Determinants of Smallholder Farmers' Maize Productivity and Adaptation Strategies Amidst Rainfall Variability in Chongwe, Zambia

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Abstract
Climate change, which is a global challenge, is caused by accelerated anthropogenic activities. It leads to an increase in the amount of greenhouses gases in the atmosphere. Its impacts are profound in climate sensitive sectors such as smallholder agriculture. Zambia's smallholder farmers are dependent on rainfed agriculture, and are thus vulnerable to climate change and climate variability. Climate variability, manifested through extreme events such as droughts, floods and abnormal temperatures, works synergistically with other factors to affect crop productivity. This study examined the determinants of smallholder farmers' crop productivity amidst variability in seasonal rainfall received in Chongwe District of Zambia. Five study sites (villages) were purposively sampled, namely, Mudenda, Mutakama, Mulwila, Kalilika and Kangalangala. A total of 35 respondents and 3 key informants were interviewed during this study. All the respondents were smallholder farmers while the key informants were representatives from the Zambia Meteorological Department, Chongwe District Agriculture Office, and a traditional leader. The trend analysis revealed that rainfall in Chongwe District had decreased at an annual rate of 9.60 mm between 2000 and 2021. Even though the reduction is not statistically significant ($p = 0.181$) the downward trend in rainfall should compel smallholder farmers to devise adaptation measures to combat the decreased annual rainfall. Further, maize yields had decreased at an annual rate of 0.012 ton/ha between 2010 and 2019 which was not statistically significant ($p=0.812$). An assessment of social factors that could influence maize productivity revealed household size ($r = 0.754$; $p = 0.012$) and farming experience ($r = 0.344$; $p = 0.043$) as significant factors that affected maize productivity among the sampled households.. The study concludes that the smallholder farmers that were studied have been experiencing decreased rainfall trends and maize productivity which increases their vulnerability to climate variability and climate change. The study recommends that agricultural development interventions should focus on enhancing the resilience of smallholder farmers in Chongwe District through climate change awareness, household income diversification, and public social capital mechanisms.

***Keywords**:* climate change, rainfall variability, adaptive capacity, convergent research design,

Introduction

The average global surface temperature has increased by 0.74 °C since the late 19 Century and is expected to increase by1.4°C - 5.8°C by 2100 AD with significant regional variations (IPPC, 2007). The atmospheric CO_2 concentration has increased from 280 ppm to 395 ppm, CH4 concentration increased from 715 ppb to 1882 ppb and N_2O concentration from 227 ppb to 323 ppb between the years 1750 and 2012 (Ranjan, 2014). In Sub Saharan Africa, extreme climatic events are predicted to increase in both severity and frequency (Siatwinda *et al.*, 2021). This climatic change could affect agriculture in several ways such as growth rates, photosynthesis, transpiration rates, and moisture availability alterations in atmospheric composition can also directly influence crop production by its impacts on plant and soil composition. The negative consequences of climate change on agriculture are severe and may threaten the food security, and hence require special agricultural measures to combat with (IPPC, 2007).

The agriculture sector plays a pivotal role in the Zambian economy. Agriculture contributes about 7 per cent of the country's GDP and sustains the livelihoods of approximately 60 per cent of the population (Phiri *et al.*, 2020). The role of agriculture in shaping the Zambian economy is significant, influencing both short-term and long-term growth patterns. In a study by Phiri *et al.* (2020), it was found that a single-unit enhancement in agriculture makes a considerable contribution to economic growth, with effects of 0.428 per cent in the short term and 0.342 per cent in the long term (Phiri *et al.*, 2020). Despite the importance of the sector, changes in agricultural policies, as observed since 1991, particularly the liberalisation of markets for agricultural inputs and produce, have posed challenges to smallholder agricultural productivity.

In recent decades, climate variability has added to the vulnerability concerns for farming communities as increased variability in rainfall has impacted farming communities negatively. According to recent statistics, approximately 1.35 million people, constituting about 10 percent of the analysed Zambian population, were expected to experience severe food insecurity (IPC Phase 3) between July and September 2023. This figure was projected to rise, with an estimated 1.95 million people falling into IPC Phase 3 for the 2022/23 period. Notably, these challenges are particularly pronounced in the provinces of Central, Southern, Lusaka, and Eastern (IPC Zambia, 2023). The escalation in food insecurity underscores the vulnerability of farming communities and emphasises the pressing need for targeted interventions to mitigate the growing climate and food security crises.

Rainfall variability is cardinal due to its influence on the agricultural potential of any area; from the washing away of nutrients needed in the topsoil to the loss of agricultural production due to the inability of crops to grow in an area of little or too much rainfall (Ford, 2009). Recent studies indicated that the pattern of seasonal rainfall in Zambia has significantly changed due to the late onset, early off set of rains, and intra seasonal droughts (Kapila and Mubanga, 2022; Mphande *et al.*, 2022; Umar, 2021). This shift has significantly reduced the length of the crop growing season. This may have major impacts on the crop yields, especially by smallholder farmers. Scholars have indicated that while the long-term quantities of rainfall received in Zambia might not have changed significantly (Mubanga and Umar 2014), there is general agreement that the patterns of seasonal rainfall have significantly changed over time (Kapila and Mubanga 2022; Mubanga *et al.* 2020).

The new reality created by climate change and variability has created a hurdle that actors pursuing climate-sensitive livelihoods have to navigate to adapt and survive. Smallholder farmers are one such group that has to constantly navigate the impacts of climate change and variability in addition to a range of other factors which affect crop productivity

Therefore, this study assessed the determinants of smallholder farmers' crop productivity amidst variability in rainfall received in Chongwe District. The objectives were threefold; (i) to investigate the trends in rainfall variability in Chongwe District from 2000 to 2020; (ii) to examine factors affecting smallholder farmers' maize productivity amidst variable rainfall patterns in Chongwe District, and; (iii) to investigate the responses of smallholder farmers to rainfall variability in Chongwe District.

Methodology

Description of the study area

Chongwe district is located between latitudes 15° 19' 58and XX S and longitudes 28° 40' 44 and YY" E. The district is about 35km east of Lusaka which is the capital city of Zambia (Figure 1). The central business district of Chongwe lies on a high plateau of 1,300m meters to 1,500 meters above sea level (GRZ, 2013).

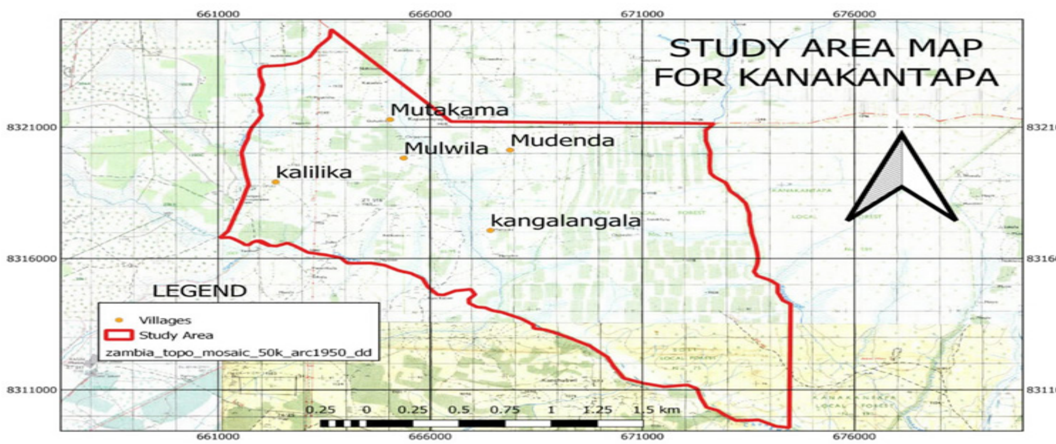

Figure 1. Location of study sites

Chongwe District falls in agro-ecological region IIa, which is a medium rainfall region that receives between 700-1000mm of annual rainfall with a growing season of 100-140 days (Chikowo, 2013). The district has a cool and dry season from May to August, when temperatures begin to increase giving rise to a hot and dry season from September to October and a warm and wet season from November to April (CSO, 2012). The temperature ranges from a minimum of 8.9 °C to a maximum 31.7°C. The hot season lasts from September to December, with October being the hottest month. The coldest temperatures are 9.4°C to 23.3°C in July. The month with the most days of rain is January at an average of 185.4 mm (Weatherspark, 2022).

Data collection

Both primary and secondary data was used in this study. Primary data was collected through key informant interviews, semi-structured interviews and focus group discussion. Archival monthly rainfall data for the years 2000 to 2021 for Chongwe was obtained from the Zambia Meteorological Department . The data was used to show rainfall variation overtime and how crop yield varies with weather variables. Another set of secondary data on maize yield and area harvested were collected from the Zambia Statistical Agency for the years 2010 to 2019.

Study Participants and Selection Criteria

The study involved a total of 38 research participants, comprising 3 key informants and 35 respondents. The key informants were purposefully selected based on their expertise in climate change and smallholder agriculture within Chongwe District. The key informant group included an officer from the Zambia Meteorological Department, an officer from the Chongwe District Agriculture Office, and a traditional leader from one of the sampled villages. The selection of these key informants aimed to capture diverse perspectives on climate-related issues affecting agriculture in the district.

The 35 farmers were selected using quota sampling. Quota sampling involved non-random selection from predetermined strata, which, in this case, were the villages namely; Mudende, Mutakama, Mulwila, Kalilika, and Kangalangala. The distribution included 7 farmers from Mudende, 6 from Mutakama, 10 from Mulwila, 7 from Kalilika, and 5 from Kangalangala. A focus group discussion was held which involved a group of 8 farmers aged eighteen years and above. It included 4 men and 4 women randomly selected from the 35 farmers interviewed using the semi-structured interview schedule. The discussions aimed to explore the impacts of climate change on crop yield, farmers' perceptions of rainfall variability, and adaptation measures.

Data Analysis

Qualitative data from the key informant interviews and focus group discussions were analysed thematically with the aid of Microsoft Excel.. The methodology encompassed the initial development and application of codes in concise phrases or words representing thematic elements. Subsequently, themes were derived from identified patterns within the coded data. The final stage involved summarising the findings and establishing connections to the study's primary aims and objectives, as described in Jackson *et al*, (2019) and Connaway and Powell (2010).

Descriptive statistics such as the mean and standard deviation were used to summarize key variables under study. Pearson correlation analysis was conducted in Statistical Package for Social SciencesVersion 26 (SPSS 26) to explore relationships between crop yield and various factors including education, access to irrigation, household size, age, and access to climate information.

The study employed multiple linear regression modeling, using maize yields as the response variable. The selected predictor variables encompassed a range of factors such as age, income, experience, access to climate information, household size, education, farm size, crop income, livestock ownership, access to extension services, and access to agricultural credit and access to water for irrigation. The decision to include these variables was driven by their potential impact on maize yields, their known influence on agricultural outcomes, and their significance in existing literature. The goal was to capture a comprehensive set of factors that could collectively contribute to the understanding of maize yield variations. All statistical analyses were conducted using SPSS 26, with a significance level set at p=0.05.

Trend analysis, following the procedures outlined by Scott and Chandler (2011), was applied to the rainfall data from 2000 to 2021 and the crop data from 2010 to 2019. Following Scott and Chandler (2011), the resultant trends were visually presented using line graphs to illustrate patterns and seasonality, aiding in the interpretation of rainfall and crop production characteristics.

Results and Discussion

Demographic and socio-economic characteristics of farmers' households

This section highlights the demographic and socio-economic characteristics of households that play an important role in farming such as age, sex, level of education, farming experience and marital status (Table 1).

Table 1 Demographic and Socio Characteristics of respondents in Chongwe, 2022.

Village	**Percentage of respondents**	**Education**	**Percentage of respondents**	**Marital Status**	**Percentage of respondents**
Mudenda	20	Primary	54.3	Single	17.1
Mutakama	17.1	Senior Secondary	5.7	Married	62.9
Mulwila	28.6	Junior Secondary	34.3	Divorced	8.6
Kalilika	20	Higher education	5.7	Widowed	11.4
Kangalangala	14.3				
Age (Years)	**Percentage of respondents**	**Years Engaged in Farming**	**Percentage of respondents**	**Household Size**	**Percentage of respondents**
21-30	8.6	<5	5.7	<5	17.2
31-40	42.9	6-10	28.6	6-10	77.1
41-50	31.4	11-15	14.3	11-15	5.7
51-60	17.1	16-20	28.6		
		21-25	14.3		
		>25	8.5		
Sex	**Percentage of respondents**	**Terrain Distribution**	**Percentage of respondents**		
Male	38	Low land	65.7		
Female	62	Hilly land	20		
		Near Stream	14.3		

The sample, consisting of 37.1 per cent male and 62.9 per cent female respondents, reflecting the higher probability of finding women at home during the day due to the common gender roles in the study area. Gender dynamics play a crucial role in adaptation, with male-headed households more likely to receive technological information due to traditional barriers restricting women's access to resources (Deressa *et al.*, 2009). Educationally, 54.2 per cent completed primary school, 39.9 per cent reached secondary school, and 5.7 per cent attained tertiary education. A literate community was observed, aligning with studies indicating higher educational backgrounds correlate with increased adoption of climate change adaptation strategies (Nor Diana *et al.*, 2022). The sample spans various age groups, with 31.4 per cent falling within the 31 to 40 years range and 17.1 per cent aged over 50. This diversity signifies the involvement of both young and experienced farmers, highlighting a positive correlation between youthful manpower and farming experience in adopting improved agricultural techniques (Deressa *et al.*, 2009).

Farmers with an average of fifteen years of experience were well-represented, ranging from less than five years (5.7%) to over twenty years (25.7%). Experience enhances the ability to notice and respond to climate change (Maddison, 2007). Household size, with a modal size of six members (74.3%), aligns with the national statistics on household size Larger households are more likely to adopt labour-intensive technologies due to the availability of household labour (Gbetibouo, 2009). Marital status indicates 62.9 per cent of the sample is married. Married farmers, as suggested by Ngeywo *et al.* (2015), tend to make better decisions, leading to increased agricultural produce and effective adaptation methods compared to single or divorced individuals.

Most of the farmers interviewed had their farmlands located in lowlands (65.7%) which are prone to flooding in the event of heavy rains. However, about 20 per cent of the farmlands were on hilly land while 14.3 per cent of farmers cultivated near a stream. Generally, location is important because it determines the wetness and dryness of an area and the nutrient content in the soil (Kolay, 2007). Most farmers that were sampled cultivated between one to five hectares of land (63%). The sample also had respondents who cultivated less than a hectare of land (17 %) and those who cultivated more than five hectares (20%) (Figure 3).

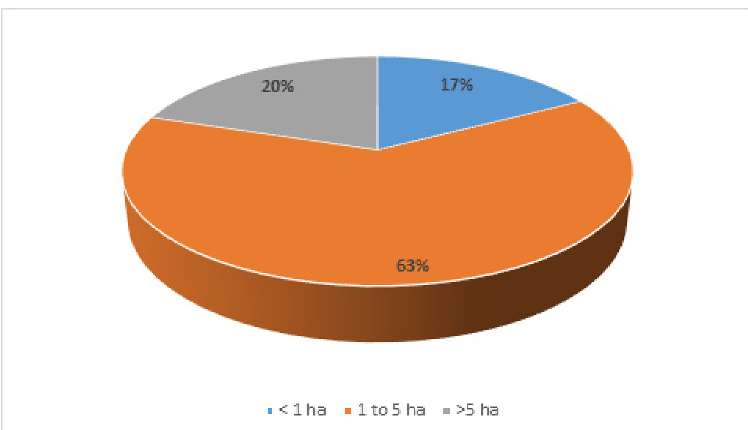

Figure 3. Farm size cultivated by sampled smallholder farmers in Chongwe District, 2022

Some studies have found that farmers with large sizes of farms are able to better perceive climate change and variability than those with a smaller farm size (Ehiakpor *et al*, 2016).

Rainfall Trends in Chongwe District

Rainfall in Chongwe generally exhibited a decrease of 9.60 mm annually over the period 2000 to 202, with the year 2016 showing lowest recorded at 291.6mm and 2008 the highest at 1,201.2mm. However, the annual rainfall was not statistically significant ($p = 0.414$) (Figure 4).

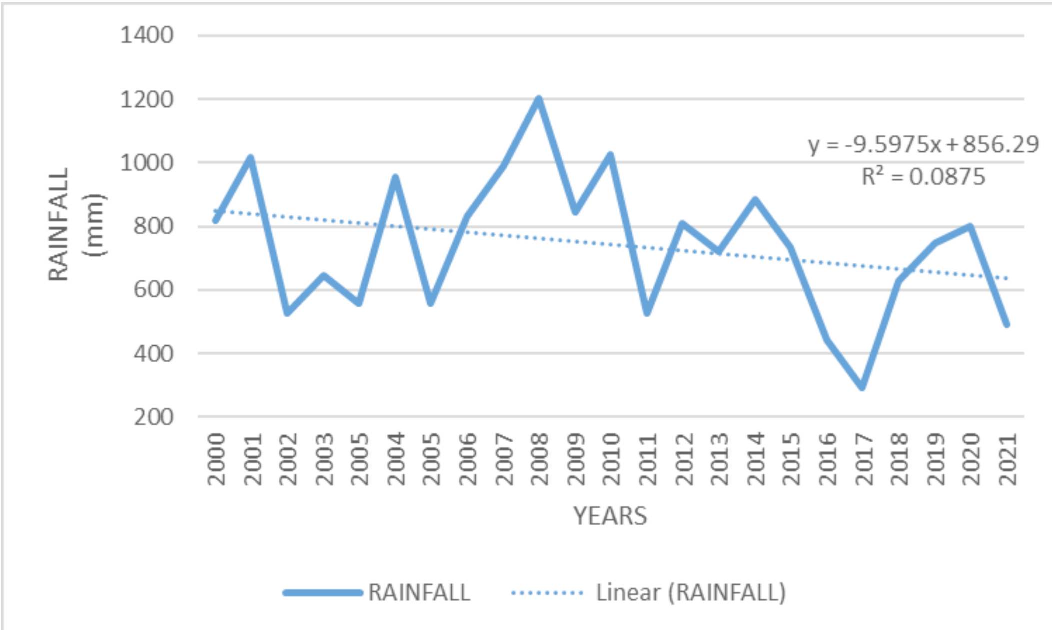

Figure 4. Annual rainfall (mm) in Chongwe, 2000 to 2021.

Trends in maize productivity, maize harvested area and rainfall from 2010 to 2019

Generally, there was an annual decrease of 0.012 ton/hectare per year in maize productivity between 2010 and 2019, even though this reduction was not statistically significant ($p = 0.819$) (Figure 5a). The lowest yields were recorded in 2015 (1.18 t/Ha) while the highest yields were recorded in 2012 (2.68 t/Ha). The area harvested had generally increased over the period 2010 to 2019 at a rate of 319.35 hectare per year with the year 2016 showing the largest area harvested at 27,834 ha and the lowest in 2015 at 16,369.91 ha (Figure 5b). This increase in harvested area over time was not statistically significant ($r = 0.291$; $p = 0.414$).

Annual maize production (Figure 5c) exhibited an increase of 4,672.3 Ha/year between 2010 and 2019 while maize productivity hovered around 1.18 Mt/Ha and 2.57 Mt/Ha over the same period with the highest maize yield being at 2.57 Mt/Ha (27,834 Ha) in 2016 and the lowest at 1.18 Mt/Ha (16,369.91 Ha) in 2015. This increase in harvested area for maize yield was statistically not significant (r=0.595; p =0.0695). Over the period 2010 to 2019, trends in maize yields exhibited an annual reduction of 129.24 Mt/Ha with decreased rainfall over the same period (Figure 5d), even though this reduction was not statistically significant (r=0.253; p=0.481).

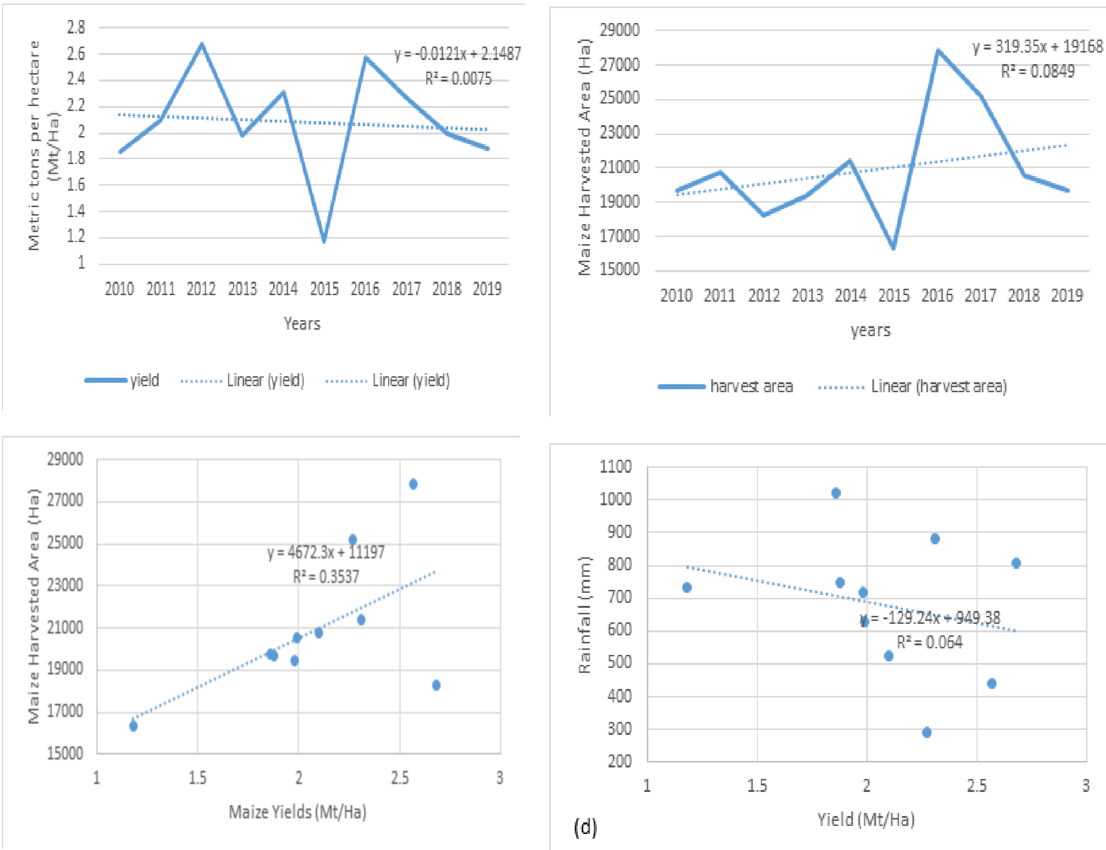

Figure 5. (a) Trends in maize productivity , 2010 to 2019 (b)Trends in area harvested , 2010 to 2019 (c) Scatter plot of maize harverted area (ha) against maize yield (t/ha) in Chongwe, 2010 to 2019 (d) Scatter plot of rainfall against maize yield, 2019 to 2021.

Determinants of smallholder farmers' maize yields

A multiple regression analysis model was used to estimate the contribution of different social factors to maize productivity. Several factors (independent variables) were regressed with maize yields and these included; access to climate information, access to agricultural credit, access to extension services, household size, farming experience, age, livestock ownership, education, access to irrigation, and farm size (Table 2). Generally, respondents found credit to be risky. To mitigate this, alternative sources for financing working capital requirements were explored, including utilisation of cash reserves, liquidation of assets or loans from informal sectors characterised by favourable acquisition of interest rates. Hence, farmers would have the flexibility to make productivity decisions based on various factors, without being constrained or pressured.

Table 2. Variables contributing to small holder farmers' maize yield,

Determinants of maize yield	**R values**	**P-value**
Access to climate information	0.017	0.923
Access to agricultural credit	0.405	0.015*
Access to extension services	0.170	0.329
Household size	0.754	0.012*
Farming experience	0.344	0.043*
Age	0.110	0.529
Livestock ownership	-0.087	0.619
Education	-0.155	0.511
Access to irrigation	-0.124	0.478
Farm size	-0.170	0.329

* value is significant at $p \leq 0.05$.

Smallholder farmers' perception and adaptation to impacts of rainfall variability

Generally, most of the farmers sampled were aware of climate change (69%) and had experienced occurrence of extreme climate events such as floods, drought, dry spells and extreme temperatures in the study area, while 31 per cent indicated that they were not aware of climate change. For those aware of climate change, 69 per cent cited radio, 48 per centcited television 22 per cent cited neighboring farmers while 4 per cent citedrelatives as modes of access to climate change information. Awareness of climate change has made smallholder farmers devise ways of adapting to various impacts of climate change.

Adaptation to changed onset and offset of rainfall

Majority of the farmers (72.2%) had observed a late onset of rains in Chongwe.

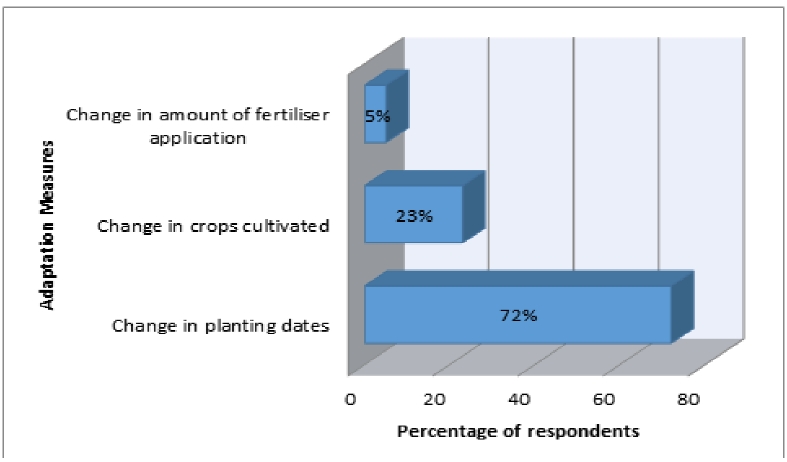

Figure 6. Adaption measures of small holder farmer to onset of rainfall in Chongwe District, 2022

To address the altered onset of rainfall, 73 per cent of smallholder farmers implemented adaptive strategies by engaging in delayed planting, aligning their agricultural activities with the commencement of the rainy season. Some of the respondents changed their production to include new crops (such as millet) that are drought tolerant while others (5%) increased fertilizer application to expedite crop growth, particularly in anticipation of the shortened crop growing season.

Slightly over half (53%) of the respondents had observed an early offset of rains in Chongwe District. To combat the changed early offset of rains, 55 per cent of them adapted by planting less maize to reduce the amount of maturing maize crop lost but concentrating more on other crops that are more drought tolerant. The rest (45%) of the respondents changed their production to include new crops (such as sunflower and popcorn) which do not require a lot of water to grow (Kole, 2022). Similarly, the focus group discussants observed that the rainy season started later but ended earlier than was the case five to twenty years ago and was increasingly characterised by intra seasonal droughts.

Adaption to the perceived rainfall variability

The farmers in the study area adapted to rainfall variability by employing climate smart agricultural practices (Figure 7). Climate smart agriculture has been said to be able to conserve moisture and organic matter in the soil. Thus, farmers have been able to sustain crop yields even under reduced rainfall circumstances. Some respondents (8.5%) had reduced their cultivated area to a manageable size due to reduced length of the crop growing season.

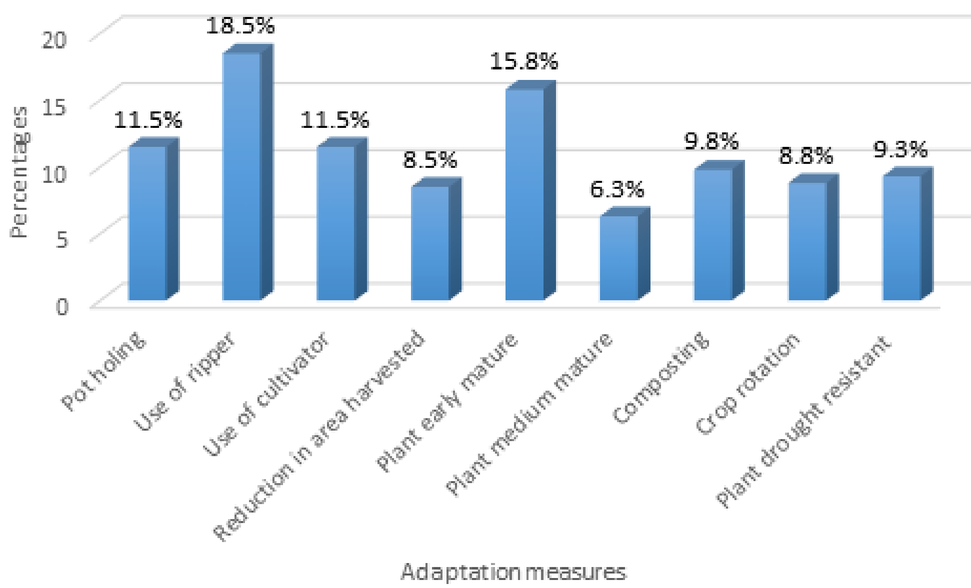

Figure 7: Adaption measures to the perceived rainfall variability by smallholder farmers in Chongwe, 2022

Moisture conservation was aided by the addition of soil organic matter, use of pot holes and rippers. These strategies have been widely reported to enhance soil moisture retention. Focus group discussants also alluded to the benefits of using potholes and rippers during periods of low rainfall. Other strategies used were planting early and medium maturing crop varieties and mechanisation by switching to the use of cultivators. These strategies were meant to ensure that the crops matured within the reduced crop growing period.

Conclusions

This study examined trends in rainfall in Chongwe District and explored the determinants of maize yields, in a changing climate context. It revealed a decreasing trend in the amount of annual rainfall even though it was not statistically significant. Maize yields were found to have a decreasing trend. Household size, access to credit facilities, and farming experience were found to be significant in affecting smallholder famer's maize productivity. Small holder farmers responded to rainfall variability through adoption of several strategies such as late and reduced maize planting, cultivating drought tolerant crops, crop rotation, composting, and the use of a ripper. Notably, the use of a ripper and early maturing plant varieties, along with the shift toward crops such as sunflower, emerged as key adaptation measures. These adaptive strategies showcased the community's proactive response to climate challenges.

The study recommends using labour pooling practices between small and large households to optimise labour resources, fostering collective efforts to address challenges posed reduced rainfall periods. Secondly, it is crucial to establish knowledge-sharing platforms to harness the experience of seasoned farmers, thereby facilitating continuous learning to adapt more efficiently to changing environmental conditions. Thirdly, the streamlining of financial support mechanisms, particularly targeted at experienced farmers and those in larger households, is essential for empowering farmers to adopt effective adaptive practices which can be achieved by offering favourable credit terms for agricultural purposes Lastly, the introduction and promotion of policies through the Ministry of Agriculture that actively encourage livelihood diversification as a robust strategy to mitigate vulnerabilities faced by smallholder farmers. As diversifying livelihoods enhances farmers' resilience to the impact of unpredictable rainfall patterns, ensuring sustained agricultural productivity and improved economic well-being.

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