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Building Climate Resilience in Tomato Production: Evidence from Smallholder Farmers in Peri-Urban Zambia

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Abstract: Climate variability poses a growing threat to tomato production among smallholder farmers in sub-Saharan Africa, yet evidence on the effectiveness of farm-level adaptation strategies remains limited. This study assessed the contribution of climate adaptation practices to tomato productivity among 150 smallholder farmers in Lusaka West, Zambia, using a convergent mixed-methods design. Quantitative data were analysed using descriptive statistics and Pearson correlation, while qualitative data were analysed thematically. Most farmers (88%) reported experiencing climate variability, mainly through irregular rainfall, drought, and rising temperatures. Adaptation strategies were widely adopted (86%), with irrigation and improved seed varieties being the most common. About 76% of respondents reported improved tomato yields and 72% reported increased household income following adaptation. A strong positive relationship was observed between adaptation strategies and tomato yields ($r = 0.718$, $p < 0.001$), indicating that increased adoption of adaptation practices significantly enhanced production performance. Qualitative findings confirmed that adaptation improved resilience but highlighted financial constraints, limited irrigation infrastructure, and inadequate climate information as major barriers. The study concludes that climate adaptation strategies strengthen the resilience and productivity of smallholder tomato farming systems. Strengthening extension services, expanding access to affordable irrigation technologies, and promoting climate-smart agriculture are essential for enhancing sustainable horticultural production and food security in Zambia.

Keywords: *Climate Resilience; Climate Variability; Tomato Production; Adaptation Strategies; Smallholder Farmers; Zambia.*

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I. INTRODUCTION

Climate variability has emerged as one of the most significant challenges to global agricultural production, affecting crop yields, food security and rural livelihoods through increasing temperatures, erratic rainfall patterns and more frequent extreme weather events. Agriculture is particularly vulnerable because crop productivity depends heavily on climatic conditions, and these changes are projected to intensify in many regions, especially in sub-Saharan Africa where farming systems are predominantly rain-fed (IPCC, 2021; Ngoma *et al.*, 2021). Tomato (*Solanum lycopersicum* L.) is among the most economically important vegetable crops worldwide, contributing substantially to household nutrition, employment and income generation. However, tomato production is highly sensitive to climatic stresses such as high temperatures, water deficits and irregular rainfall, which adversely affect flowering, fruit development, fruit quality and marketable yields. As climate variability becomes more pronounced, sustaining tomato productivity has become an important priority for achieving resilient and sustainable horticultural systems (IPCC, 2021). Sub-Saharan Africa is recognised as one of the regions most susceptible to climate-related agricultural losses because of its dependence on smallholder farming, low irrigation coverage and limited adaptive capacity. Climate variability has reduced agricultural productivity, increased production risks and weakened rural livelihoods across the region. Consequently, strengthening farmers' adaptive capacity has become a central component of climate-smart agriculture and sustainable food systems (IPCC, 2021; Ngoma *et al.*, 2021).

In Zambia, agriculture remains a key contributor to employment, household income and national food security,

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yet it is increasingly affected by recurrent droughts, erratic rainfall and rising temperatures. Ngoma *et al.* (2021) projected that continued climate change is likely to reduce agricultural production, household welfare and national economic growth, with the Southern and Western regions among the most vulnerable. These findings highlight the need for effective adaptation strategies capable of improving productivity while reducing farmers' exposure to climate risks. Tomato production is an important livelihood activity for many peri-urban households in Zambia, supplying fresh vegetables to rapidly growing urban markets. Farmers have responded to increasing climate variability by adopting practices such as supplementary irrigation, improved seed varieties, mulching, crop diversification and adjustments to planting dates. A recent study by Mwamba *et al.* (2025) found that although tomato farmers in Zambia are generally aware of climate change and have adopted several adaptation practices, their adaptive capacity remains constrained by limited financial resources, inadequate extension support and restricted access to climate-resilient technologies. Despite increasing research on climate adaptation, empirical evidence on the effectiveness of adaptation strategies in improving tomato productivity remains limited in Zambia. Most previous studies have focused on farmers' awareness of climate change, adaptation behaviour or the broader impacts of climate change on agriculture, with relatively little attention given to quantifying the relationship between adaptation practices and tomato productivity under peri-urban production systems (Ngoma *et al.*, 2021; Mwamba *et al.*, 2025). This study therefore assessed the contribution of climate adaptation strategies to tomato productivity among smallholder farmers in Lusaka West, Zambia. By integrating quantitative and qualitative evidence, the study provides empirical insights into the effectiveness of farm-level adaptation practices in strengthening climate resilience and improving tomato productivity among peri-urban smallholder farming systems. The findings contribute to the growing body of knowledge on climate-smart horticulture and provide evidence to support policies aimed at enhancing sustainable vegetable production under increasing climate variability.

II. LITERATURE REVIEW

➢ *Climate Variability and Tomato Production*

Climate variability has emerged as one of the principal factors constraining agricultural productivity worldwide. Rising temperatures, irregular rainfall patterns, prolonged droughts and increasing frequencies of extreme weather events have disrupted crop production systems, particularly those dependent on rain-fed agriculture (IPCC, 2023). Horticultural crops are especially vulnerable because they require relatively stable temperature and moisture conditions throughout their growth cycle. Tomato (*Solanum lycopersicum* L.), one of the world's most widely cultivated vegetable crops, is highly sensitive to heat stress and water deficits, which affect germination, flowering, fruit set, fruit size and overall marketable yield (Saadi *et al.*, 2015; Cammarano *et al.*, 2022). Several studies have demonstrated that climate variability adversely affects tomato production through both direct and indirect mechanisms. Elevated temperatures reduce pollen viability and increase flower abortion, while prolonged moisture stress limits nutrient uptake and fruit development. Conversely, excessive rainfall promotes fungal diseases, nutrient leaching and poor fruit quality (Saadi *et al.*, 2015; Cammarano *et al.*, 2022). Climate-induced shifts in pest and disease dynamics have further increased production risks and management costs for tomato growers worldwide (IPCC, 2023).

In sub-Saharan Africa, the impacts of climate variability are intensified by widespread dependence on smallholder farming systems, limited irrigation infrastructure and restricted access to agricultural technologies. Studies across the region consistently report declining horticultural productivity associated with erratic rainfall, prolonged dry spells and increasing temperatures (Niang *et al.*, 2014; Makate *et al.*, 2019). In Zambia, agriculture remains predominantly rain-fed, exposing farmers to recurrent droughts and rainfall variability that negatively affect crop productivity and household livelihoods (Ngoma *et al.*, 2021). Tomato producers in peri-urban areas are particularly vulnerable because production is increasingly constrained by declining water availability, increasing pest pressure and rising production costs (Mwamba *et al.*, 2025).

➢ *Climate Adaptation Strategies Among Smallholder Tomato Farmers*

Adaptation has become an essential component of climate-resilient agriculture because it enables farmers to minimise production losses and sustain productivity under changing climatic conditions. Climate adaptation in tomato production includes practices such as supplementary irrigation, mulching, crop diversification, adjustment of planting dates, conservation agriculture and the adoption of improved or drought-tolerant varieties (Lipper *et al.*, 2014; Makate *et al.*, 2019). Empirical evidence suggests that these practices improve water-use efficiency, reduce soil moisture losses and enhance crop resilience during periods of climatic stress. Makate *et al.* (2019) reported that adoption of climate-smart agricultural practices significantly improved crop productivity and household resilience among smallholder farmers in sub-Saharan Africa. Similarly, Diro *et al.* (2022) found that integrated adaptation strategies combining improved crop varieties, soil conservation and efficient water management generated greater productivity gains than single adaptation practices. Despite these benefits, adoption remains uneven because of financial, institutional and technical constraints. Limited access to irrigation equipment, agricultural credit, extension services and reliable climate information reduces farmers' capacity to implement effective adaptation strategies (Lipper *et al.*, 2014; Odoom *et al.*, 2023). Evidence from Zambia indicates that although tomato farmers generally recognise climate-related risks and have adopted several adaptation measures, inadequate financial resources, weak extension support and limited access to climate-resilient technologies continue to constrain adaptation (Banda *et al*., 2025; Mwamba *et al.*, 2025).

➢ *Climate Adaptation and Tomato Productivity*

The ultimate objective of climate adaptation is to sustain or improve agricultural productivity despite increasing climatic variability. Numerous studies have shown

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that adaptation practices enhance crop yields by improving water availability, reducing climatic risks and increasing production efficiency (Makate *et al.*, 2019; Diro *et al.*, 2022). However, productivity gains vary considerably according to climatic conditions, resource availability, institutional support and farmers' capacity to adopt multiple adaptation practices simultaneously. Although considerable progress has been made in understanding climate adaptation, important knowledge gaps remain. Much of the existing literature has focused on farmers' perceptions of climate change, determinants of adaptation or the adoption of climate-smart agriculture in general. Comparatively few studies have examined whether adaptation strategies adopted by smallholder tomato farmers translate into measurable improvements in productivity, particularly within peri-urban production systems in Zambia (Mwamba *et al.*, 2025; Phiri *et al.*, 2025). Furthermore, limited research has combined quantitative evidence with farmers' experiences to explain why some adaptation strategies are more effective than others under local production conditions. This study addresses these gaps by evaluating the relationship between climate adaptation strategies and tomato productivity among smallholder farmers in Lusaka West, Zambia. By integrating quantitative and qualitative evidence, the study provides a comprehensive assessment of how adaptation practices contribute to improved productivity and resilience within peri-urban horticultural production systems.

III. MATERIALS AND METHODS

➤ *Study Area*

The study was conducted in the Mwembeshi farming area of Lusaka West, approximately 30 km west of Lusaka, Zambia. The area is one of the country's principal peri-urban horticultural production zones, supplying tomatoes and other fresh vegetables to Lusaka and surrounding urban markets. Lusaka West is situated within Zambia's Agro-Ecological Region IIa, which is characterised by moderate rainfall, relatively fertile soils and favourable conditions for crop production. The region receives an average annual rainfall of 800–1,000 mm, with a growing season of approximately 100–140 days (Ministry of Agriculture, 2024). Increasing rainfall variability, prolonged dry spells, delayed onset and early cessation of rainfall, together with occasional flooding, have become common features of the area's climate, contributing to increased production risks for smallholder farmers (Ngoma *et al.*, 2021). Tomato production is one of the major livelihood activities in the Mwembeshi farming area because of its proximity to the Lusaka urban market and the availability of groundwater that supports irrigated vegetable production throughout the year. Despite these advantages, farmers continue to experience climate-related challenges, including declining water availability, rising production costs, and increased pest and disease pressure associated with changing climatic conditions (Mwamba *et al.*, 2025). These characteristics make the study area appropriate for assessing the impacts of climate variability on tomato production and the adaptation strategies employed by smallholder farmers.

➤ *Research Design*

The study adopted a convergent mixed-methods research design, in which quantitative and qualitative data were collected concurrently, analysed separately and integrated during interpretation. The quantitative component was used to assess the effects of climate variability on tomato production and to examine the relationship between adaptation strategies and production outcomes using descriptive and inferential statistical techniques. The qualitative component explored farmers' experiences, perceptions and challenges associated with climate variability and adaptation through key informant interviews. Integrating the two datasets provided a more comprehensive understanding of the research problem by combining statistical evidence with contextual explanations (Creswell and Plano Clark, 2018). The convergent mixed-methods design was considered appropriate because it enabled triangulation of findings, thereby enhancing the validity and credibility of the study.

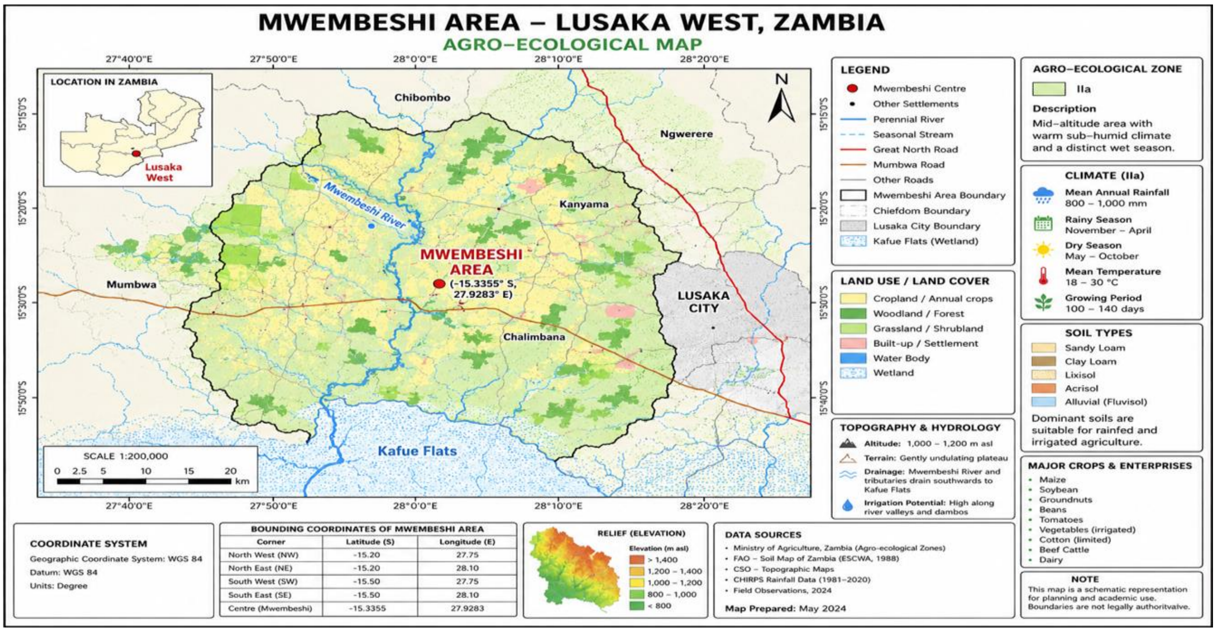

Fig 1 Map of Zambia Showing Mwembeshi Area Luska West

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➢ *Study Population and Sampling Procedure*

The target population comprised smallholder tomato farmers actively engaged in tomato production within the Mwembeshi farming area of Lusaka West. A sample of 150 farmers was selected using simple random sampling to ensure that every eligible farmer had an equal probability of selection. In addition, 15 key informants, comprising agricultural extension officers, farmer leaders and horticultural specialists, were purposively selected because of their experience and knowledge of climate variability and tomato production.

➢ *Data Collection*

Primary data were collected using structured questionnaires administered to sampled farmers. The questionnaire captured information on household characteristics, farmers' perceptions of climate variability, adaptation strategies and tomato production outcomes. Semi-structured interviews were conducted with key informants to obtain detailed information on climate-related production challenges, adaptation measures and institutional support available to farmers. Secondary data were obtained from published literature, meteorological reports and government publications to provide background information on climate variability and agricultural production in the study area.

➢ *Measurement of Variables*

Climate variability was assessed using farmers' perceptions of changes in rainfall patterns, temperature, drought occurrence and extreme weather events. Adaptation strategies were measured by assessing the adoption of practices such as irrigation, improved seed varieties, mulching, crop diversification and adjustment of planting dates. Tomato productivity was measured using farmers' reported changes in yield, production performance and household income following the adoption of adaptation strategies.

➢ *Data Analysis*

Quantitative data were analysed using IBM SPSS Statistics Version 26. Descriptive statistics, including frequencies, percentages, means and standard deviations, were used to summarise respondents' characteristics, perceptions of climate variability and adaptation practices. Pearson's correlation analysis was employed to examine the relationship between climate adaptation strategies and tomato productivity. Statistical significance was assessed at the 5% significance level ($p < 0.05$). Qualitative data obtained from key informant interviews were analysed using thematic analysis. Interview transcripts were coded, categorised into emerging themes and integrated with the quantitative findings to provide contextual explanations of farmers' experiences and adaptation practices.

IV. RESULTS

➢ *Characteristics of the Respondents*

The demographic characteristics of the respondents are presented in Table 1 to provide background information on the smallholder tomato farmers who participated in the study.

Table 1 Demographic Characteristics of Respondents (N = 150).

Variable	Category	Frequency (n)	Percentage (%)
Sex	Male	93	62.0
	Female	57	38.0
Age (years)	18–25	18	12.0
	26–35	39	26.0
	36–45	45	30.0
	46–55	30	20.0
	≥56	18	12.0
Farming experience (years)	0–5	21	14.0
	6–10	39	26.0
	11–15	42	28.0
	16–20	30	20.0
	>20	18	12.0

The demographic characteristics of the respondents are presented in Table 1. Of the 150 smallholder tomato farmers surveyed, 62.0% were male and 38.0% were female. The majority of respondents (56.0%) were between 26 and 45 years of age, with farmers aged 36–45 years constituting the largest age category (30.0%). In terms of farming experience, 72.0% of the respondents had more than six years of experience in tomato production. These characteristics indicate that the study population comprised predominantly experienced farmers with substantial involvement in tomato production, providing an appropriate basis for assessing the effects of climate variability, the adoption of adaptation strategies and tomato production outcomes.

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➢ *Perceived Effects of Climate Variability on Tomato Production*

* *Quantitative Findings*

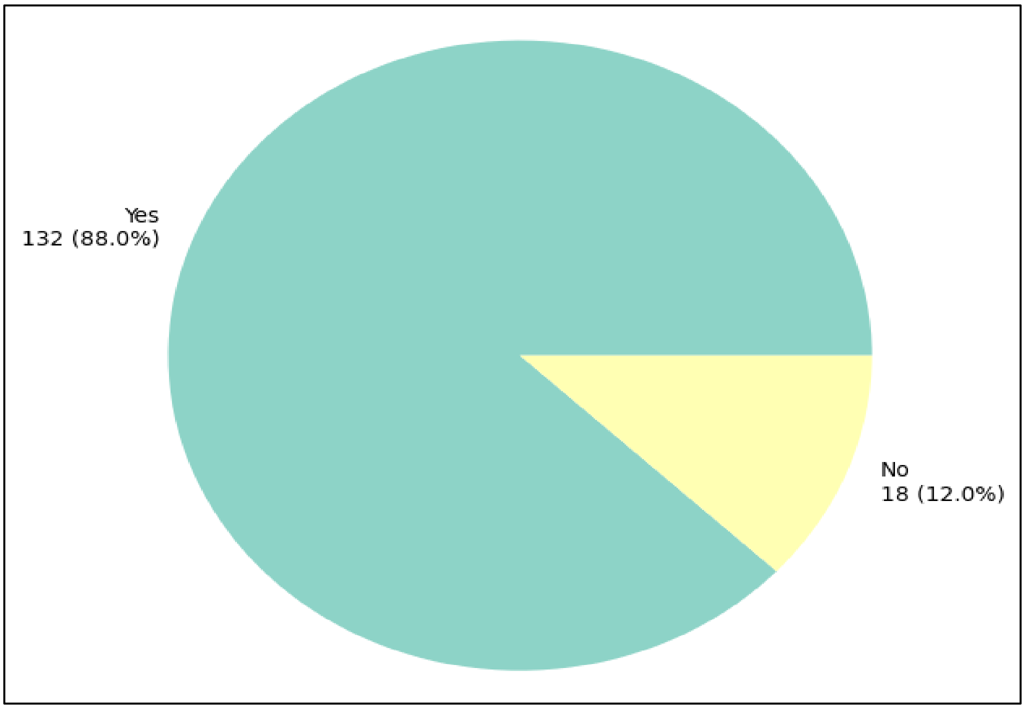

Fig 2 Respondents' Observation of Climate Variability

The findings presented in Figure 2 show that the majority of respondents (88.0%) had observed noticeable changes in climatic conditions during the previous five years, whereas only 12.0% indicated that they had not experienced any significant climatic changes. The high proportion of respondents reporting changes suggests that climate variability was widely recognised among smallholder tomato farmers in the study area. By comparison, relatively few respondents reported no observable changes in climatic conditions during the same period.

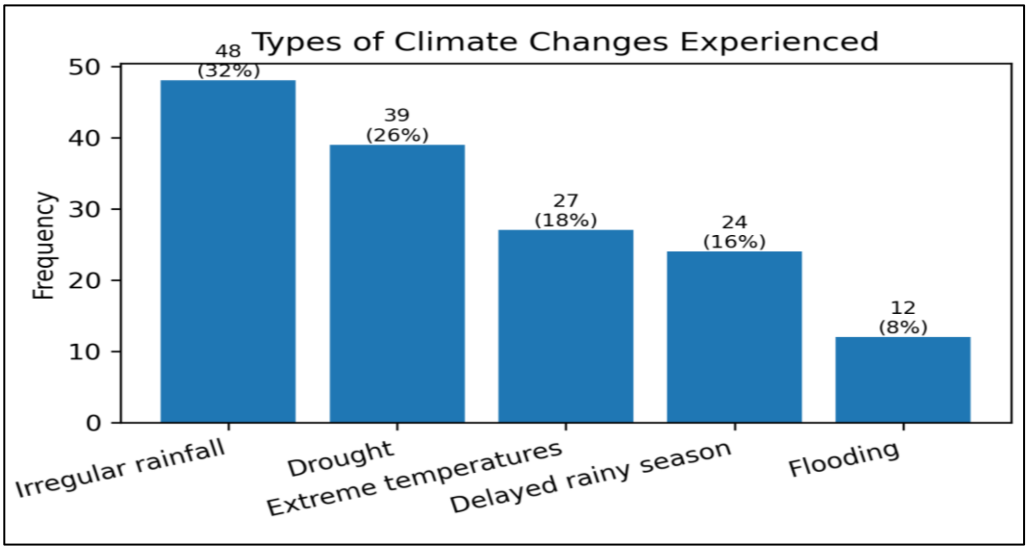

Fig 3 Types of Climate Variability Experienced by Respondents

Figure 3 presents the different forms of climate variability reported by respondents. Irregular rainfall was the most frequently reported climatic change, accounting for 32.0% of responses, followed by drought (26.0%), extreme temperatures (18.0%), delayed onset of the rainy season (16.0%) and flooding (8.0%). Collectively, irregular rainfall and drought represented more than half (58.0%) of all reported climatic changes. In contrast, delayed rainfall onset and flooding were reported less frequently than the other forms of climate variability.

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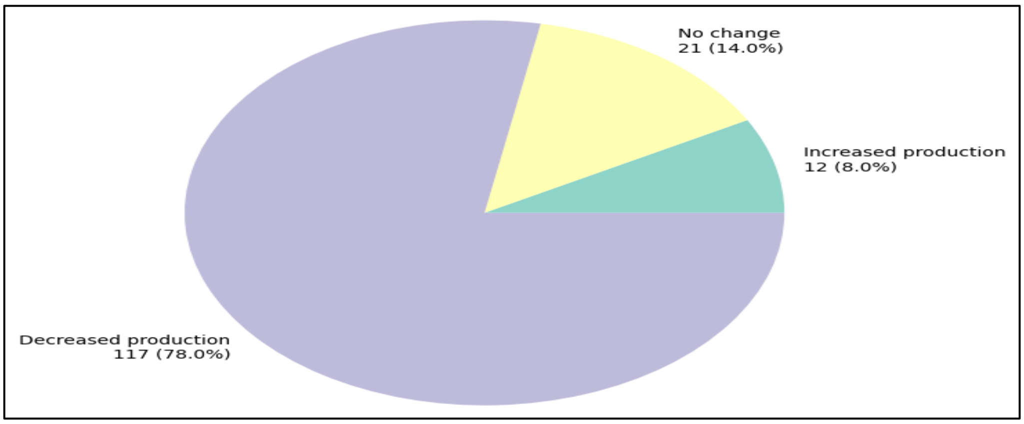

Fig 4 Perceived Effects of Climate Variability on Tomato Production

The perceived effects of climate variability on tomato production are presented in Figure 4. Most respondents (78.0%) reported that climate variability had reduced tomato production, while 14.0% indicated that production had remained unchanged. Only 8.0% of respondents reported an improvement in tomato production despite the changing climatic conditions. The distribution of responses indicates that reports of declining production were considerably more common than reports of stable or improved production.

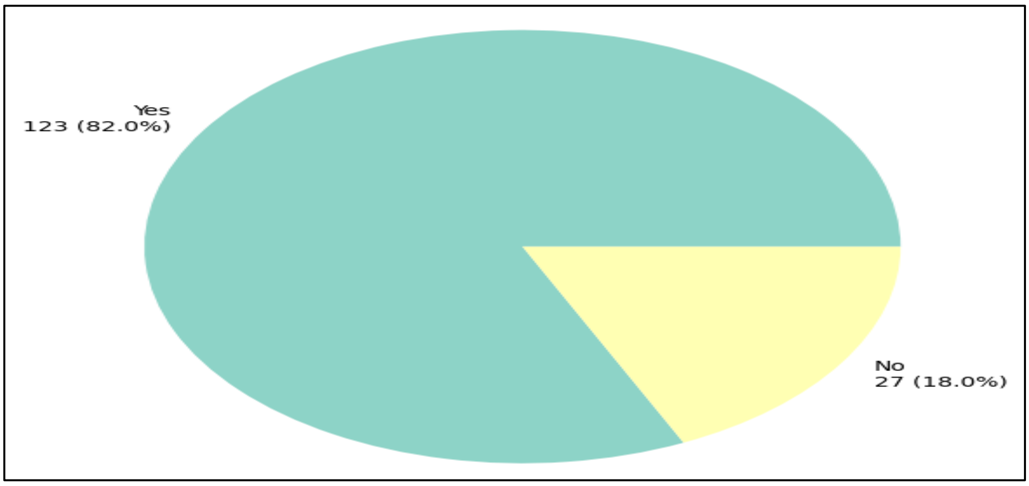

Fig 5 Perceived Effects of Climate Variability on Tomato Quality

Figure 5 shows respondents' perceptions of the effects of climate variability on tomato fruit quality. The majority of respondents (82.0%) reported that climate variability had negatively affected tomato fruit quality, whereas 18.0% indicated that no noticeable effects had been experienced. Negative effects on fruit quality were therefore reported by more than four out of every five respondents, while fewer than one-fifth reported no observable changes.

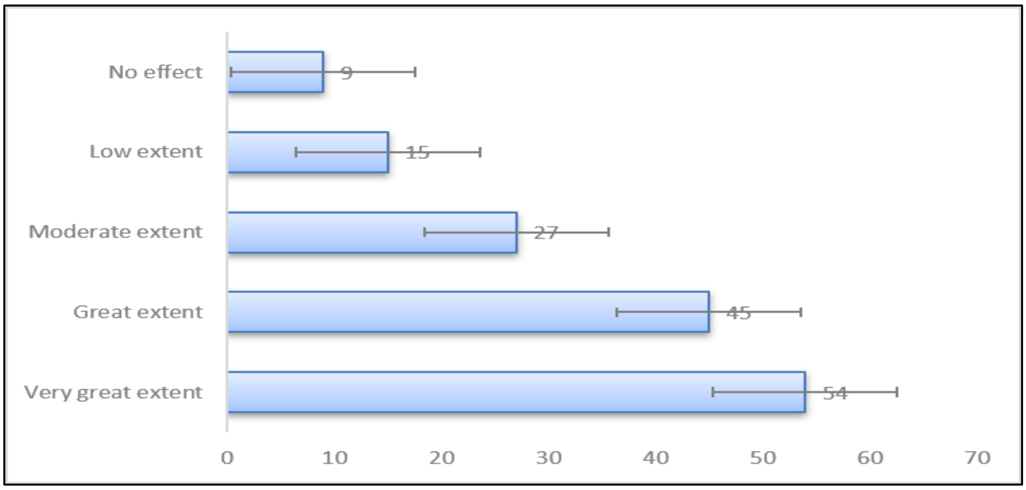

Fig 6 Extent to which Climate Variability Affected Tomato Yields

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Respondents were further asked to indicate the extent to which climate variability had affected tomato yields, and the results are presented in Figure 6. More than one-third (36.0%) reported that yields had been affected to a very great extent, while 30.0% indicated a great extent. Moderate effects were reported by 18.0% of respondents, whereas 10.0% and 6.0% reported low and no effects, respectively. Overall, two-thirds of the respondents (66.0%) indicated that climate variability had affected tomato yields to either a great or a very great extent.

- *Qualitative Findings*

The qualitative interviews complemented the survey findings by providing detailed accounts of farmers' experiences with climate variability. Four recurring themes emerged from the interviews: unpredictable rainfall patterns, increasing drought frequency, declining tomato yields and deterioration in tomato quality.

Participants consistently described rainfall patterns as becoming increasingly erratic, characterised by delayed onset of the rainy season, prolonged dry spells and occasional heavy rainfall events that disrupted planting schedules and crop establishment. As one agricultural extension officer explained:

"The biggest challenge facing tomato farmers today is irregular rainfall. The rain comes late, stops suddenly, and sometimes falls heavily within a short period. This disrupts the entire farming calendar." (Extension Officer 1)

✓ *Similarly, a Farmer Leader Observed:*

"In the past, we knew when the rains would start, but now it is difficult to predict. Many farmers plant expecting rainfall and end up losing seedlings." (Farmer Leader 7)

Interview participants also identified prolonged drought as a major production constraint. Reduced water availability for irrigation was reported to have increased crop stress, particularly during flowering and fruit development. An agricultural expert stated:

"Drought has become more frequent in Lusaka West. Water sources that farmers depend on are drying up earlier than before." (Agricultural Expert 1)

✓ *Another Participant Added:*

"Tomatoes require consistent moisture. When drought occurs during flowering stages, yields drop significantly." (Farmer)

Most participants further reported that climate variability had contributed to declining tomato yields. Farmers indicated that harvest quantities had decreased over time because of increasingly unpredictable weather conditions.

"Five years ago, I could harvest more boxes from the same field. Today the harvest is much lower because weather conditions are no longer favourable." (Farmer Leader 7)

In addition to reducing yields, participants explained that climate variability had adversely affected fruit quality through increased sunburn damage, reduced fruit size and higher disease incidence.

"Excessive heat causes smaller fruits and sunburn damage, while irregular rainfall increases disease outbreaks." (Extension Officer 3)

➢ *Climate Change Adaptation Strategies Adopted by Smallholder Tomato Farmers*

- *Quantitative Findings*

Table 2 Climate Change Adaptation Strategies Adopted by Respondents (N = 150)

Adaptation strategy	Frequency (n)	Percentage (%)
Irrigation	51	34.0
Improved seed varieties	36	24.0
Crop diversification	27	18.0
Changing planting dates	21	14.0
Soil conservation practices	15	10.0
Total	**150**	**100.0**

Source: Field Survey Data (2026).

Table 2 presents the principal climate change adaptation strategies adopted by respondents to minimise the effects of climate variability on tomato production. Irrigation was the most frequently reported adaptation strategy, adopted by 51 respondents (34.0%), followed by improved seed varieties (36 respondents, 24.0%). Crop diversification accounted for 27 respondents (18.0%), while changing planting dates and soil conservation practices were reported by 21 (14.0%) and 15 respondents (10.0%), respectively. Collectively, irrigation and improved seed varieties constituted 58.0% of the principal adaptation strategies reported by respondents.

- *Qualitative Findings*

The qualitative interviews provided further insights into the adaptation practices employed by farmers and the factors influencing their adoption. Four major themes emerged from the interviews: increased irrigation, improved soil moisture conservation, adjustment of planting calendars and diversification of production practices.

Participants consistently identified irrigation as the most effective strategy for sustaining tomato production

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under increasingly unpredictable rainfall conditions. Farmers explained that irrigation enabled them to maintain crop growth during prolonged dry spells and reduce dependence on seasonal rainfall.

"Without irrigation, it has become very difficult to grow tomatoes because rainfall can no longer be relied upon. Most farmers now depend on boreholes, wells and nearby streams." (Extension Officer 2)

Mulching and the application of organic manure were also widely recognised as important practices for conserving soil moisture and improving soil fertility.

"We use crop residues and grass to cover the soil because it keeps moisture in the field and reduces water loss during hot periods." (Farmer)

Several participants reported changing planting dates in response to increasingly erratic rainfall patterns. Rather than following the traditional planting calendar, farmers indicated that they now waited until rainfall patterns became more reliable before transplanting seedlings.

"We no longer plant according to the old calendar. We first observe the weather before deciding when to transplant our tomatoes." (Farmer Leader)

Participants further explained that they had diversified production practices by combining several adaptation measures to reduce production risks. These included improved pest and disease management, crop rotation, use of improved seed varieties and better water management.

"Today we cannot depend on one practice alone. Farmers combine irrigation, mulching, improved varieties and careful field management to reduce losses." (Agricultural Expert)

Overall, the qualitative findings indicate that farmers increasingly rely on integrated adaptation strategies to improve the resilience of tomato production under changing climatic conditions.

➢ *Relationship Between Farmer Adaptation Strategies and Tomato Production Outcomes*

- *Quantitative Findings*

Pearson's correlation analysis was conducted to examine the relationship between farmer adaptation strategies and tomato production outcomes. The results are presented in Table 3.

Table 3 Pearson Correlation Between Adaptation Strategies and Tomato Yields (n = 150).

Variable	Adaptation strategies	Tomato yields
Adaptation strategies	1.000	0.718**
Tomato yields	0.718**	1.000
Sig. (1-tailed)	–	<0.001
N	150	150

Note: Correlation is Significant at the 0.01 Level (1-Tailed).

The Pearson correlation analysis revealed a strong positive and statistically significant relationship between farmer adaptation strategies and tomato yields ($r = 0.718$, $p < 0.001$). The positive correlation coefficient indicates that farmers who adopted more climate change adaptation strategies generally achieved higher tomato yields than those who adopted fewer or no adaptation measures.

The magnitude of the correlation coefficient (0.718) suggests a strong association between the two variables, while the probability value confirms that the observed relationship was statistically significant. Consequently, the null hypothesis stating that there is no significant relationship between farmer adaptation strategies and tomato production outcomes was rejected.

These findings demonstrate that the adoption of climate change adaptation strategies contributes substantially to improved tomato production outcomes among smallholder farmers in Lusaka West. Adaptation measures such as irrigation, improved tomato varieties, crop diversification, adjustment of planting dates and soil conservation practices appear to enhance farmers' capacity to maintain production under increasingly variable climatic conditions.

- *Qualitative Findings*

The qualitative findings reinforced the statistical results by illustrating how adaptation strategies contributed to improved tomato production outcomes. Participants consistently reported that farmers who implemented multiple adaptation measures experienced higher yields, reduced production losses and more stable household incomes than those who relied primarily on rain-fed production.

✓ *An Agricultural Expert Explained:*

"Farmers who consistently adopt adaptation measures generally record better yields than those who rely solely on rainfall." (Agricultural Expert 2)

✓ *Similarly, an Extension Officer Observed:*

"Adaptation practices help farmers manage climatic risks and maintain production levels even during difficult seasons." (Extension Officer 3)

Participants further noted that improved production translated into higher household incomes because farmers experienced fewer crop failures and were able to market larger quantities of tomatoes.

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"When farmers reduce crop losses through adaptation, they harvest more produce and generate higher income." (NGO Officer 5)

A farmer leader also highlighted the differences between adapting and non-adapting farmers:

"Those who use irrigation and improved seed varieties are usually able to earn more than those who depend entirely on natural rainfall." (Farmer Leader 1)

Despite these benefits, participants acknowledged that limited financial resources, inadequate irrigation infrastructure and restricted access to climate information constrained the effective implementation of adaptation strategies among many smallholder farmers.

"Adaptation is effective, but challenges such as limited finances, inadequate irrigation infrastructure and insufficient climate information reduce its effectiveness." (Agricultural Expert 4)

Overall, the qualitative findings corroborated the quantitative evidence by demonstrating that climate change adaptation strategies improve tomato production outcomes while highlighting the resource constraints that continue to limit farmers' adaptive capacity.

V. DISCUSSION

➢ *Climate Variability as a Production Constraint*

Climate variability has become an important constraint to tomato production in Lusaka West, with rainfall uncertainty, prolonged dry spells and increasing temperatures disrupting the stability of peri-urban horticultural systems. The combined quantitative and qualitative evidence suggests that these climatic changes affect tomato production throughout the cropping cycle by reducing water availability, altering planting schedules and increasing crop exposure to moisture and heat stress. Rather than representing isolated climatic events, these changes reflect an increasingly unpredictable production environment in which maintaining consistent yields has become progressively more difficult.

These observations are consistent with current understanding of tomato physiology. Tomato is highly sensitive to fluctuations in soil moisture and temperature because reproductive development depends on relatively stable environmental conditions. Water deficits restrict nutrient uptake and fruit expansion, while excessive temperatures reduce pollen viability, increase flower abortion and impair fruit set, leading to lower yields and poorer fruit quality (Saadi et al., 2015; Cammarano et al., 2022). Similar responses have been documented across sub-Saharan Africa, where increasing climatic variability continues to reduce horticultural productivity in production systems characterised by limited irrigation and heavy reliance on seasonal rainfall (Makate et al., 2019; IPCC, 2023). The close agreement between the present findings and previous studies suggests that the production challenges observed in Lusaka West are manifestations of broader regional climatic processes rather than isolated local conditions.

An important contribution of this study lies in demonstrating how these climatic changes influence peri-urban vegetable production systems. Unlike cereal production, tomato cultivation requires continuous water availability throughout the production cycle and supplies highly perishable produce to urban markets. Consequently, interruptions in water supply or episodes of extreme heat not only reduce biological productivity but also diminish market quality and household income. This highlights the increasing vulnerability of commercial vegetable production to climate variability and emphasises the need for adaptation strategies specifically designed for intensive horticultural systems.

➢ *Adaptation as a Climate Risk Management Strategy*

The widespread adoption of climate adaptation practices demonstrates that farmers are actively modifying production systems in response to increasing climatic uncertainty. The predominance of irrigation, improved tomato varieties, moisture conservation and adjustments to planting schedules indicates a shift from traditional production practices towards more integrated climate risk management. Rather than relying on individual interventions, farmers increasingly combine complementary practices to reduce exposure to rainfall variability while maintaining crop growth throughout the production cycle.

This pattern reflects broader developments in climate-smart agriculture, where integrated adaptation is recognised as more effective than isolated technologies because different practices address different sources of production risk simultaneously. Improved varieties enhance tolerance to climatic stress, irrigation reduces dependence on rainfall, while soil moisture conservation increases water-use efficiency and moderates soil temperature. Collectively, these practices improve crop performance under variable climatic conditions and strengthen the resilience of farming systems (Lipper et al., 2014; Makate et al., 2019; Diro et al., 2022). The adaptation strategies observed in the present study therefore represent practical management responses that reduce the cumulative effects of climatic stress rather than isolated technological innovations. However, the findings also demonstrate that farmers' adaptive capacity remains constrained by institutional and economic factors.

Limited financial resources, inadequate irrigation infrastructure and restricted access to climate information reduced the extent to which recommended adaptation measures could be implemented consistently. Similar barriers have been reported throughout sub-Saharan Africa, where adoption of climate-smart agriculture is frequently constrained by limited investment, weak extension services and inadequate access to production technologies (Odoom et al., 2023). Comparable observations among tomato farmers in Zambia further indicate that awareness of climate variability alone is insufficient to sustain effective adaptation without complementary institutional support (Mwamba et al., 2025).

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These findings suggest that adaptation should be understood not only as a technological response but also as an institutional process. Strengthening resilience will therefore depend on improving the enabling environment through investment in irrigation development, agricultural extension, climate information services and affordable production technologies that allow farmers to implement adaptation measures effectively.

➢ *Adaptation and Tomato Productivity*

The positive relationship between adaptation strategies and tomato production outcomes provides empirical evidence that adaptation contributes directly to improved agricultural performance under conditions of increasing climatic variability. Farmers adopting multiple adaptation measures consistently achieved better production outcomes than those relying primarily on conventional production practices, indicating that resilience is strengthened when adaptation is implemented as an integrated management strategy rather than through isolated interventions. This relationship is supported by previous studies demonstrating that climate-smart agricultural practices improve productivity by reducing exposure to climatic stress and increasing production efficiency (Makate et al., 2019; Diro et al., 2022).

The present findings extend this evidence by showing that similar relationships occur within peri-urban tomato production systems in Zambia, where adaptation contributes not only to maintaining crop yields but also to stabilising household livelihoods dependent on commercial vegetable production. The integration of quantitative analysis with qualitative evidence strengthens this conclusion by demonstrating that the observed statistical relationship is consistent with farmers' practical experiences and observations. The study also addresses an important gap identified in the literature. Existing research in Zambia has focused predominantly on farmers' awareness of climate variability and the factors influencing adaptation decisions (Ngoma et al., 2021; Mwamba et al., 2025). Considerably less attention has been given to evaluating whether adaptation translates into measurable improvements in production outcomes. By demonstrating a strong association between adaptation and tomato productivity, this study provides empirical support for the effectiveness of climate-smart agricultural practices within peri-urban horticultural systems and contributes evidence that extends beyond documenting adaptation behaviour.

Nevertheless, the observed relationship should not be interpreted as evidence that adaptation alone determines production performance. Tomato productivity is influenced simultaneously by soil fertility, pest and disease pressure, input availability, market incentives and management skills, factors that were beyond the scope of the present analysis. While adaptation clearly improves resilience to climatic variability, its effectiveness depends on broader production and institutional environments that enable farmers to implement recommended practices consistently. This provides a plausible explanation for the continued variation in production outcomes among farmers despite widespread adoption of climate adaptation measures.

Collectively, the evidence indicates that climate adaptation should be viewed as a long-term investment in resilient horticultural production rather than as a short-term response to climatic shocks. Expanding access to irrigation technologies, strengthening extension systems and improving climate information services are therefore likely to enhance the effectiveness of adaptation while supporting sustainable vegetable production under increasingly variable climatic conditions.

➢ *Study Contribution and Limitations*

This study makes an important contribution to climate adaptation research by providing integrated quantitative and qualitative evidence on the relationship between climate adaptation strategies and tomato productivity within a peri-urban smallholder farming system in Zambia. Unlike previous studies that have concentrated primarily on perceptions of climate variability or determinants of adaptation, the present study demonstrates that adaptation is associated with measurable improvements in production outcomes. These findings strengthen the empirical basis for promoting climate-smart horticulture as a strategy for improving resilience and productivity in vegetable production systems.

Several limitations should nevertheless be acknowledged. Production outcomes were based partly on farmers' reported experiences, which may be affected by recall bias, while the cross-sectional research design limits the ability to infer causal relationships. Future research should combine longitudinal production records, objective yield measurements and observed climatic data to quantify the long-term effectiveness of individual adaptation strategies under different agroecological conditions.

VI. CONCLUSION

Climate variability continues to threaten tomato production in Lusaka West by reducing productivity and increasing production risks. Farmers have responded by adopting climate adaptation strategies, particularly irrigation, improved varieties, moisture conservation and adjustments to planting dates, which have strengthened production resilience. The study further demonstrates a positive relationship between adaptation and tomato productivity, providing empirical evidence that climate-smart practices improve production outcomes among peri-urban smallholder farmers.

However, financial constraints, inadequate irrigation infrastructure and limited access to climate information continue to limit the effectiveness of adaptation. Strengthening institutional support, expanding irrigation development and improving extension and climate information services will therefore be essential for enhancing sustainable tomato production under increasing climate variability.

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RECOMMENDATIONS

- Improve access to affordable irrigation infrastructure to reduce farmers' vulnerability to rainfall variability and prolonged dry spells.
- Strengthen agricultural extension and climate information services to support the effective adoption of climate adaptation practices.
- Increase financial support for climate-smart agricultural technologies, including improved tomato varieties and efficient water management practices, to enhance farmers' adaptive capacity and productivity.

DECLARATIONS

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- *Conflicts of Interest*

The authors declare that they have no conflicts of interest regarding the publication of this study.

- *Ethical Approval*

Ethical approval for this study was obtained from the relevant institutional authorities before data collection commenced. Participation in the household survey was voluntary, informed consent was obtained from all respondents, and confidentiality and anonymity were maintained throughout the study.

- *Data Availability*

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

- *Author Contributions*

- Evaristo Nyeleti: Conceptualisation, methodology, data collection, formal analysis, interpretation of findings, and manuscript preparation.

- Joseph. T. Mwale: Supervision, methodological guidance, manuscript review, editing, and approval of the final manuscript.

REFERENCES

[1]. Banda, R., Muyabe, O., Tembo, A., Musenge, D.C., Ngoma, A.A., Silombe, M., Makwakwa, E. and Mbewe, M. (2025) 'An analysis of risk perception and management among smallholder maize farmers in Mazabuka District, Southern Province [2015–2017]', *International Journal of Current Science Research and Review*, 8(4), pp. 1588–1596. https://doi.org/10.47191/IJCSRR/V8-i4-05.

[2]. Cammarano, D., Ronga, D., Caradonia, F. and Francia, E. (2022) 'Impact of climate change on processing tomato production: A review', *Agronomy*, 12(11), 2670.

[3]. Creswell, J.W. and Plano Clark, V.L. (2018) *Designing and Conducting Mixed Methods Research*. 3rd edn. Thousand Oaks, CA: Sage Publications.

[4]. Diro, R., Tesfaye, K., Tadesse, M. and Shiferaw, B. (2022) 'Climate-smart agriculture and productivity among smallholder farmers in sub-Saharan Africa: A review', *Climate and Development*, 14(9), pp. 821–835.

[5]. Intergovernmental Panel on Climate Change (IPCC) (2021) *Climate Change 2021: The Physical Science Basis*. Cambridge: Cambridge University Press.

[6]. Intergovernmental Panel on Climate Change (IPCC) (2023) *Climate Change 2023: Synthesis Report*. Geneva: IPCC.

[7]. Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., Sen, P.T. and Sessa, R. (2014) 'Climate-smart agriculture for food security', *Nature Climate Change*, 4(12), pp. 1068–1072.

[8]. Makate, C., Makate, M., Mango, N. and Siziba, S. (2019) 'Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations: Lessons from Southern Africa', *Journal of Environmental Management*, 231, pp. 858–868.

[9]. Ministry of Agriculture (2024) *National Agricultural Mechanization Strategy 2024–2028*. Lusaka: Ministry of Agriculture.

[10]. Mwamba, F.K., Mwelwa, M.M., Banda, P. *et al.* (2025) 'Exploring tomato farmers' knowledge and adaptation practices to climate change: Insights from Chinsali District, Zambia', *Cogent Food & Agriculture*, 11(1).

[11]. Ngoma, H., Lupiya, P., Kabisa, M. and Hartley, F. (2021) 'Impacts of climate change on agriculture and household welfare in Zambia', *Climatic Change*, 167, Article 43.

[12]. Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014) 'Africa', in Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. Cambridge: Cambridge University Press, pp. 1199–1265.

[13]. Odoom, D.A., Antwi-Agyei, P., Dougill, A.J. and Stringer, L.C. (2023) 'Barriers and opportunities for climate-smart agriculture adoption among smallholder farmers in sub-Saharan Africa', *Climate and Development*, 15(6), pp. 547–561.

[14]. Phiri, M., Tembo, A., Musenge, D.C., Muyabe, O., Silombe, M., Chola, E., Mubita, S. and Banda, R. (2025) 'The impact of land use types on selected soil fertility indicators: A comparative study of natural forest, forest plantation, and cropland in Ndola District, Zambia', *International Journal of Research*

Studies in Agricultural Sciences, 11(1), pp. 19–27. https://doi.org/10.20431/2454-6224.1101003.

[15]. Saadi, S., Todorovic, M., Tanasijevic, L., Pereira, L.S., Pizzigalli, C. and Lionello, P. (2015) 'Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield', *Agricultural Water Management*, 147, pp. 103–115.