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Climate change awareness and adaptation strategies by smallholder farmers in semi-arid areas of Zimbabwe

Sandra Makaita Madamombe [a,b], Stanley Karanja Ng'ang'a [c], Ingrid Öborn [a,d], George Nyamadzawo [e], Ngonidzashe Chirinda [f], Job Kihara [g] and Libère Nkurunziza [a]

[a]Department of Crop Production Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden; [b]Alliance of Bioversity International and International Centre for Tropical Agriculture, Harare, Zimbabwe; [c]Alliance of Bioversity International and International Centre for Tropical Agriculture, National Agricultural Research Laboratories - Kawanda, Kampala, Uganda; [d]World Agroforestry (ICRAF), Gigiri, Nairobi, Kenya; [e]Faculty of Agriculture and Environmental Science, Bindura University of Science Education, Bindura, Zimbabwe; [f]Mohammed VI Polytechnic University (UM6P), AgroBioSciences (AgBS), Agricultural Innovations and Technology Transfer Centre (AITTC), Benguerir, Morocco; [g]Alliance of Bioversity International and International Centre for Tropical Agriculture, Nairobi, Kenya

ABSTRACT

Agricultural production, food, nutrition and income security of smallholder farmers in sub-Saharan Africa are threatened by extreme weather events, such as increased frequency of mid-season dry spells and increased temperatures. Their impacts are exacerbated by the prevalence of sandy soils, characterized by limited water and nutrient retention capacity leading to low crop productivity. In this study, we aimed at assessing farmers' awareness of extreme weather events, identify adaptation strategies and evaluate maize yield from different soil fertility and water management practices. A household survey including 245 smallholder farmers in Marange, Zimbabwe was carried out. The results revealed that farmers were aware of and had experienced extreme weather events. Among adaptation strategies used were soil water-harvesting, use of improved varieties, mulching and planting trees. Maize yield remains significantly low, averaging 0.62 t ha^{-1} among farmers using some forms of soil fertility and water management strategies. To further understand the reason for low maize yields and improve climate change related adaptation strategies, more research is needed to quantify and confirm management practices applied by farmers, such as fertilizer use and rates, water and nutrient management, use of improved varieties as well as socio-economic factors.

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Extreme weather; maize; soil and water management

1. Introduction

Agricultural production and the related food, income and nutrition security of smallholder farmers in developing countries are under threat from extreme weather events caused by climate change (Belay et al., 2017). Altered patterns of rainfall, increased frequency of mid-season dry spells, and increased temperatures are some of the extreme weather events that are evident in sub-Saharan Africa (Arslan et al., 2014; Brazier, 2015; Serdeczny et al., 2017), including Zimbabwe (Chanza & Gundu-Jakarasi, 2020; Makate et al., 2017; Belloumi, 2014). Nearly 68% of the Zimbabwean population lives in rural areas, and agriculture is their primary source of livelihood (Lachaud et al., 2018; ZIMSTAT, 2017). However, since most of the crop production on smallholder farms is rain-fed (Bhatasara, 2017; Nciizah et al., 2022; Nyagumbo et al., 2019), recurrent droughts cause low maize crop productivity, which has generally resulted in yields averaging less than a tonne per hectare over

CONTACT Sandra Makaita Madamombe sandra.makaita.madamombe@slu.se Swedish University of Agricultural Sciences, Department of Crop production Ecology, P.O Box 7043, SE-750 07 Uppsala, Sweden

the past 10 years (Mujeyi et al., 2021; Ngema et al., 2018).

In Zimbabwe's semi-arid areas, drought impacts are exacerbated by the prevalence of sandy soil, which constitutes 70% of arable land (Nyamapfene, 1991). These sandy soils are characterized by limited water and nutrient retention capacity and high water permeability, leading to low crop productivity (Bruand et al., 2005; Leogrande & Vitti, 2019). Farmers attempt different adaptation strategies to overcome extreme weather events and challenges related to sandy soils. These strategies include soil management practices that improve water and nutrient holding capacity and use efficiencies. For instance, previous research conducted in rural Zimbabwe has shown that combining soil water harvesting, manure and inorganic fertilizers increases crop yields (Biazin et al., 2012; Gram et al., 2020; Kubiku et al., 2022; Nyagumbo et al., 2019). A combination of manure and the deployment of rainwater harvesting technologies improves moisture and nutrient retention within the root zone, thus improving biomass production (Kubiku et al., 2022; Kugedera et al., 2020). A study on sandy and clay soils in Harare showed that cattle manure improved water retention and nutrient availability, resulting in a maize grain yield increase of 3.7 times (Shumba et al., 2020) compared to unfertilized treatments. Since sandy soils have a low water holding capacity, supplementary irrigation may improve soil moisture management and support crop growth and yields. However, due to prohibitively high initial investment costs, irrigation is uncommon in smallholder farming areas of Zimbabwe, especially for cereals. Usually, irrigation is done on high-value horticultural crops, which are typically located close to water sources to reduce irrigation labour costs.

Despite evidence from research on the problem of limited crop productivity of sandy soils in semi-arid regions, costly potential solutions and bleak socio-economic realities cause farmers to continue with business-as-usual (BAU) practices. In this context, BAU practices refer to the use of farming methods that are not well suited for the unique characteristics of the soil and the climate of the region. The BAU practices may include reliance on non-resilient crops, smallholder farmers may continue to grow crops that are not well adapted to specific temperature and rainfall patterns without exploring more climate resilient crop varieties (Cacho et al., 2020; Newsham et al., 2023). Inadequate implementation of water management technologies such as rain water harvesting and irrigation improvements (Magombeyi et al., 2018). Inappropriate planting techniques such as monocropping poor soil fertility management such as insufficient use of organic matter, cover crops and poor mineral fertilizer management are other BAU methods (Mupambwa et al., 2022). The prevalence of BAU agricultural practices seems to suggest a lack of adoption of management options that could increase farmer adaptation to recurrent drought conditions. Several possible reasons for the lack of adoption of best-bet options include farmers having limited knowledge of best-bet options, inadequate technical skills and a shortage of financial resources to support the adoption of best-bet options (Makate et al., 2017; Mehmood et al., 2022). Sustainable solutions for climate change and variability adaptation require an assessment of the levels of awareness on the occurrence and impacts of climate change amongst rural smallholder farmer households and an in-depth understanding of the reasons for their choices and the impacts of those choices on crop production.

This study aimed to assess climate change awareness; in this study, awareness refers to farmer consciousness of extreme weather events. Furthermore, our objective was to compile a catalogue of methods employed by smallholder farmers for coping with harsh weather conditions in the semi-arid Marange area, Mutare district of Zimbabwe, primarily distinguished by its sandy terrain and frequent periods of drought. The specific objectives were to (i) assess farmer awareness of extreme weather events caused by climate change, (ii) identify adaptation strategies implemented and which factors underlying them, and (iii) evaluate maize yield outcomes from different soil fertility and water management practices.

2. Materials and methods

2.1. Study area

The study was conducted in the Marange region of the Mutare district and Manicaland province of Zimbabwe (18°59′ – 19°25′ S; 32°1′ – 32°37′ E) (Figure 1). The choice of the Marange area was guided by the extensive area of sandy soils, which can accrue enormous potential benefits from adopting soil and water management practices to improve crop production under recurrent seasonal droughts (Kubiku et al., 2022). The area is located in Agro-ecological Region IV, characterized by an annual rainfall of

<650 mm (unimodal rainfall pattern from October to March) and a mean maximum air temperature of 28°C (Manatsa et al., 2020). Mid-season dry spells are common during the crop-growing period. The vegetation in the area is typically a semi-arid Savanna comprising deciduous trees and shrubs interspaced with overgrazed grass. The landscape is relatively flat, with scattered rocky outcrops. The area is suitable for drought-tolerant crops such as cowpeas (*Vigna unguiculata L.*), maize varieties requiring 105–120 days to maturity, extensive cattle ranching, rearing small livestock such as goats, and wildlife (Manatsa et al., 2020). Farmers in the area grow crops such as maize (*Zea Mays L.*), sorghum (*Sorghum bicolor L.*), pearl millet (*Pennisetum glaucum (L.) R. Br.*), finger millet/rapoko (*Eleusine coracana L.*) and groundnuts (*Arachis hypogea* L.) (Chiturike et al., 2022).

2.2. Data collection

Seven wards within the Marange area were selected to capture the variability in the awareness of climate change and adaptation strategies. The seven wards included Mutanda, Nyagundi, Mafararikwa, Nyachityu, Takarwa, Mudzimundiringe and Munyoro. Data was collected using a structured household questionnaire survey conducted in September 2019. The sample for the population-based household survey was selected using a non-probability-based snowballing sampling approach (Naderifar et al., 2017) to provide a statistically representative sample of the project implementation wards in Marange, Mutare district, selected through the help of extension officers (Figure. 1). Snowballing sampling technique was applied because farmers were not easily accessible (i.e. they were unattainable using probability sampling methods), and the data collection team had to rely on strong networking among farmers to identify those who were available and willing to take the interview. Therefore, interviewing farmers by the enumerators was a gradual process, with one farmer leading the interviewer to the next, continually until saturation of at least 35 farmers was interviewed from each of the selected wards. Two hundred forty-five smallholder farmers within the seven wards of the study zone were each subjected to in-person interviews and their responses were recorded on printed questionnaires by trained local enumerators. Key farming indicators grouped in modules were collected at the household level. Among the modules, the survey questionnaire had socio-economic data, land management and agricultural inputs, crop information, livestock, poultry and their products, labour source, gender-related aspects, access to capital, credit, extension services and external resources, climate and soil, food security and wealth status (Appendix 1). To understand climate awareness and adaptation strategies, relevant variables were selected. The most relevant indicators to answer the objectives of this study were farmer awareness of extreme weather events, types of events, adaptation strategies, barriers to adaptation, and maize production per hectare.

2.3. Data management

In order to evaluate the effect of adaptation strategies on maize yield (a common crop among the 245 farms), data from different modules were combined and only farmers with maize crops were considered. The combination of data from the different modules yielded farmer categories based on a single or combination of soil or water management strategies. Farmers with NA or missing values were removed from the study. At the household level, maize yield (in tonnes per hectare) was calculated using the information obtained from crop information in the farmland and farm sizes module. Soil fertility management options comprising mineral fertilizer and organic fertilizer categories were derived from sections of mineral fertilizer application and manure use in the land management and agricultural inputs module. For example, the fertilizer category was derived from questions asking if the farmer uses any mineral fertilizer, followed by a follow-up question to specify the crop on which the fertilizer is applied. The same was done for the manure category. If a farmer responded to both fertilizer and manure use sections, they were categorized as using manure + fertilizer. If a farmer had a maize crop and stated that they neither use mineral fertilizer nor manure, they were assigned to the no fertilizer category. The retained soil fertility categories were (i) manure only, (ii) fertilizer only, (iii) manure + fertilizer, and (iv) no fertilizer (Table 1). The manure quality in the study area was characterized as low in total nitrogen (N) (0.72 ± 0.22%), phosphorus (P) (0.23 ± 0.07%) and potassium (K) (0.55 ± 0.19%).

Farmers were also grouped according to the water management strategy applied over the past five years. This information was obtained from irrigation and other water management practices in the land management and agricultural inputs module. Soil moisture

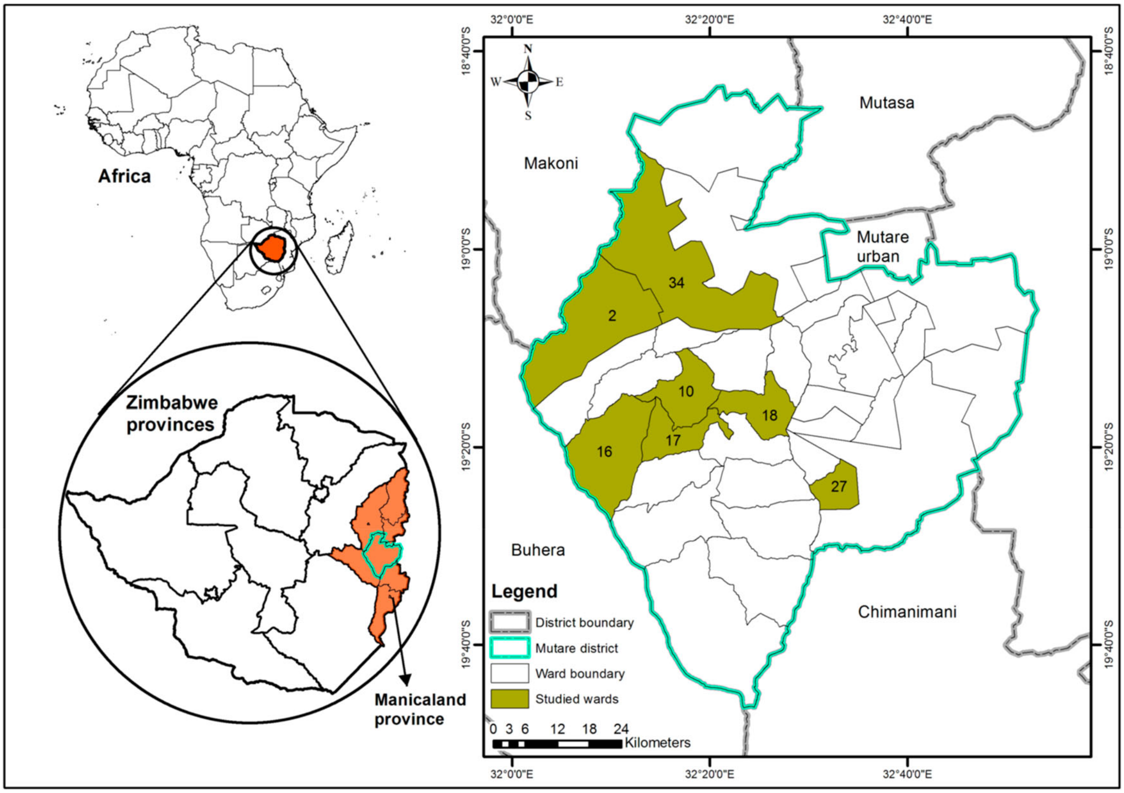

Figure 1. Maps showing the location of Manicaland province in Zimbabwe (left) and the study area (wards) in Marange, Mutare district (right). The 7 wards are 2 (Mutanda), 34 (Nyagundi), 16 (Mafararikwa), 10 (Nyachityu), 17 (Takarwa), 18 (Mudzimundiringe) and 27 (Munyoro), indicated on the map (right).

management strategies such as mulching, pot-holing, basins, ridges, and autumn ploughing were set as in-field water management options. Standard contours, tied contours, infiltration pits, and terracing were set as out-field water management strategies. This approach was taken because multiple responses were obtained for soil moisture management on most of the farmers. Thus, the categories for soil moisture management were as follows: (i) Irrigation, (ii) In-field, (iii) Out-field, (iv) Irrigation + In-field, (v) Irrigation + Out-field, (vi) Irrigation + In-field + Out-field, and (vii) No soil water management (Table 1).

Yield depends on the interactions between genotype, management and environment (G × M × E) (Mahmood et al., 2022). To further understand the effect of soil moisture and fertility management, maize variety was considered an additional factor influencing yield. Only two categories of maize variety emerged from the data: improved and non-improved varieties. The information on variety was extracted from the improved seeds section in the land management and agricultural inputs module.

The module on climate change awareness highlighting the farmers' experience with extreme weather events, adaptation strategies and reasons for no adaptation was used to obtain general farmer perspectives and responses to climate change and variability.

2.4. Statistical analyses

The data was analysed using the IBM SPSS statistical package and R v 4.2.1(R Core Team, 2022). Data analysis involved descriptive statistics of percentages of farmers who experienced extreme weather events. Cross tabulations were done for adaptation options and reasons for no adaptation linked to the weather event experienced. Linear models using the linear model function were used to analyse variances in the management categories explored by farmers to improve maize yield.

Maize yields were either expressed as a function of water management, soil fertility management

Table 1. Soil fertility and water management categories and respective percentages of Farmers per category, $n = 151$.

Management category	category meaning	percentage of farmers
Soil fertility	**A factor with four levels**	
Manure only	Cattle manure, compost, poultry manure used on maize crop	10
Fertilizer only	Mineral fertilizer (ammonium nitrate, compound D)	32
Manure + fertilizer	Use any manure type and mineral fertilizers to enhance crop growth	38
No fertilizer	Neither organic nor inorganic fertilizers was applied to the maize crop	20
Soil moisture management	**A factor with seven levels**	
Irrigation	Pouring water by hand using a bucket	33
In-field	Mulching, pot holing, basins, ridges, autumn ploughing	7
Out-field	Standard contours, tied contours, infiltration pits, terracing	5
Irrigation + In-field	Irrigation + one or multiple in-field soil moisture management	36
Irrigation + Out-field	Irrigation + one or multiple out-field soil moisture management options	6
Irrigation + In-field + Out-field	Categories as defined above combined	1
No soil water management	Not using any of the soil water management options stated above	11
Variety	**A factor with two levels**	
Improved variety	Certified maize hybrid seed variety	63
Non improved variety	Seed returned from previous seasons	37

practices or crop variety (Eq. i) (Welham et al., 2015).

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk} \qquad (i)$$

Where:

y_{ijk} is the average kth reported maize yield by farmers in the ith level or category of either soil fertility management or water management,

μ is an intercept, α_i is the effect of the ith level or category of either soil fertility management or water management, β_j is the effect of the jth level or category of maize variety,

$(\alpha\beta)_{ij}$ is the effect of the interaction between the ith level of either soil fertility or water management and the jth level of maize variety on maize yield and $e_{ijk}\sim(N, 0\sigma_e^2)$. Maize yield was assigned as the response variable, soil fertility management with four levels, water management with seven levels and crop variety with two levels as factors (Table 1) for the analysis of variance.

Where there were no significant interactions, the Kruskal–Wallis test was used to test if there were differences within groups. A significant Kruskal Wallis test was followed by a post-hoc pairwise multiple comparison to separate the different groups using Wilxocon Mann–Whitney test.

To understand the factors that influence farmers to adopt adaptation strategies, a generalized linear regression model (glm) with a logit link was used (Eq. ii) (James et al., 2022)

$$\text{logit } E(Y) = \eta$$

$$\eta = \beta_O + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_{14} d_{14} \qquad (ii)$$

Where:

E(Y) is the expected value of the adaptation strategy, and logit E(Y) = ln(E(Y))/(1 – E(Y)). Furthermore, β_0 is an intercept, and β_1 through β_{14} are the regression coefficients for the predictor variables X_1 through $X_{14}$and dummy variables d_1 through to $d_{14.}$

This study's response variables (Y), which were all binary, were crop diversification (where farmers had more than one crop per farm), improved seeds, irrigation, soil water management, crop-livestock integration, early planting, and planting trees (Table 2). Explanatory variables included in the model were socio-economic characteristics, age and household size as continuous variables, education as a factor with five education levels dummy variables of gender and access to land (Table 2). The other explanatory variables were derived from the farmer's reasons for not using adaptation strategies such as dummy variables shortage of labour, no loans, no information on climate change and adaptation (Table 2). Other dummy explanatory variables were derived from different modules on access to extension services, association with farmer groups, and knowledge of adoption projects in the area (Table 2).

Table 2. Definition of variables used in the GLM model.

Variable name	Variable defination	Source
Response variables		
Crop diversification	Binary variable, 1 = where farmers had more than one crop per farm, 0 = where farmer reported only one crop	Crop production module
Improved seeds	Binary variable, 1 = yes the farmer uses improved seeds, 0 = otherwise	Improved seeds Module and climate change awareness module
Irrigation	Binary variable, 1 = yes the farmer uses irrigation, 0 = otherwise	Irrigation use module and climate change Awareness module
Soil water management	Binary variable, 1 = yes the farmer uses soil water management, 0 = otherwise	
Crop-livestock integration	Bbinary variable, 1 = yes the farmer use crop-livestock integration as a response to extreme weather event, 0 = otherwise	Climate change Awareness module
Early planting	Binary variable, 1 = yes the farmer practices early planting, 0 = otherwise	Climate change awareness module
Planting trees	Binary variable, 1 = yes the farmer has planted some trees, 0 = otherwise	Integrated farming modue and climate Change awareness module
Explanatory variables		
Age	Continous variable, Age of household head	Respondent information module
Household size	Continous variable, number of people staying in the house	Household population module
Gender	Binary variable, 1 = male, 0 = female (household head gender)	Respondent information module on gender
Education	Factor, education level experessed as 1 = no school, 2 = primary, 3 = secondary, 4 = post – secondary, 5 = adult education literacy school or parish	Respondent information module on education level
Access to land	Binary variable, 1 = access to land, 0 = no access to land	Climate change Awareness module
Shortage of labour	Binary variable, 1 = yes there is a shortage of labour, 0 is otherwise	climate change Awareness module
No loans	binary variable, 1 = yes the farmer has no access to loans or credit, 0 is otherwise	Climate change Awareness module
No information on climate change and adaptation	Binary variable, 1 = yes the farmer has not come across any information on climate change and adaptation strategies, 0 is otherwise.	climate change Awareness module
Access to extension services	Binary variable, 1 = farmer has access to extension services, 0 otherwise,	Extension access module
Association with farmer groups	Binary variable, 1 = farmer is a member of a farmer group, 0 = farmer is not a member of any farmer group	Social capital module
Knowledge of adoption projects in the area	Binary variable, 1 yes the farmer knows of any project or program targeting farmers in the area that promotes the adoption of specific technology, 0 is otherwise	External support Information module

3. Results

3.1. Farmer characteristics

About 73% of the respondents out of the 245 farmers interviewed were household heads, while 37% comprised either the spouse, child or other family members (Table 3). The composition of the households head by gender was 73% and 26% for men and women, respectively. The mean age for men and women household heads in the study area was 50 and 56 years, respectively (Table 3). About 53% and 36% of the farmers had attained secondary and primary education, respectively. Only 8% of the farmers had no formal education (Table 3). All the farmers in the study owned agricultural land on which they grew crops and kept some livestock. Out of the 245 farmers studied, 90%, 7% and 2% reported having owned, rented and had access to common land, respectively (Table 3). Owned farms had sizes ranging between 2.8 ha to 3.8 ha per farm (Table 3).

The most common type of labour to facilitate farm activities is household labour (86%), followed by social arrangement with community members and extended family (10%), while hired labour is used the least (4%).

About 69% of the farmers in the study area grow maize as the main cereal crop. The proportion of farmers growing pearl millet**,** soghum, and rapoko were 42%, 26% and 9%, respectively. About 35% of farmers grew groundnuts**,** 20% grew roundnuts **(***Vigna subterranea***)** and 8% grew cowpea. Other crops grown in the area include cotton (*Gossypium hirsutum*), tobacco (*Nicotiana tabacum*), sesame (*Sesamum indicum*), and sunflower (*Heliantus annuus***)** grown by 11%, 10%, 5% and 3% of farmers respectively (Table 3).

Table 3. Farmer household characteristics in Marange, Mutare district, Zimbabwe ($n = 245$).

Household characteristic	Percentage of famers per category	
Interviewed respondents		
Household head	73	
Spouse, child or other family member	37	
Gender of households head		*Mean age of household heads*
Female	26	56
Male	73	50
Education of household heads		
Secondary education	53	
Primary education	36	
No formal education	8	
Household ownership of land		*Farm size (ha)*
ownership of land	90	2.8–3.8
rented land for own use	2	1–1.8
rented out land for others	1	0.4–2
common land	7	2.2–2.4
Farm labour source		
family	86	
arrangement	10	
Hired	4	
Crop types		
Maize	69	
Cotton	11	
Sorghum	26	
Rapoko	9	
Groundnut	35	
Tobacco	10	
Cowpeas	8	
Groundnut	20	
Pearl millet	42	
Sesame	5	
Sunflower	3	
Food insecurity, months		
January	55	
February	25	
March	14	
April to July	2	
August	10	
September	30	
October	42	
November	48	
December	50	

Out of the 245 farmers included in the study, 50%–55% reported having suffered from food insecurity from December to January. About 25% and 14% of the farmers experienced food insecurity in February and March, respectively. Only 2% of the farmers experienced food insecurity from April to July. In August, September, October and November, 10%, 30%, 42% and 48% of farmers experienced food insecurity, respectively (Table 3).

Farmers in the study area receive aid in the form of food, cash and agricultural inputs such as fertilizer and seeds. Food aid alone was received by 46% of farmers, whereas 44% of farmers did not receive any form of aid during the last 12 months. Only 10% of the farmers received agriculture inputs, cash or packaged aid (containing food and agriculture inputs). The government is the primary source of aid (91%) among other sources such as NGOs and Gifts (from family, friends and neighbours).

3.2. Farmers' awareness and adaptation strategies to extreme weather events

All 245 interviewed households confirmed that they had experienced extreme weather events in the past five years. Drought was the most experienced extreme weather event reported by 46% of farmers. The other extreme weather events reported were higher than average temperatures, strong winds, and floods, which were correspondingly reported by 26%, 12% and 10% of the farmers. Lower than average winter temperatures were also reported by 5% of the farmers. A few farmers (<5%) had also experienced erratic rainfall patterns, short crop growing seasons and cyclones (0.3%).

Out of the eight types of reported extreme weather events, farmers have adaptation strategies for five, including drought, floods, strong winds, and increased and reduced temperatures (Appendix 2). Ten adaptation strategies were reported against drought, whereas three to five were reported for other types of extreme weather events. Common adaptation strategies against drought are water harvesting, changing planting dates, soil moisture management, alternative crops and use of improved seeds (Appendix 2).

Farmers highlighted several reasons why they fail to adapt to extreme weather events. The most important reason is the lack of resources (i.e. agricultural inputs and financial credit facilities) and information on climate and adaptation practices (Figure 2). Some farmers reported facing labour availability challenges (Figure 2) to implement best-bet adaptation practices as some technological options, such as the construction of water harvesting structures, are very labour-intensive.

Results from the generalized linear model indicate that a farmer's association with farmer groups positively impacts planting trees, early planting and irrigation strategies for adapting to extreme weather events (Table 4). Farmer access to extension services positively impacts adopting soil water management

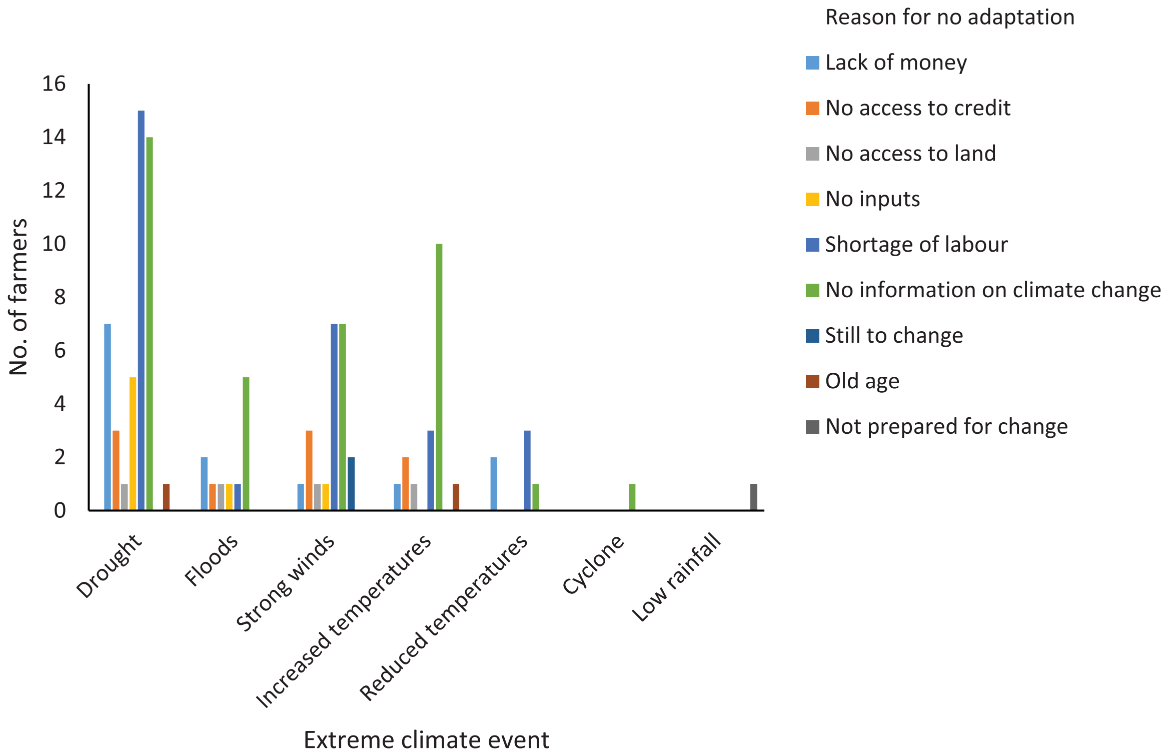

Figure 2. Farmer reasons for not using adaption practices to deal with each of the extreme weather events experienced in Marange, Mutare district.

strategies whereas it negatively impacts adopting planting of trees and use of irrigation. Farmer knowledge of other projects or programmes promoting the adoption of specific technologies negatively impacts the adoption of irrigation. A farmer´s education level of either primary or secondary education positively impacts the adoption of irrigation. Household size positively impacts farmer adoption of irrigation and crop-livestock integration (Table 4). Gender, age and secondary education level positively impact adopting crop diversification, whereas adult education level negatively impacts crop diversification (Table 4).

3.3. Effect of soil fertility, maize variety and water management strategies on maize yield

Results from the analysis of variances had no significant interactions effect of management practices soil fertility, maize variety and water management strategies on maize yield reported by farmers.

3.3.1. Soil fertility management effect

The grouping of farmers according to soil fertility management showed that 10%, 32%, and 38% of the farmers apply manure, fertilizers, and a combination of manure and fertilizers, respectively. The other 20% do not apply any fertilizers (Table 1).

Farmers who reported applying fertilizer only obtained an average maize yields (0.614 t ha^{-1}), whereas those who applied manure only reported harvesting an average of 0.621 t ha^{-1} (Figure 3). The farmers stating that they used organic and inorganic fertilizers had an average maize yield of 0.327 t ha^{-1}. In contrast, the farmers who reported that they neither applied inorganic fertilizer nor organic fertilizer got 0.197 t ha^{-1} (Figure 3). The Kruskal–Wallis *p*-value for the soil fertility categories suggested a significant difference in the reported maize yields ($p = 0.03044$), and pairwise comparisons using the Wilcoxon Mann–Whitney test did find some significant differences in the soil fertility management categories (Figure 3). The reported maize yield for farmers who stated that they neither applied organic nor inorganic fertilizer significantly differed from the maize yield of farmers who applied manure only, fertilizer only and a combination of both manure and fertilizer (Figure 3).

Table 4. Estimated socio-economic factor coefficients explaining the farmers´capacity to adopt adaptation strategies in Marange.

Variables	Crop diversification	Improved seeds	Irrigation	Soil water management	Crop livestock integration	Early planting	Planting trees
Gender	0.827 (0.409)**	0.148 (0.348)	−0.060 (0.409)	0.024 (0.423)	0.553 (0.577)	0.614 (0.462)	0.249 (0.414)
Age	0.034 (0.014)**	0.012 (0.011)	0.018 (0.013)	−0.007 (0.014)	0.013 (0.018)	−0.009 (0.014)	0.009 (0.414)
Education2	0.710 (0.699)	−0.161 (0.603)	1.143 (0.667)*	0.391 (0.768)	−16.36 (1495)	−0.148 (0.890)	0.095 (0.721)
Education3	1.373 (0.775)*	0.309 (0.659)	1.532 (0.754)**	0.153 (0.819)	−15.80 (1495)	0.532 (0.924)	0.371 (0.782)
Education4	−2.478 (1.418)*	−0.082 (1.381)	0.547 (1.443)	−17.21 (3552)	−19.08 (1495)	−17.22 (5503)	−15.25 (1340)
Education5	14.12 (882)	13.98 (882)	13.70 (882)	−16.54 (6523)	−1.967 (6691)	34.4 (11490)	−15.97 (2400)
Shortage of labour	0.528 (0.755)	0.775 (0.618)	0.141 (0.615)	−1.529 (1.07)	1.118 (1.299)	−34.17 (2818)	0.634 (0.619)
Knowledge of adoption projects in the area	−0.581 (0.393)	0.223 (0.315)	−0.670 (0.361)*	0.425 (0.365)	−0.507 (0.599)	0.108 (0.373)	0.540 (0.381)
No loans	−0.438 (0.708)	−0.605 (0.628)	−0.055 (0.765)	0.399 (0.699)	−1.423 (1.050)	−19.15 (2904)	−0.746 (0.742)
Access to extension services	−0.083 (0.553)	0.650 (0.443)	−1.163 (0.606)*	1.383 (0.785)*	0.833 (0.625)	−0.530 (0.542)	−0.845 (0.503)*
Access to land	0.963 (1.387)	1.614 (1.344)	−0.151 (1.316)	17.07 (3638)	2.081 (1.660)	−18.33 (2029)	15.57 (1375)
Association with farmer groups	−0.074 (0.418)	0.155 (0.337)	0.856 (0.415)**	−0.317 (0.398)	1.231 (0.835)	0.811 (0.396)**	1.082 (0.379)**
No information on climate change and adaptation	0.095 (0.713)	0.199 (0.539)	0.337 (0.728)	−17.1 (1456)	−1.092 (0.838)	−1.804 (1.108)	0.870 (0.564)
Household size	0.034 (0.049)	0.003 (0.034)	0.142 (0.056)**	0.034 (0.036)	0.170 (0.100)*	−0.038 (0.044)	0.038 (0.037)
Constant	−2.747 (1.932)	−2.957 (1.718)*	−0.849 (1.829)	−19.63 (3638)	13.683 (1495)	17.630 (2029)	−17.510 (1375)

Standard errors within brackets, * significance at $p < 0.1$, **significance at $p < 0.05$

3.3.2. Maize variety

Most smallholder farmers in Marange use improved maize varieties; 63% use certified maize hybrid seed, whereas 37% use seed returned from the previous season (Table 1).

Where farmers reported the use of improved seed variety maize yields were significantly higher ($p =$ 1.268e-05) than those farmers who stated that they use non-improved seeds (Figure 4).

3.3.3. Soil water management

Smallholder farmers in Marange use different soil water management strategies on field crops, such as irrigation and in-field and out-field water management technologies. The grouping of farmers according to soil water management showed that about 6% use in-field, 34% use irrigation (low technology), 37% use a combination of irrigation and in-field, 2% use a combination of irrigation, in-field and out-field, 6% use a combination of irrigation and out-field, 5% use out-field water management only whereas 10% of the farmers do not use soil water management strategies (Table 1).

The maize yields reported for farmers who applied soil water management strategies had no significant differences compared to yield reported for farmers who did not use any water management strategy ($p = 0.05$) (Figure 5).

4. Discussion

4.1. General discussion on farmer characteristics

For male-headed households, the average age of the family head was 50 (median age 47), suggesting that testing and implementing new technology might not be challenging. Similarly, in female-headed households, the family head had an average age of 56 (median age 55). Female-headed households constitute 26% of the study population. Young farmers can also provide labour much easier as they are agile, and the age of the household head is an essential factor in making decisions associated with adopting new technologies (Uhunamure et al., 2019). Most farmers have acquired basic education since 53% have secondary education, which suggests that they can understand simplified agricultural operations and make sound observations of their experiences in farming. Generally, 90% of farmers in the study area own land, which is essential for the livelihoods

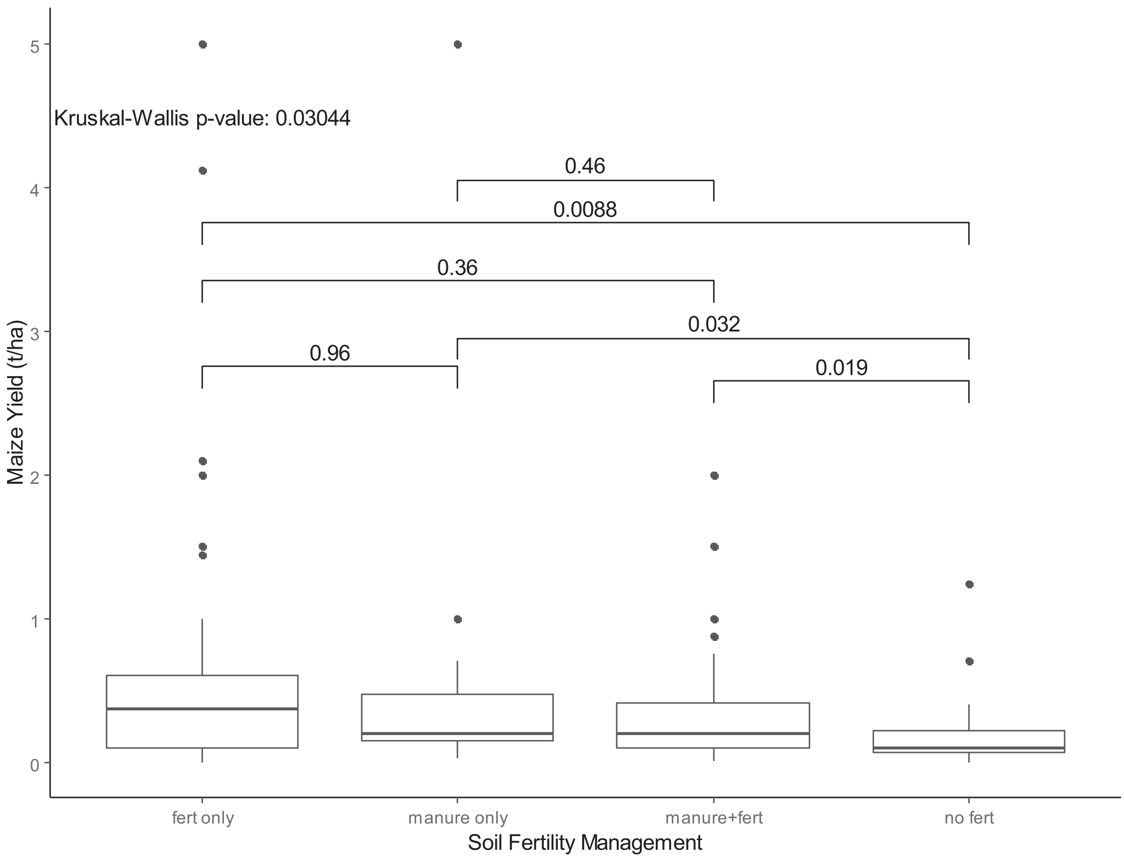

Figure 3. Average maize yield response to soil fertility management reported by smallholder farmers in Marange area, Mutare district. The bars connect compared groups of soil fertility management and the numbers above each bar are Wilcoxon *p*-values. (Fert represents fertilizers).

and welfare of rural households in agricultural-based rural economies (Holden & Tilahun, 2020). Household labour is the most common type of labour, which is usually common in smallholder farm set-ups (Musara et al., 2019).

Farmers in the Marange area grow various crops, including cereals, legumes, oil seeds, and cash crops. The crop diversity suggests that smallholder farmers are working towards addressing food security issues. However, most farmers are food secure for a very short period, only three months, from April to July. Most field crops are harvested in April, shelled and stored for future use. The percentage of farmers who are food insecure rises from August to January. The reason is that farmers in this area are not harvesting enough grain to sustain them until the next harvest, as there is only one crop harvest per year for rainfed agriculture, and the yield is very low. Therefore, some farmers receive food aid from August to January to alleviate the food insecurity challenges, which are provided by the government and NGOs. However, during the cropping season (October–March), farmers must balance working in their fields and simultaneously looking for food. The trade-off is that one of these priorities is compromised, and less time and resources are allocated to managing their farms. Hence, the food insecurity cycle persists. The percentage of food insecure farmers decreases towards February and March, suggesting the availability of food options from the field, such as green mealies and cowpeas.

4.2. Farmer's awareness and adaptation strategies to extreme weather events

Confirmation of experiencing extreme weather events by farmers shows that they are aware of climate change and variability and its impacts on their agricultural production systems. This is consistent with experiences recorded across Southern Africa (Mavhura et al., 2022; Mtambanengwe et al., 2012; Sani & Chalchisa,

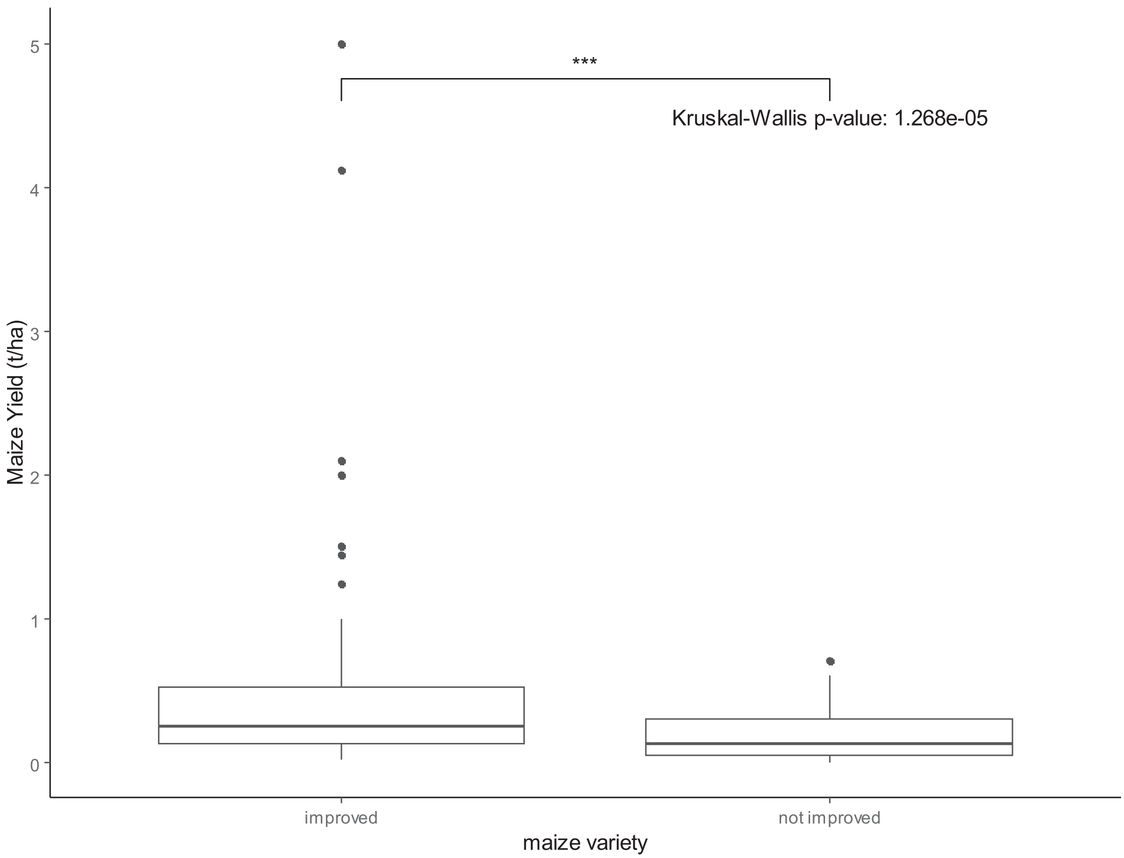

Figure 4. A comparison between maize yield reported for improved and non improved maize variety by smallholder farmers in Marange area, Mutare district. The bar with ***connects different maize variety groups significant at $p < 0.05$.

2016), showing that farmers are active observers of environmental changes (Ramborun et al., 2020). To respond to these extreme weather events, several farmers reported adopting management practices and technological options based on the extreme weather events they frequently encountered. For example, farmers responded to the drought by adopting water management strategies, early planting and changing the crop type (Sani & Chalchisa, 2016). This is in line with findings by Abid et al. (2020) who reported that farmers adopted planting early and use drought tolerant varieties after experiencing drought. However, farmers also highlighted several barriers to adapting to extreme weather events, such as lack of resources in the form of inputs or access to credit, information on climate and adaptation practices and labour availability.

The fact that other previous studies have also highlighted the same adaption barriers (Chingombe & Musarandega, 2021; Fisher et al., 2015; Nyahunda & Tirivangasi, 2021; Sen et al., 2021) suggests that while the problem and its impacts are known, there is no significant improvement in the way resources are allocated to improve farmer adaptation to climate change and variability in marginal areas. Farmers have adopted possible adaptation technologies and practices despite limited progress based on their socio-economic resource endowment (Mutenje et al., 2019; Sani & Chalchisa, 2016). Since the resource endowments of rural farmers only allow slow changes, smallholder farmers remain constrained, and it is not easy to achieve food self-sufficiency. For transformational change that increases food self-sufficiency in marginal semi-arid regions, there is a need for an integrated approach encompassing innovations in policies, credit facilities, and technological and management options.

Some level of education such as primary or secondary education, positively impacts crop diversification and irrigation adoption. This suggests that education

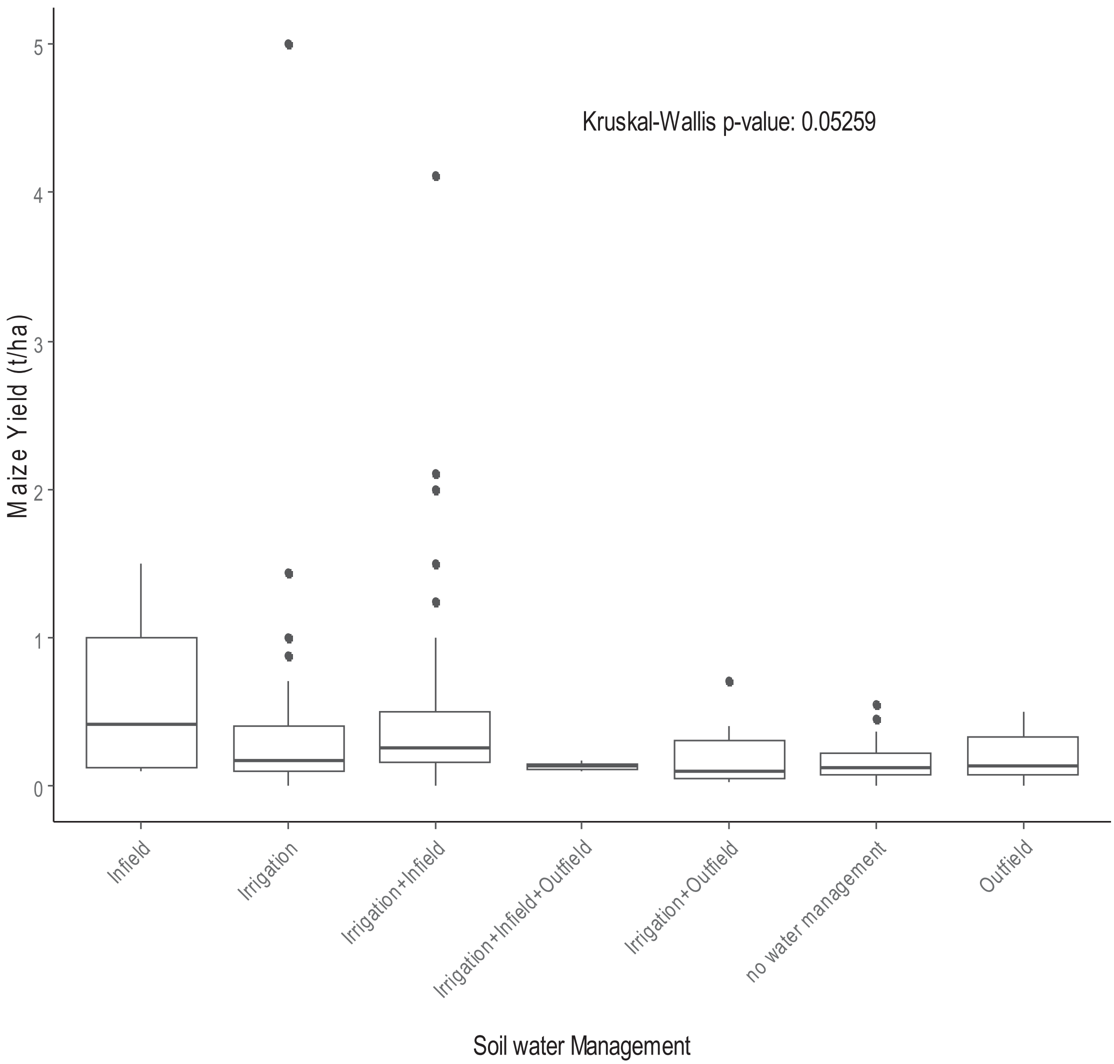

Figure 5. Average maize yield response to soil water management use by smallholder farmers in Marange area, Mutare district.

translates to a better understanding of agricultural practices and decision-making to adopt (Vanlauwe et al., 2023). However, primary and secondary education alone may not guarantee the adoption of a technology; other factors, such as practical training, are crucial.

Association with farmer groups positively impacts adopting adaptation strategies such as planting trees, early planting and irrigation. Farmers learn by doing and experimenting on platforms such as farmer groups. These farmer groups are often used to speed up technology adoption (Norton & Alwang, 2020). Sharing information and experiences among farmers in farmer groups can create a positive learning environment that encourages the exchange of knowledge and best practices (Fisher et al., 2018), leading to greater awareness and understanding of the benefits of planting trees, early planting, irrigation, and an increased willingness to try them out. Household size positively impacts irrigation adoption and use of crop-livestock integration, which translates to the availability of labour from the household members.

Farmer access to extension services positively impacts the adoption of soil water management strategies. Extension services are vital in disseminating new technologies and effectively assisting smallholder farmers in managing climate risks and impacts (Antwi-Agyei & Stringer, 2021). New technologies are promoted through field days and workshops (Antwi-

Agyei & Stringer, 2021; Makate et al., 2019). However, in the study area, farmer access to extension services negatively impacts the adoption of irrigation and planting of trees, and this can mean that farmers selectively choose options that suit them. Therefore, while access to extension services is essential, it is not the only factor influencing the positive adoption of irrigation practices or planting of trees. In the current study, the type of irrigation practised is watering using a bucket which they can encourage each other in farmer groups. Farmer knowledge of other adoption projects in the area negatively impacts the adoption of irrigation. When farmers have information about successful projects that their peers have implemented, they may be more likely to adopt similar practices, especially if they have been shown to improve agricultural productivity (Fisher et al., 2018).

4.3. Maize yields in relation to management strategies

Adopting soil fertility and water management practices is expected to improve maize productivity (Chiturike et al., 2022; Ndegwa et al., 2023); however, the average maize yields remain below 0.8 t ha^{-1} in Marange, Mutare district. Extreme weather events could explain these low yields (Kubiku et al., 2022). For example, according to Kubiku et al. (2022), rainfall in the area during the 2018–2019 season was above 650 mm and more than expected (450–650 mm) for the agro-ecological region. These high rainfalls in Marange probably resulted in high nutrient leaching on the predominantly sandy soils, reducing the nutrient use efficiencies of already low amounts of fertilizers applied by smallholder farmers. The total rainfall may have been above average, but the distribution may have been poor. During the 2018–2019 season, > 150 mm was received in 1 week. Consequently, this reduces crop growth and yield unless fertilizer is applied again to compensate for the leaching losses.

Generally, extreme weather events affect the response of crops to applied fertilizers (Rosenstock et al., 2019). Farmers who apply less than 8.5 kg ha^{-1} of fertilizers and manure often see insignificant differences in yields compared to those who apply sole fertilizer or sole manure (Twomlow et al., 2006). Due to the risk of crop failure during droughts and dry spells in semi-arid areas, smallholder farmers tend to apply fertilizers below the recommended rates (Nezomba, Mtambanengwe, Chikowo et al., 2015) to mitigate losses (Mashingaidze et al., 2013). The recommended fertilizer application rate for maize grown in agroecological zone where Marange is located is 250 kg ha–^{1} compound D (7% N, 14% P_20_5, 7% K) and at least 100 kg ha–^{1} of ammonium nitrate (FAO, 2006). Smallholder farmers, who are often resource-constrained, may find mineral fertilizer expensive and out of reach (Fairhurst, 2013; Nezomba, Mtambanengwe, Tittonell et al., 2015). Manure application also depends on availability and is often allocated to many crops, including family gardens resulting in farmers applying less than 3 t ha^{-1} to field crops like maize (Mtangadura et al., 2017). Socio-economic challenges, such as resource constraints and competing demands for fertilizer resources, may prevent farmers from recognizing the yield benefits of applying fertilizers.

Management practices and soil types influence the effectiveness of applied fertilizers. For maize production, the effective management of nitrogen fertilizers requires split application considering the timing, quantities, weather conditions, and available soil mineral nitrogen (Masvaya et al., 2017). Manure management from the kraal to the field is crucial to maintaining manure's nutrient quality. If the manure stays too long in the open, the mineral nitrogen volatilizes as NH_3 or N_2O (Peng et al., 2022). In the study area manure was found to be of low quality with 0.72% nitrogen thus emphasizing the need for maintaining manure nutrient quality. Broadcasting vs. precise application of manure also determines the ultimate crop yield. Nitrogen is lost into the atmosphere from broadcasted manure, and the remaining organic fraction decays slowly on the surface, resulting in very little proportion of nutrients available for root uptake (Nkebiwe et al., 2016).

Soil moisture management strategies grouped as in-field (mulching, potholing, basins, ridges, and autumn ploughing) and out-field (standard contours, tied contours, infiltration pits, and terracing) water management strategies did not give significant yield responses. Although a greater percentage of farmers, 34%, use the traditional irrigation method, such as bucket irrigation on maize crops. The traditional irrigation method has no proper scheduling, is manually implemented and is affected by the distance from the water source. Such irrigation systems may not be sustainable for field crops such as maize. Previous studies have shown that in-field water harvesting techniques with improved nutrient management significantly increased maize yields in sandy soils (Chiturike et al., 2022; Kugedera et al., 2022). However, this was not the case with the farmers in this study. In the previous studies, it was observed that the effect of water harvesting technologies on crop yield could significantly differ from farmer to farmer due to technical management and accuracy in the construction of water harvesting structures (Chiturike et al., 2022) . Perhaps this was the case in the current study, where poor management and faulty construction of water harvesting may have contributed to the lack of significant yield increases.

The use of improved varieties is one of the ways of adapting to extreme weather events, and the results from this study are in line with the previous findings (Fisher et al., 2015; Makate et al., 2017; Mashingaidze et al., 2013; Parwada et al., 2022). Maize yields for improved varieties were highly significant, but the average maize yield reported shows that farmers are still within the category of low yields, less than 0.8 t ha^{-1}. Overall, based on the rainfall received in the 2018–2019 season and information collected from the farmers about using fertilizers, water management options and improved varieties, the average maize grain yields would have been significantly above 0.8 tha^{-1}. Since this study was based on practices that farmers in Marange were currently practising and not an experiment where other factors that can affect yield were controlled, the response of maize yield may have been influenced by other socio-economic factors. Thus, a robust approach of trans-disciplinary action is required to reach smallholder farmers in semi-arid areas and assist them in adopting good skills and practices for improved crop production and adaptation to extreme weather.

5. Conclusions

Farmers in Marange, Mutare district, confirmed experiencing extreme weather events and are aware of the risks posed on agricultural production. They are aware of the need to take proactive steps to protect their crops and livelihoods from the potential damage caused by extreme weather events. Farmers have also prioritized adopting some strategies to cope with extreme weather events. The farmers implemented adaptation strategies such as soil and water management, use of improved varieties, mulching, planting trees, early planting, reducing the area under cultivation, and changing the types of crops in their crop production systems. Despite the reported adaptation strategies on fertility and water management, maize yields remain very low for smallholder farmers.

To improve yields, further research is needed to determine the exact amounts of fertilizer and water management inputs needed to optimize the productivity of improved crop varieties. Therefore, we recommend that farmers receive training and support on the best evidence-based fertilizer and water management practices. Access to climate and weather information services by farmers will also help them carry out farming operations on time, adjust their farming practices and minimize the impacts of extreme weather events on their crops. Finally, there is a need to promote and adopt drought-tolerant maize varieties and alternative crop options that are more resilient to extreme weather events and better suited to the local climate conditions.

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Notes on contributors

Sandra Makaita Madamombe holds MSc in Soil and Environmental Management from the University of Zimbabwe. She is currently working on a PhD in Crop Production Science with the Swedish University of Agricultural Sciences with particular focus on soil and water management and climate -mart technologies for crop production in semi-arid areas; food security and smallholder farming systems.

Stanley Karanja Ng'ang'a is an agricultural development economist at the Alliance of Bioversity International and International Centre for Tropical Agriculture. He holds a PhD in Development Economics from Wageningen University in the Netherlands. He has extensive international contributions in economics of climate change, cost-benefit analysis, and the scale-up of sustainable, climate-smart agricultural practices. Currently, he leads research on cost-benefit analysis for climate-smart agricultural practices, impact evaluation, and mobilizes resources for research projects at the Alliance of Bioversity and CIAT.

Ingrid Öborn is professor of Agricultural Cropping Systems at the Swedish University of Agricultural Sciences (SLU) and a Senior Research Fellow at World Agroforestry (ICRAF). She holds a PhD in Soil Science from SLU. She has remarkable experience in interdisciplinary international research focusing on sustainable intensification, diversification of farming systems, ecosystem services, agroforestry and nutrient cycling.

George Nyamadzawo is a professor of Soil Science and Environmental Science, Department of Environmental Science, Bindura University of Science Education, Zimbabwe. He has experience in field rainwater harvesting techniques, crop intensification, small grain and legume production in semi-arid regions of Zimbabwe; sustainable utilization of seasonal wetlands in smallholder farming areas of Zimbabwe. His research focus on climate change adaptation, promoting marginalised crops through their cultivation, use and value chains.

Ngonidzashe Chirinda is a climate change mitigation scientist and a professor in Sustainable Tropical Agriculture at Mohammed VI Polytechnic University in Morocco. He holds a PhD in Climate Change and Agroecology from the University of Copenhagen. His research focuses on greenhouse gas emissions, uptake, monitoring and modelling; identifying and evaluating climate change mitigation options; and assessing environmental policy implications.

Job Kihara is an expert in soil health with particular interests in soil micronutrients and integrated soil fertility management in smallholder farmer contexts of sub-Saharan Africa, developing decision support tools for site-specific nutrient management. He is the Principal Scientist on soil and water management at the Alliance of Bioversity International and International Centre for Tropical Agriculture and co-lead of Excellence in Agronomy Initiative at the CGIAR.

Libère Nkurunziza is an agro-ecologist researcher and an associate professor in Agricultural Cropping Systems at the Swedish University of Agricultural Sciences. His research work emphasizes improvement and evaluation of agriculture production systems to meet the socio-ecological requirements. His current research focuses on crop nutrient management, water productivity, socio-economic and climate change and adaptation.

ORCID

Sandra Makaita Madamombe http://orcid.org/0009-0009-2890-2042
Stanley Karanja Ng'ang'a http://orcid.org/0000-0002-6166-7920
Ingrid Öborn http://orcid.org/0000-0003-3847-6082
George Nyamadzawo http://orcid.org/0000-0001-8048-935X
Ngonidzashe Chirinda http://orcid.org/0000-0002-4213-6294
Job Kihara http://orcid.org/0000-0002-4394-9553
Libère Nkurunziza http://orcid.org/0000-0002-9418-0043

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Appendices

Appendix 1: The questionnaire used for the household survey

The survey questionnaire comprised of separate modules addressing the following topics:

- General comments (introducing the objective and aims)
- Metadata
  - Respondent information
- Farmland and their sizes
  - Crop information
  - Vegetable information
  - Information on fruits
- Land management and agricultural inputs
  - Mineral fertilizer
  - Manure
  - Chemical
  - Improved seeds
  - Inputs for harvest storage
  - Irrigation
  - Other water management practices
  - Integrated farming
  - Preventive measures utilized
- Livestock, Poultry, Bees and their products
  - Livestock information
  - Livestock products – milk, skin and hides
  - Purchased feeds
  - Veterinary medicines
  - Livestock manure
  - Poultry information
  - Beekeeping
- Labour source
- Gender related aspects
- Access to capital, credit, extension support, and external support
  - Social capital
  - Access to credit and loan
  - Extension services
  - External support
- Climate and soil
  - Climate change awareness
  - Soil water retention technology
- Food security and wealth status
  - Food security issues
  - Household wealth status

Appendix 2: The number of farmers in the Marange area that reported the use of different adaptation strategies to extreme weather events (n = 245)

Climate event	Adaptation strategy	Number of farmers
Drought	Increase the acreage under crop production	9
	Reduced area under cultivation	16
	Irrigation	8
	Water harvesting	23
	Use improved seeds	7
	Early planting	46
	Soil moisture management	9
	Crop-livestock integration	2
	Surface mulch to prevent cold on vegetables	3
	Change crops grown	11
Floods	Water harvesting	4
	Early planting	16
	Soil moisture management	5
Strong winds	Reduced area under cultivation	5
	Water harvesting	3
	Use of improved seeds	3
	Early planting	18
	Plant trees	2
Increased temperatures	Reduce the area under cultivation	5
	Water harvesting	10
	Use improved seed	7
	Early planting	31
	Soil moisture management	14
Reduced temperatures	Use of improved seed	3
	Early planting	3
	Soil moisture management	3