriculture and infrastructure. The Southern Agricultural Growth Corridor for Tanzania (SAGCOT) initiative has recently launched the "Kilombero cluser," which will cover the entire Morogoro Region, and aim to increase investments in industrial agriculture in the area (The Citizen, 2021). Today agroecological intensification is gaining increased international and institutional recognition as a sustainable development pathway to obtain more resilient and just future food and farm systems (FAO, 2018; Anderson et al., 2019). Agroecology is not only about agricultural practices, but can be framed as a social movement, or as a set of agricultural principles (Wezel et al., 2009). It is generally centered around the synergetic relationships between people and nature, and the agency, knowledge and rights of all food system actors - from producers to consumers (Anderson et al., 2019).

Mvomero district is an area where many farmers have been trained in agroecology by NGO's like Sustainable Agriculture Tanzania (SAT). Since 2011, SAT have trained over 2000 smallholders in Morogoro Region, by mobilizing 70 groups from 50 villages through farmer field schools (kilimo.org). Fellow farmers also learn about agroecological practices through peer-to-peer teaching by farmers previously been trained by SAT, contributing to a growing number of farmers practicing agroecology. The goal of educating farmers in agroecology is to intensify crop production in a sustainable and inclusive way. SAT aims to transform farming practices in Tanzania through knowledge dissemination; build capacity among farmers to participate in the value chain; and to collaborate with the public and private sector to strengthen their capacity in agroecology. They also aim to transform the agricultural sector to be environmentally friendly and economically viable. The organization's approach to agroecology can be seen both as a practice and a movement, as one of the key issues are to reduce and ultimately eliminate chemical inputs such as inorganic fertilizers and synthetic pesticides, and produce food appropriate for local human consumption. Furthermore, they attempt to empower marginalized producers by developing alternative markets, promoting indigenous knowledge, and transforming food systems (Carlile and Garnett, 2021).

Due to government goals for agricultural modernization, the use of inorganic fertilizers (in terms of % of area planted) has reached a national level of 61% in 2020 (NBS, 2021). In Morogoro Region, the use of inorganic fertilizers has remained relatively low, and have fluctuated between 7% (2003), 13% (2008) (NBS, 2010), and 9% (2020) (NBS, 2021). The National Agricultural Input Voucher Scheme (NAVIS) that was introduced in 2009 to promote the use of inorganic fertilizers and improved maize and rice seeds, in order to intensify agricultural production (Wineman et al., 2020). In 2020, Morogoro was the leading region in Tanzania mainland to use herbicides (20.3% of area). The promotion of agro-chemicals by the Tanzanian government can also be seen in the most recent agricultural census (NBS, 2021), where some of the main advices to farmers from governmental extension officials in 2020 were to increase the use of agro-chemicals (62%), and inorganic fertilizers (54%).

In order to eliminate the use of agro-chemicals, SAT is training farmers in how to produce botanicals from locally available plants like chili, ginger, and neem. They also teach farmers to use *chai samadi* (i.e., manure tea) instead of inorganic fertilizers, which is a liquid of fermented manure. These products are meant to replace the use of agro-chemicals that are harmful for farmers' and consumers' health, and the environment, and might also reduce expenditures spent on agro-inputs. Agroecology might therefore have the potential to reduce farmers' vulnerability to climate hazards both biophysically and socioeconomically: Through crop diversification, nutrient recycling, micro-climate control, soil moisture retention and biological pest management (Lin, 2011; HLPE, 2019); and by creating buffers related to fluctuations in input and commodity prices as agroecological practices help to replace industrial chemicals and hybrid seeds with manure, cover crops, biological forms of pest control, and local seed stocks, which reduces costs for purchasing inputs (Wezel and Silva, 2017).

2.3 Climate vulnerability framework

We use the concept of climate vulnerability to explore the differences between agroecological and conventional smallholders, as climate vulnerability constitutes the sensitivity and adaptive capacity of individuals or households in relation to exposures to climate changes and hazards (Figure 1) (IPCC, 2007; Williams et al., 2018). In this context, exposure is represented by both the measured and perceived changes in rainfall patterns and intensity over time. Sensitivity relates to the extent that a system is affected, or stressed, by certain exposures (Gabrielsson et al., 2012), e.g., How are yields affected by changes in rainfall? Adaptive capacity refers to the ability

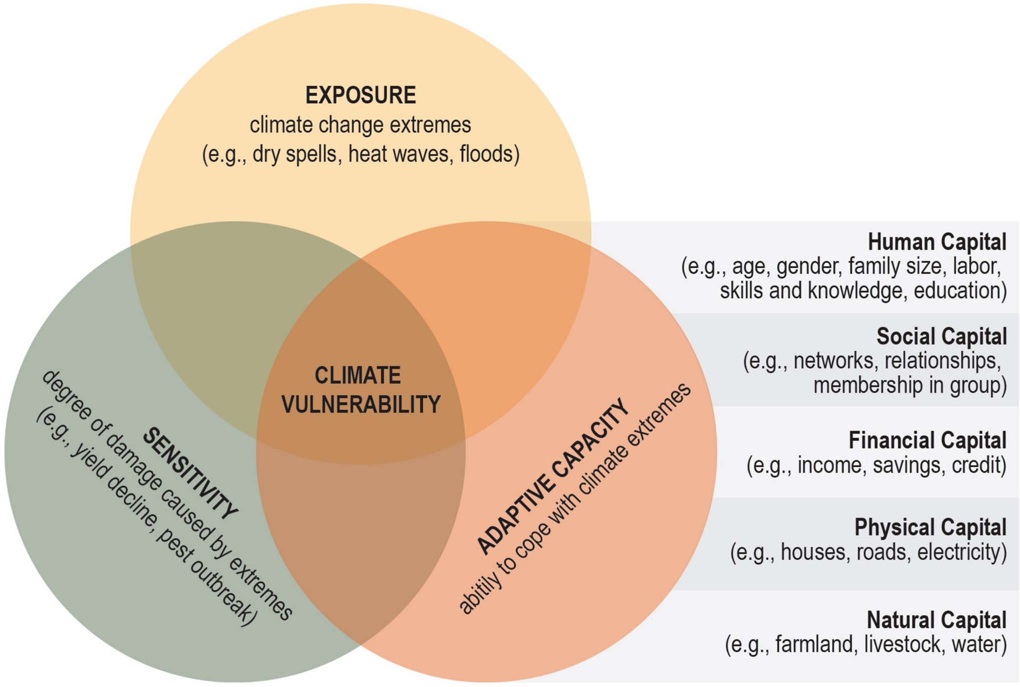

FIGURE 1
The three overlapping constituents of climate vulnerability: exposure, sensitivity, and adaptive capacity. Adaptive capacity in turn consists of five different capitals, namely human, social, financial, physical, and natural. Figure content inspired by Gebre and Rahut (2021).

to successfully respond to exposures, and the ability to moderate potential damages (Gebre and Rahut, 2021), e.g., how do farmers reduce the risks for crop failure? How do farmers cope with reduced yields? The adaptive capacity depends on the farmer's access to different types of 'capital', i.e., human, social, financial, physical, and natural (Gebre and Rahut, 2021). In the context of smallholder farming, adaptive capacity may include capabilities to change crops, to navigate optimal planting dates, to make use of climate information, have access to social networks, and years of farming experience (Mohmmed et al., 2018).

3 Materials and methods

3.1 Surveys and field visits

Initially we defined the two farmer types as those who have been trained in agroecology by SAT, and those who have not been trained in agroecology (i.e., conventional). In total, we conducted 194 surveys with 95 agroecological and 99 conventional smallholder farmers in six villages in Mvomero District, Morogoro Region (Figure 2; survey questions in Supplementary Appendix). Lists of conventional farmers were obtained from village agricultural extension officers, while for agroecological farmers, contacts were obtained from SAT. The field surveys were conducted by 8 enumerators, in September and October, 2022, and field visits were made in all villages to observe how conventional and agroecological farmers grow maize. The survey comprised both quantitative and categorical questions, as well as open-ended qualitative questions. We used SPSS for descriptive statistics, and analyzed the qualitative data through content analysis.

3.2 Focus group discussions

In February and April 2024, we performed four focus group discussions with a subset of smallholders that responded to the survey in 2022. These follow-up discussions aimed to clarify some questions that emerged from the initial survey analysis, as it was not clear how the conventional and agroecological farmers differ in terms of farming practices, and how they respond to years of drought or flood. The focus groups were conducted with farmers in Kipera, Kimambila, Mvomero, and Msongozi, re-engaging with 36 of the survey participants (22 agroecological farmers, and 14 conventional farmers; 21 women, and 15 men). The discussions aimed to improve the understanding of how the farmers themselves define agroecological and conventional farming, and to understand longer-term trends and experiences of change. In this way, the conventional and agroecological smallholder farmers could better describe and define how they differ in terms of agricultural practices, climate vulnerabilities, and motivations to engage with agroecology or not. Statements from the focus group discussions are included in the results as quotes.

3.3 Rainfall data

As long-term and continuous ground measures of precipitation are rare for the region, precipitation data of high temporal (daily) and spatial (0.05°, 4,800 m) resolution were downloaded from the Climate Engine Research App (https://www.climateengine.org/), and analyzed for each field location to

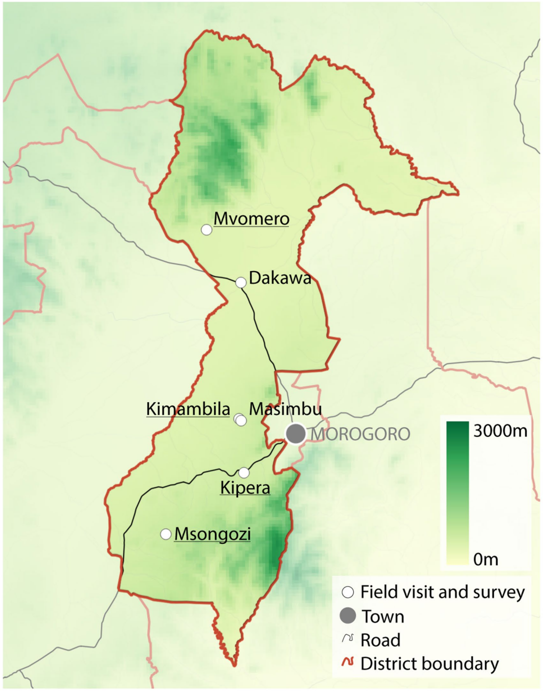

FIGURE 2
Locations for conducting field visits, surveys (white dots), and focus group discussions (text underline). The underlying map shows the topography of the landscape, and the thick red line indicates the boundary of Mvomero district.

understand changes in rainfall between 2021 and 2022. The Climate Engine Research App provide rainfall estimates from rain gauge and satellite observations that have been developed for areas where surface data is sparse, like Sub-Saharan Africa. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 35+ year quasi-global rainfall data set, spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present (Funk et al., 2015; downloaded 2022-08-31). The rainfall data was plotted, mapped, and analyzed in R, which is an open-source program suitable to manage spatial data.

3.4 Statistical analysis

Based on the survey, we generated descriptive statistics of the two farmer types. We used SPSS to perform Chi-Square tests to assess if the agroecological and conventional farmers differ in terms of farm preparation, farming and post-farming practices, yields, maize shortage and coping strategies. For the rainfall data, we used one-and two-sided t-test to compare if the monthly mean rainfall of each village (September 2020–August 2022) is significantly different from the long-term average of those months (1981–2020), along with the directionality of the difference (drier or wetter). Furthermore, we performed a Laverne's test to compare if the monthly rainfall of the years defined as better and worse are significantly different from the long-term monthly means of each village.

4 Results

4.1 What distinguishes and agroecological farmer from a conventional farmer?

The main difference between agroecological and conventional smallholder farmer is the use of botanicals, manure, and manure tea as opposed to chemical pesticides and inorganic fertilizers. According to focus group discussants, the majority of conventional farmers employ slash-and-burn and use agro-chemicals for field preparation, planting, and crop-storage, while agroecological farmers slash but do not burn, but instead use plant residues for soil improvement, and thereafter employ chemical-free options for preparing their fields, planting, and storing their crops. According to the survey, 20% of the conventional farmers do slash-and burn, in comparison to 8% of the agroecological farmers. Agroecological farmers describe that they are only able to practice agroecology on a limited area, and that these specific farm products either are sold directly to SAT or consumed by the household. Most farmers also have conventional farm plots, and through focus group discussions, it became clear that *"agroecological agriculture, using botanicals, is only possible for one acre per household."* Farmers expressed that *"the preparation and application of botanicals is time consuming, and sometimes also expensive if ingredients need to be purchased."* They further highlighted that *"agroecology is mainly for subsistence, and that farmers need at least 5 acres for business."* The survey made it clear that most farmers in our sampled villages have one to four farm plots (94%), covering an average of 5 acres (ranging between 0.25 to 77 acres). The majority of farmers have engaged in farming for more than 15 years (ranging between 1 and 49 years), and agroecological farmers started to practice agroecology between 0.2 to 10 years ago (average 4 years). Before that, they used conventional farming practices. Most agroecological farmers were represented by women (70%), while conventional farmers were represented by 54% women and 46% men. In terms of education, agroecological farmers were slightly more educated than conventional farmers, where 7% agroecological (12% conventional) were illiterate, 78% had primary education, 14% agroecological (10% conventional) had secondary education, and one agroecological farmer had a college degree.

We found significant differences in the use of botanicals, manure, and mulching ($p < 0.05$) between the farmer groups. However, a variety of agroecological practices are employed by 89% of all respondents, and intercropping is a dominant practice for both agroecological (68%) and conventional (59%) farmers. The use of botanicals was the next most used practice (79% of agroecological, 13% conventional), followed by the use of drought tolerant maize varieties (12–13% of all farmers), the use of manure (12% agroecological, 4% conventional), crop rotation (11% agroecological, 4% conventional), and mulching (13% agroecological). Irrigation is not an agroecological practice *per se*, but was employed by 28–29% of all farmers, mainly by accessing rivers or by pumping water from wells.

Agroecological farmers also employed a significantly larger combination of agroecological practices than conventional farmers ($p < 0.001$), practicing a median of two agroecological techniques together, and maximum four. Conventional farmers mainly employed one agroecological practice, and maximum three. Only seven agroecological farmers used four agroecological practices together, all using botanicals, either combined with intercropping and irrigation

(5), manure (4), crop rotation (3), mulching (2) or drought tolerant varieties (2).

4.2 Climate exposure: recent and long-term rainfall patterns

Exposure is the nature and degree to which a socio-environmental system experiences stress from climatological factors (Adger, 2006). Stresses can for example be observed as changes in the magnitude, frequency, duration, and geographic distribution of rainfall.

4.2.1 Precipitation data

The monthly precipitation for the six different villages of this study is shown as bar charts in Figure 3, showing the difference in rainfall over 2 years (September 2020 to September 2022). Participants expressed that 2020–2021 was a better agricultural year than 2021–2022, which is why we define the two agricultural years as "better" and "worse." We tested (independent samples t-test) if the monthly rainfall for each village was significantly different from long-term means (1981–2020), and found that January was significantly ($p < 0.05$) wetter in all villages during the most recent year, which farmers signified as a worse year than usual. Drier months were March, November, and December in all villages, see Figure 3 for significance. March is the second month of the first maize planting cycle (Feb-May), and November, December represents the second and third month of the second planting cycle (Oct-Jan). Hence, sufficient rainfall during these months is important for successful production over the two planting cycles.

The villages included in this study have had both drier and wetter conditions than usual, where Mvomero and Dakawa in the north were wetter than usual in both 2021 and 2022, while Msongozi and Kimambila/Masimbu were drier than usual. However, Kipera was wetter in 2021, and drier in 2022. In order to understand the geographical patterns of wetter and drier years, we look at the Standardized Precipitation Index (SPI) for February–May in relation to long-term means (1981–2022). The SPI is widely used to characterize meteorological drought on a range of timescales, and SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. Figure 4 shows the spatial distribution of the SPI for Mvomero district in 2021 and 2022 over the main maize planting season (February to May).

4.2.2 Experienced exposures due to changes in rainfall

The overall perceptions are that rains are increasingly erratic, and that the onsets of the two rainy seasons are difficult to predict,

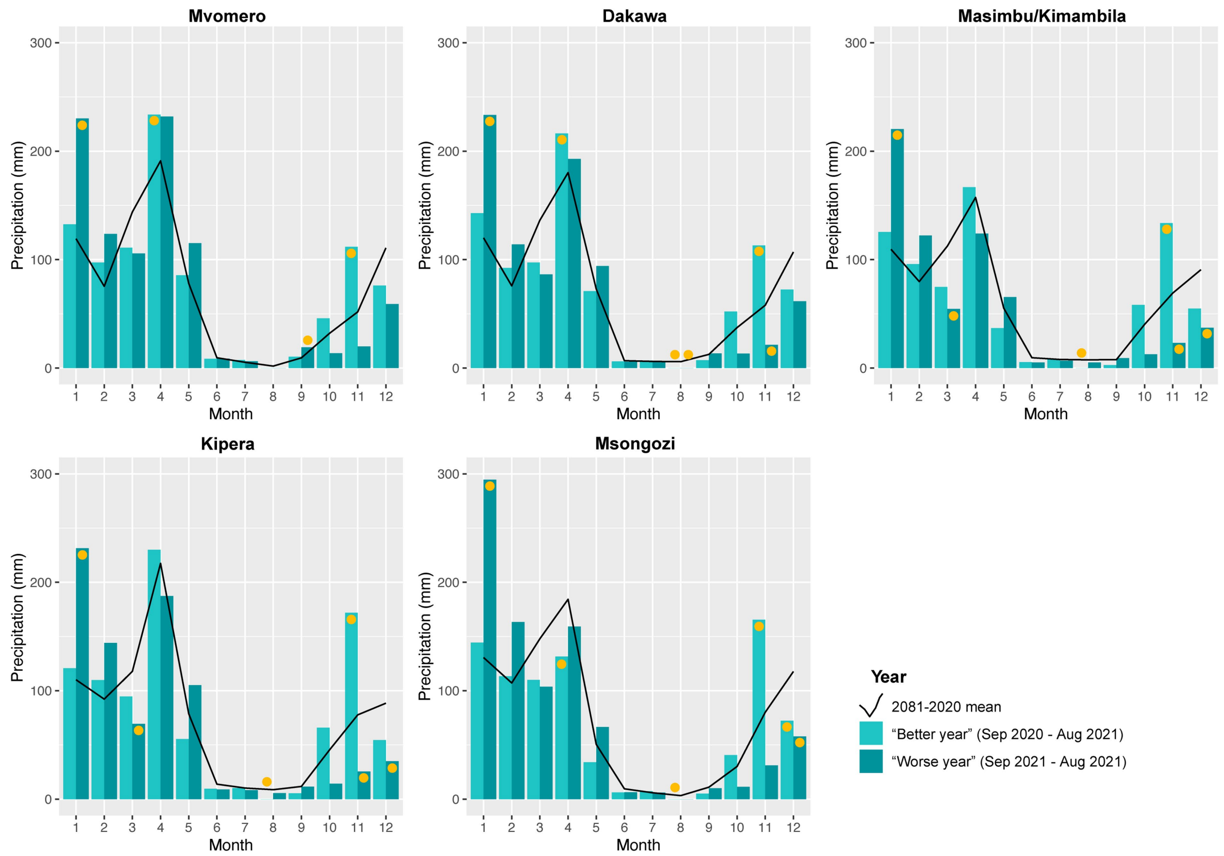

FIGURE 3
Bar charts of monthly precipitation for each field location, covering the last 2 years from September 2020 until August 2022 (the time covered in this study). The black lines show the mean precipitation for each month in relation to long-term means (1981–2020), and yellow circles indicate months that have significantly more or less rainfall in relation to the long-term mean. The main maize growing season is from February until May (months 2, 3, and 4). In Msongozi, the maize growing season is mainly from October until December (months 10, 11, and 12).

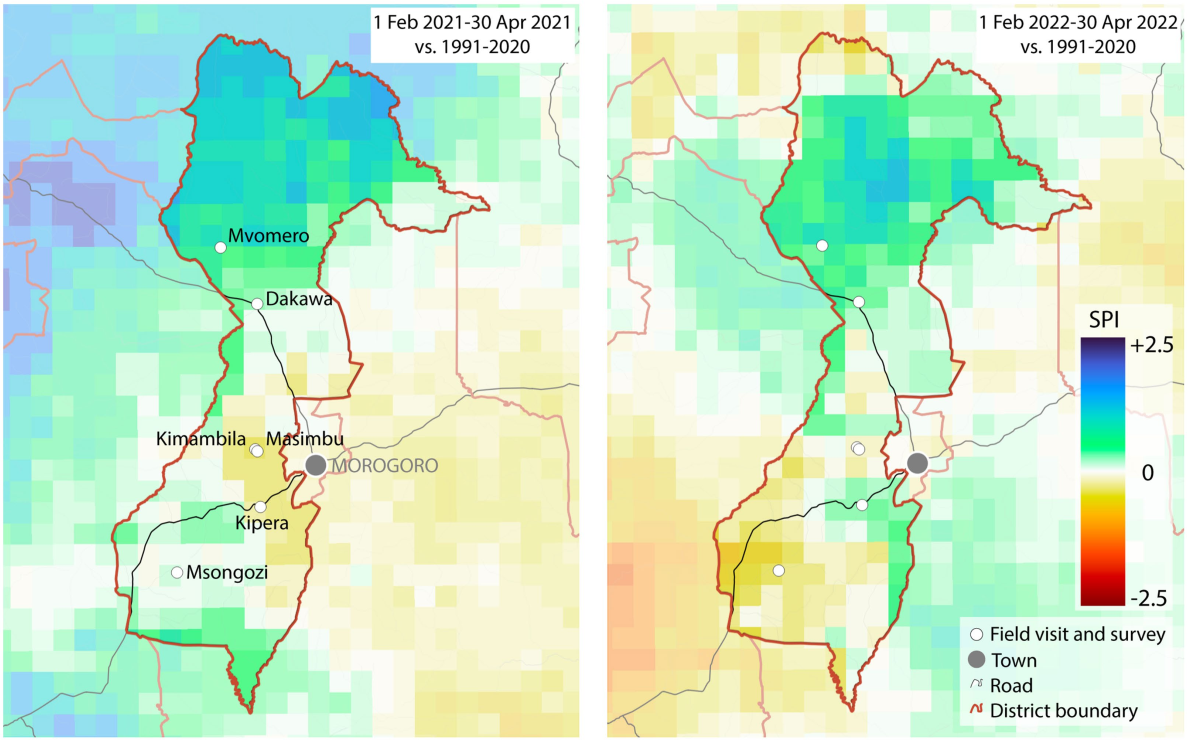

FIGURE 4
SPI for the maize growing season (February–May) in 2021 and 2022. The SPI is a drought index to analyze deviations in precipitation over selected time periods, and how it deviates from long-term means. Yellow to red colors indicate drier conditions than usual, while green to blue colors indicate wetter conditions than usual.

which in turn makes it difficult for the farmer to know when to plant. The majority (96%) of the surveyed farmers identify dry spells as one of the main challenges for farming, and a few (4%) also mentioned intense rainfall and floods (in Mvomero, Dakawa, and Kimambila). Just before our field visit in March 2022, Mvomero experienced a flash flood, which destroyed multiple farm plots and houses.

About half of the farmers experience extensive yield reductions (>75%) due to dry spells. During focus group discussions in Mvomero, farmers described that no farmer can harvest in case of long dry spells (defined by them as more than 1 month without rain), but that agroecological farmers might harvest if there is a shorter two-week dry spell, due to their use of mulching and cover crops which keep the soil moist. In Kimambila, the conventional and agroecological farmers disagreed about who is better off in a dry period, but finally agreed that agroecological farmers are better off during short dry spells due to practices that help soils to preserving water, specifically mulching. In the survey, farmers were not concise in reporting the number of consecutive days without rain that negatively affect maize yields, but most farmers indicated that maize yields are most vulnerable to drought during the pollination stage of the growth cycle (90%). In the focus group discussion in Mvomero, farmers described that *"if rain stops when maize is tasseling, the agroecological famers are more likely harvest than conventional farmers due to mulching and the use of cover crops."* In Kipera, focus group participants explained that farmers in the valley can irrigate the maize during dry spells, and that farms on the hill-slopes cannot irrigate since they do not have access to wells and pumps. They instead highlighted challenges related to pests and diseases, and that neither botanicals or chemicals manage to save their crops from pests.

Negative effects on yields from intense rainfall are not as severe as dry spells, and most farmers experience that <50% of their yields are affected by such extremes. Floods can however cause significant yield reductions, and the majority of farmers experience significant yield loss (>75%) during flooding events. Too much rain affects maize production in terms of yellowing (42%), stunting (38%), crops being washed away (26%), rotting (14%), and also lowered soil fertility through erosion (9%).

4.2.3 Other exposures related to encroachments of animals, and pests

Other main threats to maize production relate to the intrusion of wild animals, specifically elephants, which is experienced by both agroecological and conventional farmers (42%). Even though farmers guard their farms at night, elephants frequently invade fields to eat the crops. This occurs more often during dry years, since wild animals leave national parks to look for grazing land elsewhere, especially maize farms. This challenge forces farmers to harvest before the maize properly dries on the stalks. Another challenge relates to the invasion of cattle into maize fields, which is a common conflict in many parts of Sub-Saharan Africa (Mabebe, 2022). During the focus group in Kimambila, participants expressed that this challenge has been reduced as *"pastoralists have started to grow some crops as well, and now understand the value of crops."* In our data, livestock-related conflicts were relatively few (2% agroecological, 6% conventional). Pests were also mentioned as a main challenge for maize farming, where more agroecological farmers (47%) experience pests as a major threat to maize production in comparison to conventional farmers (38%). In Kipera, the agroecological farmers perceived themselves as more vulnerable to pests because the botanicals are not efficient to outbreaks of pests and diseases (e.g., Tuta Absoluta, *Lepidoptera Gelechiidae*), which are experienced to proliferate during droughts. However, conventional farmers also expressed that they experience that *"not even pesticides can kill new pests that eat mangos, watermelon, and tomatoes."*

4.3 Climate sensitivity: effects on maize yields for agroecological and conventional farmers

Sensitivity is the degree to which a system is modified or affected by an exposure (Adger, 2006). Year 2021 and 2022 are used to represent a "better" and "worse" year, as all farmers had lower yields in 2022 in comparison to the previous season due droughts and unseasonal rainfall.

4.3.1 Comparison of maize yields

There are big differences in maize yields between the six villages but there are no uniform trends between the farmer types. Reported maize yields per village, for agroecological and conventional farmers in 2021 and 2022, are shown as boxplots in Figure 5. The inability to identify big differences between the farmer types might be explained by the clarification obtained through focus groups, that agroecological farmers also have conventional plots (except in Kipera where focus group agroecological participants explained that all plots are for agroecological farming). In Kimambila, a focus group discussant emphasized that *"if all factors are kept constant, the agroecological and conventional farmers do not differ in terms of productivity, but agroecological farmers cannot plant on a big size of land, and conventional farmers can grow bigger."* Overall, conventional farmers had higher yields than agroecological farmers in 2021 (median value of 3 bags/acre versus 2.1), and 2022 (1.5 bags/acre versus 1.2). In Kipera and Dakawa, agroecological farmers had higher yields in 2021 and 2022, but in Msongozi, Mvomero, Kimambila and Masimbu, conventional farmers had higher yields in both years. However, the participants of the focus group discussion in Kipera emphasized that *"the yields of agroecological farmers were lower than for conventional farmers, mainly due to pest outbreaks, and that botanicals are not efficient."* When looking at relative yield reductions between 2021 and 2022, conventional farmers had a larger relative yield reduction (33% decline, range 32–84%) than agroecological farmers (26% decline, range 17–59%) in all villages (except in Masimbu where all farmers experienced a 100% loss). We chose to focus on median values in our comparison, as outliers tend to distort the mean. However, the comparison of relative yield loss between the farmer types is not significantly different ($p = 0.87$).

Even though there were no clear benefits for yields, agroecological farmers who participated in the focus group discussion in Msongozi expressed that *"Although you have asked about the difference in productivity, in general I can say we should not only talk about productivity in terms of how many bags of maize we get but we should also think about other benefits offered by application of agroecology principles. For me, I can say that with application of agroecology, the soil remains healthy for a long time, but we also eat safe and quality food."* A focus group discussants in Mvomero also claimed that *"conventional farmers will use more and more chemical inputs over time, while agroecological farmers will use less or the same amount of organic inputs as the soil quality improves over time,"* emphasizing the long-term benefits of improving soil health by phasing out and eliminating chemicals from their production systems.

4.3.2 Linking agricultural yields to agroecological practices

We did not find any significant impacts on yields from any specific agroecological practice or adaptation measure, nor in relation to any number of combined agroecological methods. Farmers who use small-scale irrigation, 28 agroecological and (28 conventional), had slightly higher yields than those who did not irrigate, 4.2 (3.3) bags/acre in 2021 and 2.5 (2.0) bags/acre in 2022. In Kipera, irrigation was discussed as the most important practice to secure yields in a dry year. No clear benefits on yields were seen for farmers who planted short and drought tolerant maize varieties. Farmers that use manure, 12 agroecological (4 conventional), had slightly higher yields than those who did not use manure, 4.1 (3.5) bags/acre in 2021 and 2.1 (2.1) bags/acre in 2022. However, the 12 agroecological farmers who were mulching had smaller yields than those who did not mulch, 2.0 (3.7) bags/acre in 2021 and 1.0 (2.2) bags/acre in 2022. However, the majority of these farmers (10 out of 12) also used botanicals. This contradicts the focus group discussions, where mulching was highlighted as an important practice to improves soil moisture, and perceived as a practice that can make farmers less vulnerable to droughts.

4.4 Adaptive capacity: contextualizing farmer assets and farming practices in terms of 'capital'

Farmers' adaptive capacity is linked to livelihood assets and capitals that allow for livelihood survival and adaptation (i.e., human, social, financial, physical, and natural), which provides a capacity to buffer against external shocks (Serrat and Serrat, 2017; Mohmmed et al., 2018; Gebre and Rahut, 2021). The assets and associated capitals of the two farmer types included in this study are summarized in Table 1.

4.4.1 Field preparation and animal integration

Farmers mainly rely on their own experience and knowledge to identify the best time to plant, as most farmers (90%) report that they follow tradition, while fewer are informed by meteorological information via media, by neighbors, and only 9% by agricultural extension services. Most farmers plant maize once per year (83%), while some plant maize twice (17%). All farmers plant maize in February (the onset of the long rains), while some also plant maize in October/November at the onset of the short rains (e.g., in Msongozi and Mvomero). Farmers report that it takes about 80 days (±16) from planting to maturation of maize, and that harvesting is done after maize cobs are left to dry on the stalks. In Mvomero, the focus group participants explained that they hire casual labor for farm preparation instead of tractors. More agroecological farmers use manure in the field preparation stage (12%) than conventional farmers (4%). There

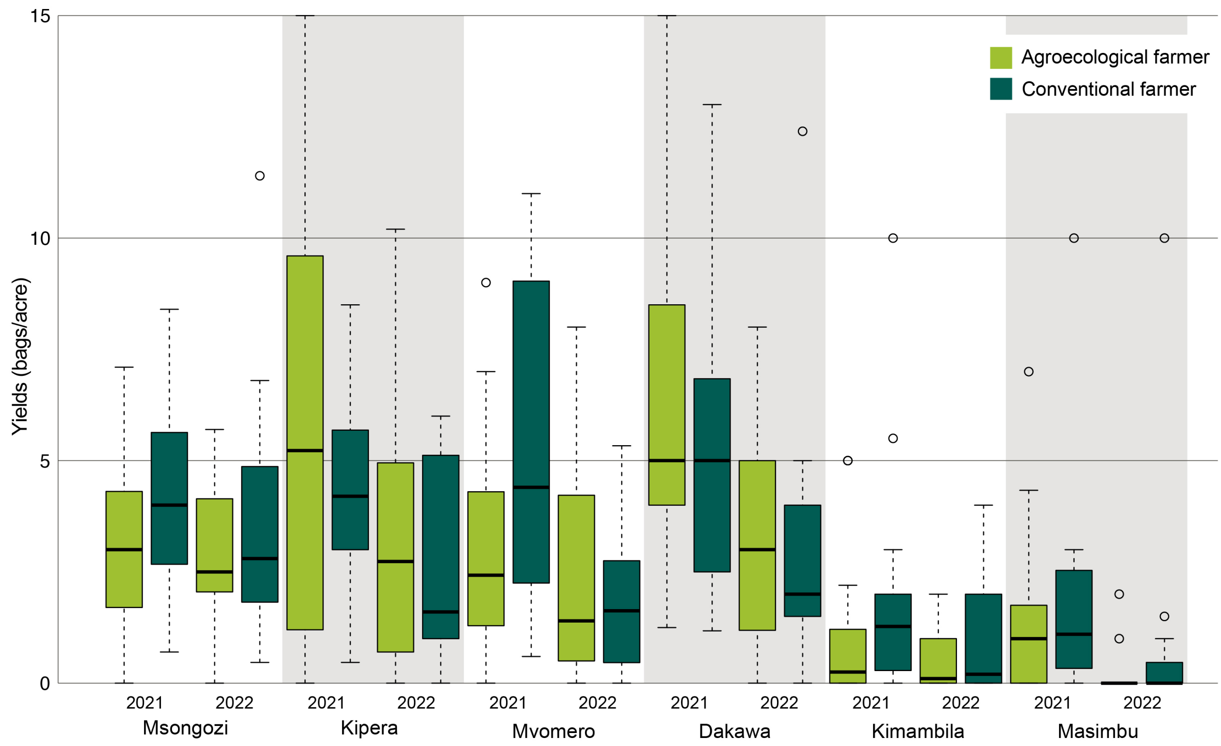

FIGURE 5
Yields (bags per acre) in 2021 and 2022 were calculated for agroecological (light green boxes) and conventional (dark green) farmers for all villages in this study. The graph shows minimum, maximum (the circles) and median (thick black line in boxes) values, the first quartile (25% of all values; colored box) and third quartile (75% of all values; dashed whiskers).

is little herbicide use among all farmers in the field preparation stage (2–3%), but a larger share of the conventional farmers burns the fields (20%) than agroecological farmers (8%). About 78% of the farmers keep animals, predominantly chicken, but also goats, ducks, and pigs, and about half of those farmers integrate the animals on the farm.

4.4.2 Weed-and pest management, and fertilization

The main difference between agroecological and conventional farmers is in their use of chemicals for weed and pest management, and fertilization. Weed control is mainly done with hand hoe (92% agroecological, 79% conventional farmers), two to three times per year depending on the type and amount of weeds on the farm, and a few farmers spray herbicides on their farms to control weeds (7% agroecological, 21% conventional).

There is a significant ($p < 0.001$) difference between agroecological and conventional farmers in terms of pest control. Most agroecological farmers use botanicals (79%) made by, e.g., *aloe vera*, neem tree leaves, pepper, ginger, and wild sunflower to manage pests, and also use ash to control fall army worms. However, this is mainly at selected plots (<1 acre) where farmers can prepare the botanicals locally. In Mvomero village, agroecological farmers highlight that *"botanicals are not as efficient as chemical pesticides, especially during dry periods, and also agroecological farmers might use chemical pesticides, but not on their agroecological plots."* According to the survey, 21% of the agroecological farmers use agro-chemicals. A few conventional farmers also use botanicals (13%), but mainly purchase pesticides from agro-shops (79%) to spray on maize, referred as *sumu* (poison for killing the pests; e.g., Karate and Ninja). Pesticides are generally applied once a week until harvest for vegetables like pepper, cucumber and tomatoes. During focus group discussions, conventional farmers described that they apply pesticides one (in Mvomero) to three (in Kimambila) times during the growth cycle (4 months). Participants further described that botanicals need to be applied as often as every third day (Kiambila), while agroecological farmers in Mvomero describe that they apply botanicals twice over the growth cycle. The participants further described that botanicals need to be applied more often if the plant is already attacked by a pest, mainly since the botanicals do not kill the pest, but rather repel pests from crops by making the leaves taste bitter.

The farmers further emphasized immediate benefits of using botanicals as they *"can eat the product the day after, but for conventional farmers they have to wait for seven days."* A main motivation for agroecological farmers to use botanicals is to get rid of chemicals, and eat more healthy foods. In Kipera, agroecological farmers expressed that *"productivity is not high, but quality is good"* since *"harvests are free from chemicals,"* they further emphasized that they are *"more vulnerable in terms of income, but better in terms of health"* and that *"health overrides everything. If we do not get enough for income, we look elsewhere for income."* In Kipera, even though the agroecological farmers stated that they produce less than conventional farmers, the survey shows that agroecological farmers reported higher maize yields than conventional farmers.

Sometimes inorganic fertilizers (referred to as boosters) are mixed with pesticides and sprayed on crops. The use of inorganic fertilizers is common among conventional farmers, while agroecological farmers

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TABLE 1 Themes explored in the survey, the livelihood assets mentioned by participants, and the adaptive capacity 'capital' they represent.

Theme	Livelihood asset	Capital	Agroecological farmer	Conventional farmer
Farmer and farm description	Household members in farming	Human	2	2
	Gender (women or men representing the farmer types)	Human	70% women, 30% men	54% women, 46% men
	Education	Human	Illiterate: 7% Primary education: 78% Secondary education: 14% College degree: 1%	Illiterate: 12% Primary education: 78% Secondary education: 10%
	Number of farm plots (average)	Natural	2	2
	Total farmland	Natural	5.1 acres (mean) 3.5 acres (median)	5.0 (mean) 3.5 (median)
	Years engaged in farming	Human	15 years (mean) 10 years (median)	17 years (mean) 18 years (median)
	Years engaged in agroecology	Human, social	0.2–10 years, (average 4 years)	0
	Access to irrigation	Natural, physical	29%	28%
Agroecological farming practices	Intercropping	Human	68%	59%
	Cover crops	Human	7%	1%
	Crop rotation	Human	11%	4%
	Mulching	Human	13%	0%
	Combined practices	Human	Median 2, maximum 4	Median 1, maximum 3
Field preparation and animal integration	Information about when to plant	Social, physical	Follow tradition: 90.5% Neighbors: 11% Agricultural extension: 9% Media/meteorological: 16% SAT: 1%	Follow tradition: 86% Neighbors: 15% Agricultural extension: 9% Media/meteorological: 13%
	Having animals	Natural	78%	78%
	Animal – farm integration (manure, feed)	Human, financial	51%	47%
	Hand hoe	Human	17%	11%
	Slash and burn	Human	8%	20%
	Use of drought tolerant seeds	Human, financial	12%	13%
	Use of herbicides	Human, financial	2%	3%

(Continued)

TABLE 1 (Continued)

Theme	Livelihood asset	Capital	Agroecological farmer	Conventional farmer
Fertilization, weed and pest management	Hand hoe for weed control	Human	92%	79%
	Use of botanicals	Human, financial, natural	79%	13%
	Use of herbicides	Human, financial	7%	21%
	Use of pesticides	Human, financial	21% (on conventional plots)	79%
	Use of manure	Human, financial, natural	12%	4%
	Use of manure tea	Human, financial, natural	NA	NA
Seed selection and storage	Save seeds for planting	Social, financial	54%	38%
	Purchase seeds from agro-dealers	Financial	59%	69%
	Seeds from neighbors	Social	10%	30%
	Seed selection (size, middle part, color)	Human, financial	75%	82%
	Seed storage in airtight bags	Physical, financial	60%	30%
	Seed storage in bags without chemicals	Human	12%	11%
	Seed storage in bags with chemicals	Physical, financial	23%	51%
Household consumption and market sales, and livelihoods	Yields	Financial, natural	2021: 2.1 bags/acre 2022: 1.2 bags/acre	2021: 3 bags/acre 2022: 1.5 bags/acre
	Bags of maize sold to market	Financial, physical	2021: 5.2 bags (mean) 2022: 5.6 bags (mean)	2021: 6.4 bags (mean) 2022: 4.1 bags (mean)
	Price per bag of maize	Financial	2021: 82000 TZS (±28,000) 2022: 95000 TZS (±35,000)	2021: 77000 TZS (±25,000) 2022: 87000 TZS (±45,000)
	Household and market sales	Financial, physical	81%	72%
	Household only	Physical	19%	27%
	Market only	Financial, physical	0%	1%
	>50% of household income from maize	Financial	71%	61%
	Alternative income activities	Human, social, financial	86% (mainly petty business)	80% (mainly petty business)

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mainly fertilize soils through the use of cover crops (leguminous crops like green grams and pigeon peas) and manure. The use of cover crops and manure differs widely between the villages. In Mvomero village, agroecological farmers mainly use manure to fertilize soils, and also intercrop maize with cover crops like pumpkins, peppers, okra, beans and cowpeas. In Kipera, agroecological farmers intercrop maize with pumpkins, beans and cowpeas, but the use of manure is not common. Apart from offering ecological functions like fixating nitrogen, the cover crops are sold or consumed in the household, especially pumpkins and pumpkin leaves. In Msongozi, all farmers intercrop maize with cover crops, but few are using manure.

4.4.3 Seed selection and storage

The main reason for using local varieties is to reduce costs, while the main reason to use improved varieties is to obtain high yields and drought resistance. Farmers mainly use open-pollinating maize seed varieties (79%), namely Staha, TMV1 and Stuka, but also local seed varieties (17%). Open-pollinating seeds allow for seed saving, and most farmers recycle the seeds one or two times because further recycling leads to low productivity. More agroecological (54%) than conventional (38%) farmers store their own maize seeds for planting. Seeds are mainly selected by size, using the middle part of the maize cob. A larger share of conventional farmers purchases their seeds from agro-dealers (69%) than agroecological farmers (59%). Neighboring farms are also a source for seeds, mainly for conventional farmers (30%), and less so for agroecological (10%). There are big differences between agroecological and conventional farmers in how they store maize harvests for household consumption or markets, where agroecological farmers mainly use air-tight bags (60%), bags without chemicals (12%), but also bags with chemicals (23%). It is unclear if the agroecological farmers store the products grown without chemicals in bags with chemicals, or if this refers to the produce from their conventional plots, but 16 out of 74 farmers who store their products in bags with chemicals say that they also use botanicals. Most conventional farmers store maize harvest in bags with chemicals (51%), but also in air-tight bags (30%), and in bags without chemicals (11%).

4.4.4 Household consumption and market sales

About 71% of agroecological (61% conventional) farmers get more than half of their income from maize production. Most households produce maize for both market sales and household use (81% agroecological, and 71% conventional farmers), but also solely for subsistence. In 2021, 47% (40%) of agroecological (conventional) farmers sold about 5 (6) bags of maize on the market, but in 2022, only 18% of the households sold 5 (4) bags of maize. In 2022, the price for a bag of agroecologically produced maize was about 95,000 (±35,000) Tanzanian shillings (TZS), while a bag of conventionally produced maize was sold for 87,000 TZS (±45,000). In 2021, a bag of agroecologically produced maize was sold for 82,000 TZS (±28,000), and a bag of conventionally produced maize was sold for 77,000 TZS (±25,000). During focus group discussions, the participants in Kimambila further described that the organic and conventionally grown maize is sold for the same price on the regular market, but that agroecologically produced maize can be sold for a higher price if it is purchased directly by SAT (up to 130,000 TZS per bag). In Mvomero, participants further highlighted that *"it is not enough to rely on SAT for purchasing agroecological products for a higher price."*

Overall, conventional households seem to suffer more from maize shortages than agroecological households. About half of the farmers experience that maize harvests for household use last throughout the year (56% agroecological, 58% conventional), but some households experience food shortage from October, peaking in January until March (Figure 6). We found no significant differences between the two farmer groups, but agroecological farmers seem to experience maize shortage for fewer months than conventional farmers, 18% over 1 month, 16% over 2 months, and 7% over 3 months (as compared to 9% 1 month, 15% 2 months, 14% 3 months). Most farmers purchase food from markets to cope with maize shortage, especially maize flour. Alternative foods like rice, potatoes, cassava and banana are also consumed to cope with maize shortage. Although the main income source for households is agriculture, most farmers also diversify their livelihood activities (86% agroecological farmers, 80% conventional farmers) by engaging in petty business, livestock keeping and charcoal making (Figure 6). Also here, we found no significant difference between the farmer types, as most farmers who diversify their livelihoods have one additional income source (64% agroecological, 61% conventional), and 21% of agroecological farmers have two additional income sources (19% conventional). In some cases, farmers do casual work to earn a wage that enable them buy food for their families. During focus group discussions, the participants in Mvomero emphasized that *"if farmers engage in agroecology, they do not have time for other activities than to produce and apply botanicals, which is a main reason for why farmers are reluctant to use botanicals."* In Kimambila, two focus group participants used to practice agroecology in the past, but decided to stop due to the labor required to produce and use botanicals. One of the participants expressed that she stopped because she cannot make enough botanicals as she is *"too old and do not have the energy, and sometimes money is not available to purchase ingredients."* A younger farmer described that he *"stopped because the botanicals failed to kill the pests."*

4.4.5 Use of coping strategies

A slightly larger share of agroecological farmers use some type of coping strategy to reduce maize plants' vulnerability to unreliable rainfall. Although the responses differ between the villages, the main coping strategies among farmers are small-scale irrigation (29%), and planting maize varieties that are short (8%) and drought tolerant (5%). The main difference between the farmer groups is that agroecological farmers do mulching (13%), and conventional farmers do not. A few farmers also use cover crops (6% agroecological, 1% conventional) or plant their crops earlier than they normally would (3% agroecological, 4% conventional) to cope with changes in rainfall. Most agroecological farmers have learnt about coping strategies from NGOs (26%), while most conventional farmers have been informed by fellow farmers (25%), others mainly follow tradition (12%), and only a few have learnt about coping strategies from agricultural extension officers (5%).

There is little difference between agroecological and conventional farmers in terms of what crops they grow, but some difference in how they grow crops. Overall, 43% of all farm plots were planted with intercropped maize, 15% with maize only, 26% with paddy, and 15% with other crops. Both farmer types do some type of intercropping of maize (68% agroecological, 59% conventional) with different types of leguminous plants (e.g., beans, cowpeas, green gram, pigeon peas), but also with sunflower, sesame, groundnuts, pumpkin, cassava, and different vegetables

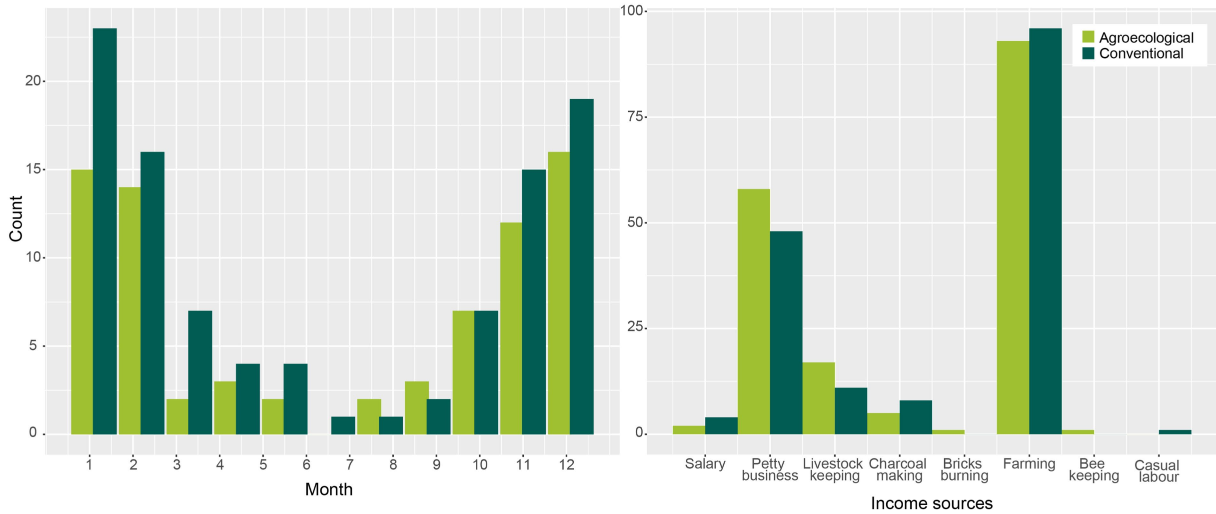

FIGURE 6
The bar chart to the left shows the months where farmers experience a shortage of maize, and the bar chart to the right shows other income generating activities that household members engage with to diversify livelihoods.

and fruit trees. However, a larger share of conventional farmers plant maize only (44%) in comparison to agroecological farmers (33%). The ability to practice intercropping (also referred to as mixed farming) and crop rotation is influenced by farm size rather than agricultural training, which was clarified by an agroecological farmer in Msongozi who described that *"we practice crop rotation, but this is challenged by the size of land or the number of plots owned. If you have one or two small plots, crop rotation is not possible because every year I need to plant maize in order to get food. It is not possible to alternate crops. For me I have only one small plot, therefore instead of crop rotation I practice mixed farming."* However, although all farmers have similar farm size, 11% of agroecological farmers practice crop rotation, as opposed to 4% of the conventional farmers.

Small-scale irrigation is described as a crucial coping strategy during the dry season in some villages, e.g., in the valleys of Kipera, Msongozi, and Mvomero both conventional and agroecological farmers sometimes irrigate their plots with water from rivers and manmade wells. During field visits in Mvomero village, we saw that farmers also minimize water demand for maize by creating long pits for soil moisture conservation. Those farmers who do not use irrigation highlight a lack of money as the main reason, since water pumps are expensive and many farmers cannot afford them. However, in Kimambila and Masimbu, farmers do not have any water source near their farms, which is why they cannot access and divert water for irrigation. Some farmers mentioned that the lack of education and knowledge about how to cope with rainfall-related challenges is the main reason for not changing farming practices, simply because they do not know how to deal with droughts. A variety of answers were provided to the question about what can be done to help farmers cope with rainfall-related challenges related to maize production. Overall, farmers express the need for training on how to cope with drought, along with education on environmental-and forest conservation. Agroecological farmers emphasized that more farmers should intercrop cover crops with maize to maintain soil moisture.

5 Concluding discussion

5.1 Focus on environmental and human health as opposed to yields

Both the survey and focus group discussion results did not reveal any significant difference in maize yields between conventional and agroecology farmers. However, the study reveals multiple benefits and constraints of practicing agroecology, and that some of the underlying motivations for farmers to engage with agroecology go beyond productivity and yields. Firstly, in our case area, the agroecological and conventional famers mainly differ in their use of agro-chemicals or organic substitutes like botanicals and manure tea. Other than that, the two farmer types use a similar range of traditional farming practices that are commonly part of agroecology. Secondly, focus group discussions helped clarify that farmers only practice agroecology on a limited size of land, mainly emphasizing the time and labor intensity of producing and applying botanicals, as compared to purchasing and applying pesticides. Agroecology is currently experienced as difficult to practice at scale, and economic benefits are not obvious. Another main constraint is that there is currently no price difference for organically grown crops as compared to conventionally grown crops, unless the products are sold directly to SAT. Thirdly, agroecology is sometimes costly, if ingredients for producing botanicals are not locally available and need to be purchased. It is also unclear if the botanicals efficiently protect the crops from insects and diseases, or if experienced inefficiencies are related to the incorrect use and application of botanicals. So, time, labor, lack of price differentiation, expenses, and lack of knowledge about when and how to use botanicals seem to be major constraints for practicing agroecology with the use of botanicals. The lack of knowledge among farmers regarding the timing of pest control application, as well as lack of knowledge regarding the targeted pest species was also emphasized by Hilbeck et al. (2024). We echo this hypothesis, as several quotes in this paper exemplifies this knowledge-gap. Despite these constraints, agroecological farmers emphasized reasons for engaging with agroecology that go beyond productivity. The main argument is that agroecological farming is chemical free, and better for the environment as well as for producers' and consumers' health. Agroecological farmers also emphasized long-term thinking and planning, as they expressed that soil improvements will lead to less labor and expenditures in the future, whereas for conventional farmers the soil quality will decline over time, and costs will increase.

5.2 Climate vulnerability of agroecological and conventional farmers

Based on the qualitative and quantitative data from nearly 200 participants, we claim that agroecological farmers might be less vulnerable to erratic rainfall, due to a combination of farming practices that lead to improved soil quality, water holding capacity, and yield stability (i.e., the variability of yields across years), enable long-term planning, and contribute to the production and supply of healthy chemical-free food, and a healthier environment. We also highlight the role of agroecological networks as an important social capital that can further reduce climate vulnerabilities. It is less clear to what extent agroecology manage to reduce expenditures and improve incomes for households.

We found that all farmers experience the same type of climate exposure in terms of increasingly erratic rainfall, and difficulties to predict and plan the planting of crops. Risks for yield reductions and crop failure are both associated with too much and too little rain throughout the growth cycle, which can explain why all participants referred to 2021 as a 'better' agricultural year than 2022, even though they had different experiences of wetter and drier farming seasons than long-term averages. Since all farmers experience the same type of exposure, we were interested to compare if and how agroecological and conventional farmers differ in terms of climate sensitivity and adaptive capacity. In order to understand aspects of sensitivity, we compared differences and changes in maize yields during the 'better' and 'worse' year. In terms of adaptive capacity, we explored differences in farming practices and market opportunities that are assumed to reduce climate vulnerabilities for agroecological farmers. We discuss these adaptive capacities in terms of changes in financial capital, but also in terms of the other types of capitals (i.e., natural, human, physical, social). In order to present our heuristic for climate vulnerability, we start off with a critique to conventional climate vulnerability indices.

Most climate vulnerability assessment focus on developing a quantitative representation of climate vulnerability as a weighted index (Rasul and Thapa, 2004; Grothmann et al., 2017; Mohmmed et al., 2018; Epule et al., 2021). For our case, we chose to *not* create such quantitative index since important social and ecological factors are notoriously difficult, or even impossible to quantify (Pretty, 1995). It is methodologically difficult to accurately attribute causes of change in complex social-ecological systems, as causes and effects might lie in details of soil mechanisms in one place, and demographic change in the other. Also, consequences of climate change are often not spectacular in the forms of, e.g., famines, droughts or other disasters, but occur incrementally over time (Borras et al., 2021). This is particularly true and relevant in the context of our study area, as differences between farmer types, farming practices, and places are subtle and not generating a coherent and 'crystal clear' and unidirectional narrative. For our case, we found that a weighted quantitative vulnerability index would simplify complexities in a rather meaningless way, as it is impossible to determine if all factors are included, and how to weigh them according to their local and individual importance. Instead, we use mixed methods and participatory approaches based on a combination of semi-structured questionnaires, field visits, focus group discussions, and precipitation data. Inspired by Gabrielsson et al. (2012), this empirically grounded and theoretically informed understanding of climate vulnerability, enabled us to highlight differences and similarities between the agroecological and conventional farmers, mainly based on descriptive statistics, but also from qualitative descriptions of some of the key constituents of climate vulnerability (i.e., perceptions of exposure, sensitivity and adaptive capacity). Based on the responses and stories that emerged through our empirical data collection, we have developed our own site-specific heuristic to understand the subtle but important differences in climate vulnerability between agroecological and conventional farmers in Mvomero District.

5.3 Contradictions and synergies related to climate vulnerability

Our first finding relates to reduced climate vulnerability of agroecological farmers due to improved yield stability, which is an improvement in a natural capital (i.e., productivity of land). Conventional smallholders generally have higher yields than agroecological farmers, due to high chemical inputs, but in terms of yield reductions in a 'bad year', agroecological farmers experienced a lower relative yield loss than conventional farmers. Although we could not trace yield stability to any specific agroecological practice, other researchers highlight the positive impacts on yield stability due to intercropping (Stomph et al., 2020), specifically maize-legume intercropping under varying rainfall (Chimonyo et al., 2019). Focus group discussions made it clear that agroecological farmers also are more resilient to shorter periods of drought, which is perceived to be linked to the use of soil moisture preserving farming methods like mulching and the use of cover crops. The benefits on yields of composting and mulching during droughts was also emphasized by Hilbeck et al. (2024) through long-term field measurements in the region. We also find support from other studies that conclude that agroecological farmers have comparable yields and a higher yield stability, particularly under extreme weather conditions (D'Annolfo et al., 2017; Sanderson Bellamy and Ioris, 2017; HLPE, 2019). Yield stability also implies that agroecological farmers are in a better position to predict expected yields, and thereby plan their agricultural year more strategically. Yield stability might be an indicator for improved soil health, as healthy soils have a better capacity to buffer against climatological variations (Qiao et al., 2022). The ability to buffer climate variations is increasingly important, as future rainfall is expected to become increasingly erratic. Rasul and Thapa (2004) highlight the long-term sustainability of agroecological farms related to soil health in their comparison between conventional and agroecological farmers. Based on local perceptions and experiences, we also have reason to believe that agroecological practices improve soil health, but due to the limits of our research design, we could not attribute any significant impacts on yields to the number of soil-improving agroecological practices used.

It is unclear if agroecology leads to reduced expenses and improved incomes, which in turn might lead to improved financial capital.

According to the survey, a slightly larger share of agroecological households produce maize for both the household and the market (than solely for the household), and also obtain a larger share of their household income from maize. Even though agroecological farmers sell fewer bags in total to the market than conventional farmers, agroecologically produced maize is sold for a higher price than conventionally produced maize (6.5% higher price in 2021, and 9.2% higher in 2022). It must however be noted that maize is currently only purchased for a higher price by SAT, and that there is no price difference between conventional and agroecological maize on the general market. In focus group discussions, participants emphasized that it is not enough to only rely on SAT. Hence, improved income from agroecology might only be the case for those farmers who sell directly to SAT. It was also clearly expressed that it is not always possible to produce enough maize for the market by practicing agroecology, since farmers can only apply agroecological practices to a small share of their land (maximum 1 acre). Even though reduced reliance on purchased inputs is likely to reduce expenditures, focus group participants also raised concerns about increased expenditures related to purchasing raw materials for making botanicals that are not always locally available, and claimed that ingredients can become more costly than inorganic inputs. However, the farmers further highlighted that expenditures are likely to decrease over time, as soil quality improves, as opposed to farmers who rely on chemicals and will experience higher input costs as quantities of input needs are likely to grow. This should also be highlighted in the context of an overall lower chemical-use for farm preparation, planting and crop storage. Agroecological systems are not dependent on chemical inputs, which make them more ecologically and socially sustainable than conventional farms in terms of pollution and health impacts (HLPE, 2019). We emphasize the need to better understand expenses of agro-chemicals and botanicals, as it is often assumed that botanicals are free of charge since their ingredients can be produced in the household and derived from local plants. We are also aware from previous studies that chemical-free and air-tight bags for storage are very expensive for farmers to obtain (redacted reference).

Agroecological households seem to suffer less from food shortages than conventional households, which implies that they are more food secure. Of all households, about 43% experienced food shortages some time over the year, but according to the survey agroecological households seem to experience food shortages over fewer months (average 1.9 months) in comparison to conventional households (2.4 months). Food security is often described as an outcome of a combination of changed livelihood assets and capitals (Lovendal et al., 2004). Based on our empirical data and other literature, we believe that the improved food security is strongly linked to on-farm crop diversity (Nyantakyi-Frimpong et al., 2017; Bezner Kerr et al., 2021), which was also observed for our case through multiple field visits. In a review article of almost 12,000 articles, Bezner Kerr et al. (2021) highlight that the majority of studies (78%) found positive outcomes on food security in the use of agroecological practices (e.g., crops diversification, intercropping, agroforestry, crop-livestock integration, and soil management measures). She further found that more complex agroecological systems (i.e., including multiple agroecological components) were more likely to have positive outcomes on food security.

Finally, we emphasize the role of agroecological networks as an important social capital to further reduce the climate vulnerability for agroecological farmers, in combination with slightly more diversified livelihood activities. However, we found contradictions between the survey and the focus groups responses in relation to livelihood diversification, where several farmers emphasized that the labor intensity of processing and using botanicals leaves little time for the agroecological farmers to engage with other livelihood activities. We find that NGOs have played an important role in teaching agroecological farmers about drought-related coping strategies. The formation of networks of agricultural innovators have been reported to reduce climate vulnerability as networks connect farmers and farmer organizations with local, national or international private companies, public organizations, non-government organizations and research institutions, thus increasing their chances of getting climate related information (van Zonneveld et al., 2020). Dapilah et al. (2020) found that the process of diversification through participation in various group activities and engagement in formal and informal social networks have reduced farmers' climate vulnerability in Ghana, mainly by increased access to resources (material and non-material). Also, in line with our findings, Abid et al. (2017) found that social networks can increase accessibility of marketing, credit and extension services which are important for increasing farmers' adaptation capacities. Agroecological farmers in Mvomero district are organized as a network through which they can communicate, learn and share knowledge and experiences with each other (redacted reference). An agroecological farmer in Msongozi emphasized the importance of agroecological networks by saying that *"farmers practicing agroecology are better off because they work in groups and see each other as brothers and sisters. Through these groups we share experiences of different agroecology practices – therefore, we are constantly learning and we help each other during the dry season.,"* the farmer continued by explaining *"conventional farmers may also form groups, but in my view bonds in agroecological groups are stronger than those in conventional farmers' groups, because those who practice agroecology are motivated by other factors than income – conserving the environment, and delivering safe and quality food. Therefore, we see each other as brothers and sisters who aim at serving the current and future generation."*

5.4 Limitations and areas for further research

In this study, we conclude that agroecological farmers might be less vulnerable to climate change than conventional farmers, mainly due to a combination of incremental but important differences in yield stability, expenses and incomes, food security, and social networks. Although few statistical tests were significant (due to the subtle differences), our conclusions are based on a combination of descriptive statistics and qualitative descriptions from field experience. The survey has some pitfalls, as we did not ask the farmers to specify incomes and expenditures to properly account for changes and differences in the financial balance of households, but rather draw our conclusion about differences in costs and incomes based on a previous study in the area (redacted reference). Indeed, the labor and time demand of agroecology are major challenges for farmers to be able, and willing, to engage in agroecology (Timmermann and Félix, 2015; Johansson et al., 2023), and we recommend that further research explores these challenges and tradeoffs in greater depth in order to come up with innovative solutions.

In our study, more women than men represented agroecological farmers. The higher representation of women engaged in agroecology might be related to the willingness of women to engage in agroecological training, or that the NGO purposively target and include women. It might also be a matter of availability, that women were more available than men when we conducted the survey. Based on our findings related to yield stability, reduced expenses, improved incomes, and signs on improved food security, a high engagement of women in agroecology might be a suitable way to reach sustainable development goals of gender equality and women's empowerment. The engagement of women in agroecology is a research gap that could be better understood in future studies, as well as gendered climate vulnerabilities in the context of agroecology (Holt-Giménez et al., 2021).

Another limitation of this study relates to the inability to understand daily changes in rainfall. A previous study by Mkonda (2014) found that decreased rainfall has led to reduced crop yields in Mvomero district, but found no significant (slightly decreasing) trends in total rain volumes. It is important to understand measured changes in precipitation in relation to local experiences of change as it can highlight research and knowledge gaps, and provide new insights about socioeconomic aspects of climate vulnerability. In terms of exposure to changes in rainfall, it is crucial to understand when farmers are vulnerable to rainfall extremes, as well as what types of rainfall extremes. The survey failed to evaluate the number of days without rain that negatively affect yields, and we emphasize the need to further explore how farmers are affected by increasingly erratic rainfall patterns at different plant growth stages. This issue was better understood in the follow-up focus group discussions, where participants clarified that agroecological farmers might have a better chance to harvest during short dry-spells (<2 weeks) at the start of the growth cycle. Also, Mkonda (2014) emphasized the need to understand the implications of dry spells through focusing on monthly and daily rainfall trends for February to April, which constitute the growing season. This is currently difficult, since there is a lack of long-term and consistent rainfall measurements from gauging stations in rural Tanzania. Also in this study, we could not account for a high temporal resolution of rainfall data even though we obtained daily data from satellite imagery estimates (since they are estimates).

5.5 Policy implications

We show that both conventional and agroecological farmers experience the same challenges related to erratic and unreliable rainfall, and difficulties to plan the planting of their crops. We found some incremental differences in the climate vulnerability of the farmer types, mainly in relation to yield stability, expenditures, incomes, and months of food shortage. Since the future is very likely to experience increasingly erratic rainfall (IPCC, 2021), all farmers need to strengthen their adaptive capacity. We believe that agroecological practices and networks have the potential to improve the adaptive capacity of farmers, since yields tend to be more stable in less favorable years, and the long-term sustainability of soils is improved through agroecological practices rather than diminished through excessive use of agro-chemicals. Farmers expressed the need for training and education in how to cope with droughts, along with strengthened adaptive capacity through investments in irrigation technology. Mvomero district currently aims to attract agricultural investors to further intensify and modernize agriculture, which might impact the future availability and quality of farmland, and also spur conflicts related to land dispossessions (Johansson and Isgren, 2017; Engström et al., 2022). We find it crucial that policies for a more sustainable agricultural intensification are developed (e.g., agroecological intensification), to also bring opportunities for the current and growing rural population. Also Snyder et al. (2019) caution against the shift of emphasis to large-scale farming as a strategy for national agricultural development, and suggest increased investment in supporting smallholder faming as a way to address poverty and rural well-being.

Data availability statement

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

Author contributions

EJ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. RM: Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing. KM: Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1423861/full#supplementary-material

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